MARINE ATLAS

MAXIMIZING BENEFITS FOR

TONGA

MACBIO

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MARINE SPATIAL PLANNING

Marine Spatial Planning is an integrated and participatory planning process and tool that seeks to balance ecological, economic, and social objectives, aiming for sustainable marine resource use and prosperous blue economies.

The MACBIO project supports partner countries in collecting and analyzing spatial data on different types of current and future marine resource use, establishing a baseline for national sustainable development planning of oceans.

Aiming for integrated ocean management, marine spatial planning facilitates the sustainable use and conservation of marine and coastal ecosystems and habitats.

This atlas is part of MACBIO's support to its partner countries' marine spatial planning processes. These processes aim to balance uses with the need to effectively manage and protect the rich natural capital upon which those uses rely.

For a digital and interactive version of the Atlas and a copy of all reports and communication material please visit **www.macbio-pacific.info**

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2019

Marine and Coastal Biodiversity Management in Pacific Island Countries

On behalf of
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

FOREWORD

While the ocean covers more than two thirds of the Earth's surface, the oceanic territory of Tonga is over 1,000 times larger than its land territory. With an exclusive economic zone (EEZ) of 700,000 km^2, Tonga is a large ocean state.

This island nation contains many marine ecosystems, from globally significant coral reefs to mangroves, seagrass areas, seamounts and deep-sea trenches supporting at least 1,142 fish species, including sharks and rays, as well as whales, dolphins and sea turtles. We are committed to conserving this unique marine biodiversity.

Tonga's marine ecosystems are worth at least TOP 47 million per year, exceeding the country's total export value. We are strongly committed to sustaining these values to build an equitable and prosperous blue economy.

The country's history, culture, traditions and practices are strongly linked to the ocean and its biodiversity. By sharing and integrating traditional and scientific knowledge, we are navigating towards holistic marine resource management.

Tonga's coastal villages co-manage inshore marine resources. We are striving to work together to sustainably manage all of Tonga's coastal marine areas through Special Management Areas (traditional fishing grounds) for the benefit of empowered and resilient communities.

At the same time, Tonga is experiencing the direct effects of climate change on its ocean and island environments.

By strengthening global partnerships, we are proudly taking leadership in climate change policy and global ocean governance. Further, through integrated and participatory planning, we are aiming to balance economic, ecological and social objectives in this EEZ for the benefit of current and future generations.

In doing so, we can maximize benefits from the ocean for Tonga, its people and its economy.

This is where the Tonga Marine Atlas comes into play. Improvements in research over the years have enabled us to better understand the ocean system and to develop solutions with a sustainable approach. A lot of data have become publicly available, with this atlas compiling over a hundred data sets from countless data providers to make this treasure trove of marine and coastal information accessible and usable for the first time—as maps with narratives, as data layers and as raw data.

In three chapters, the atlas sets out to illustrate:

- What values does the ocean provide to Tonga, to support our wealth and well-being?
- How should we plan the uses of these ocean values and best address conflicts and threats?
- On what levels and in which ways can we manage uses of, and threats to, our marine values?
- The atlas can help decision makers from all sectors appreciate the values of marine ecosystems and the importance of spatially planning the uses of these values.

Practitioners can assist these planning processes using the accompanying data layers and raw data in their Geographic Information Systems.

While the atlas provides the best data currently publicly available, the information about Tonga's waters is constantly increasing. Therefore, the atlas is an open invitation to use, modify, combine and update the maps and underlying data.

Only by involving all stakeholders in a nationwide Marine Spatial Planning (MSP) process can we truly maximize benefits for Tonga.

The e-copy and interactive version of the Tonga Marine Atlas are available here: http://macbio-pacific.info/Interactive-Atlas/Tonga/Tonga.html

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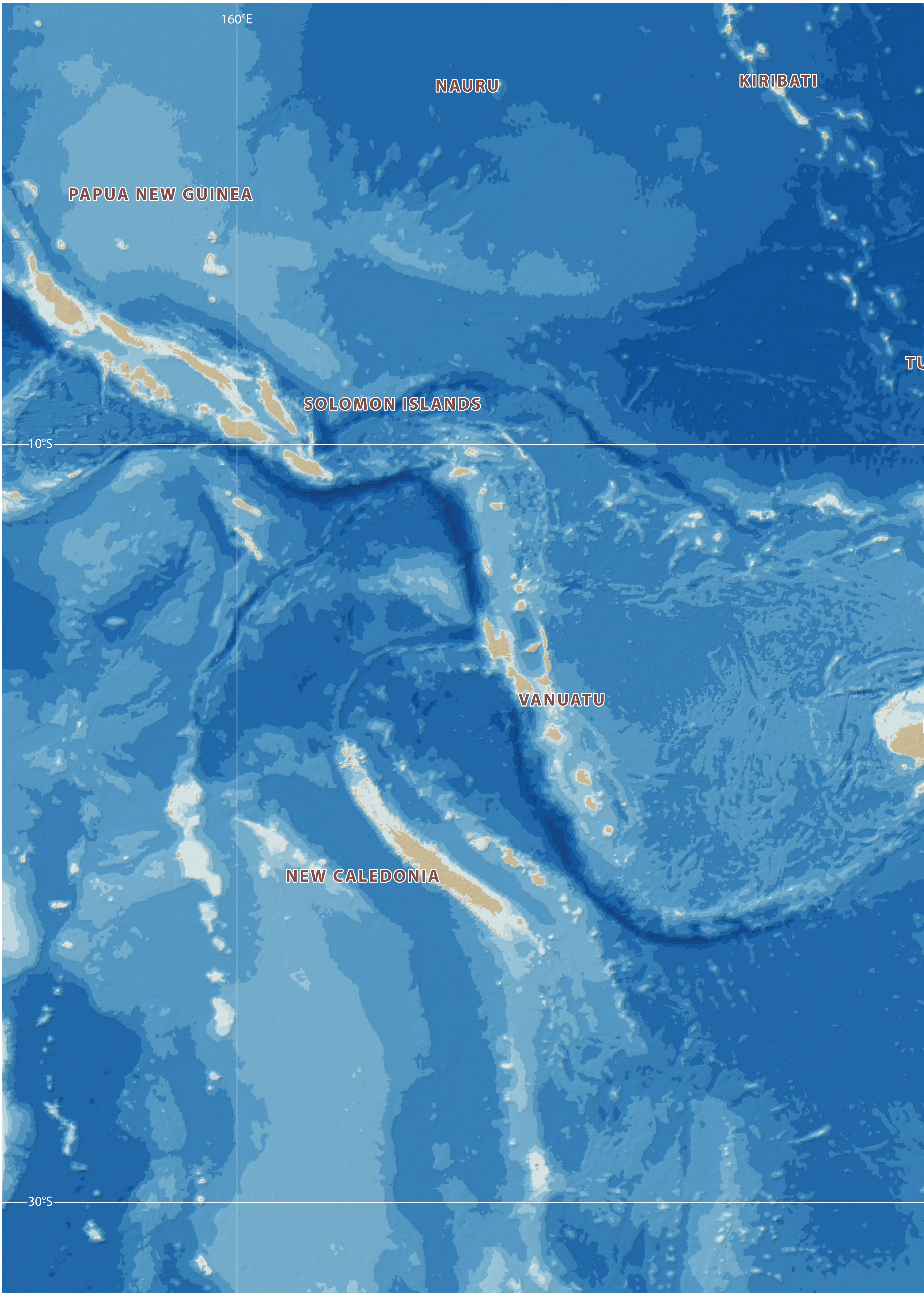
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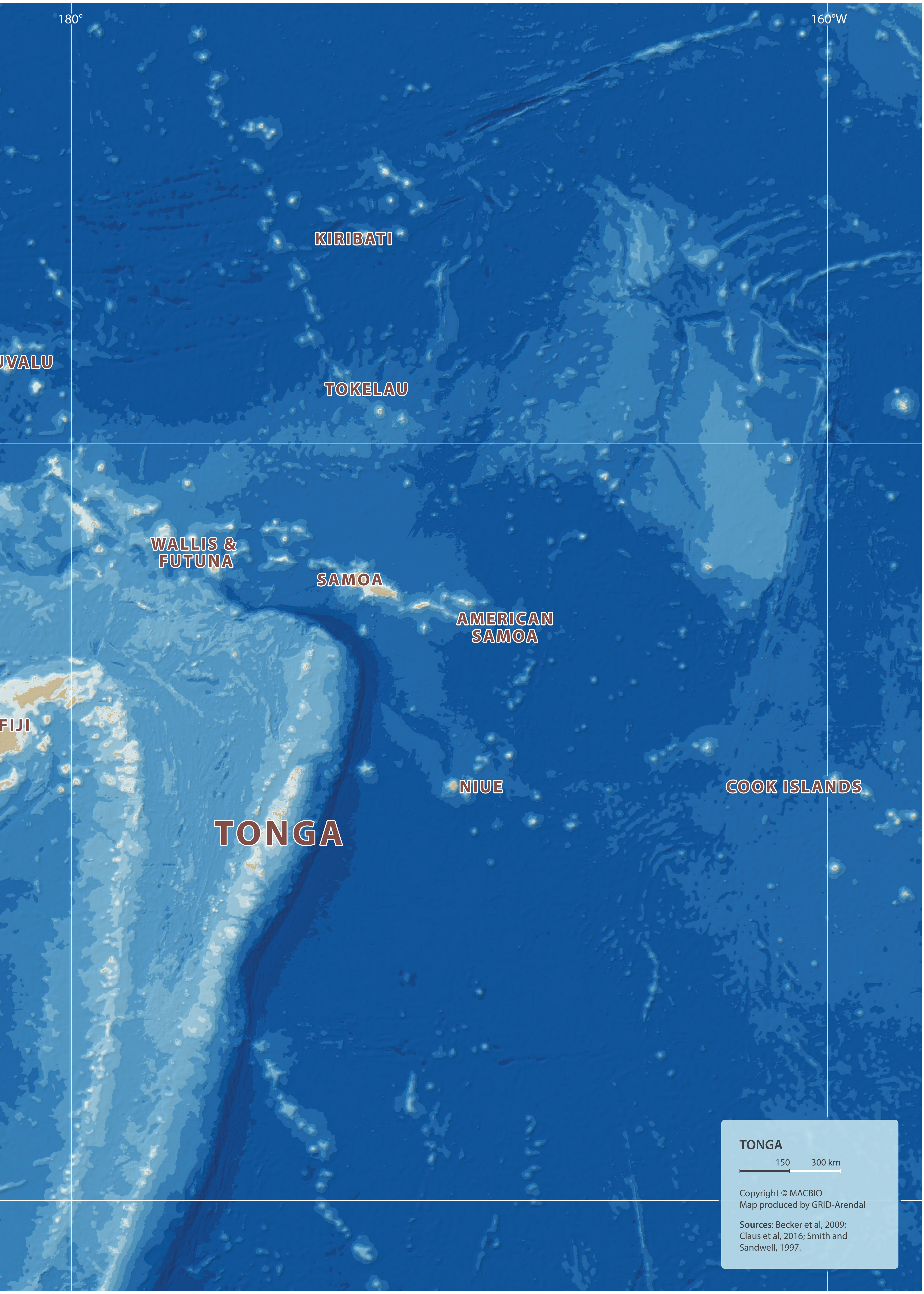
NEW CALEDONIA
30°S


180°
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KIRIBATI
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TOKELAU
WALLIS &
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SAMOA
AMERICAN
SAMOA
FIJI
NIUE
COOK ISLANDS
TONGA
TONGA
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Copyright © MACBIO
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Sources: Becker et al, 2009;
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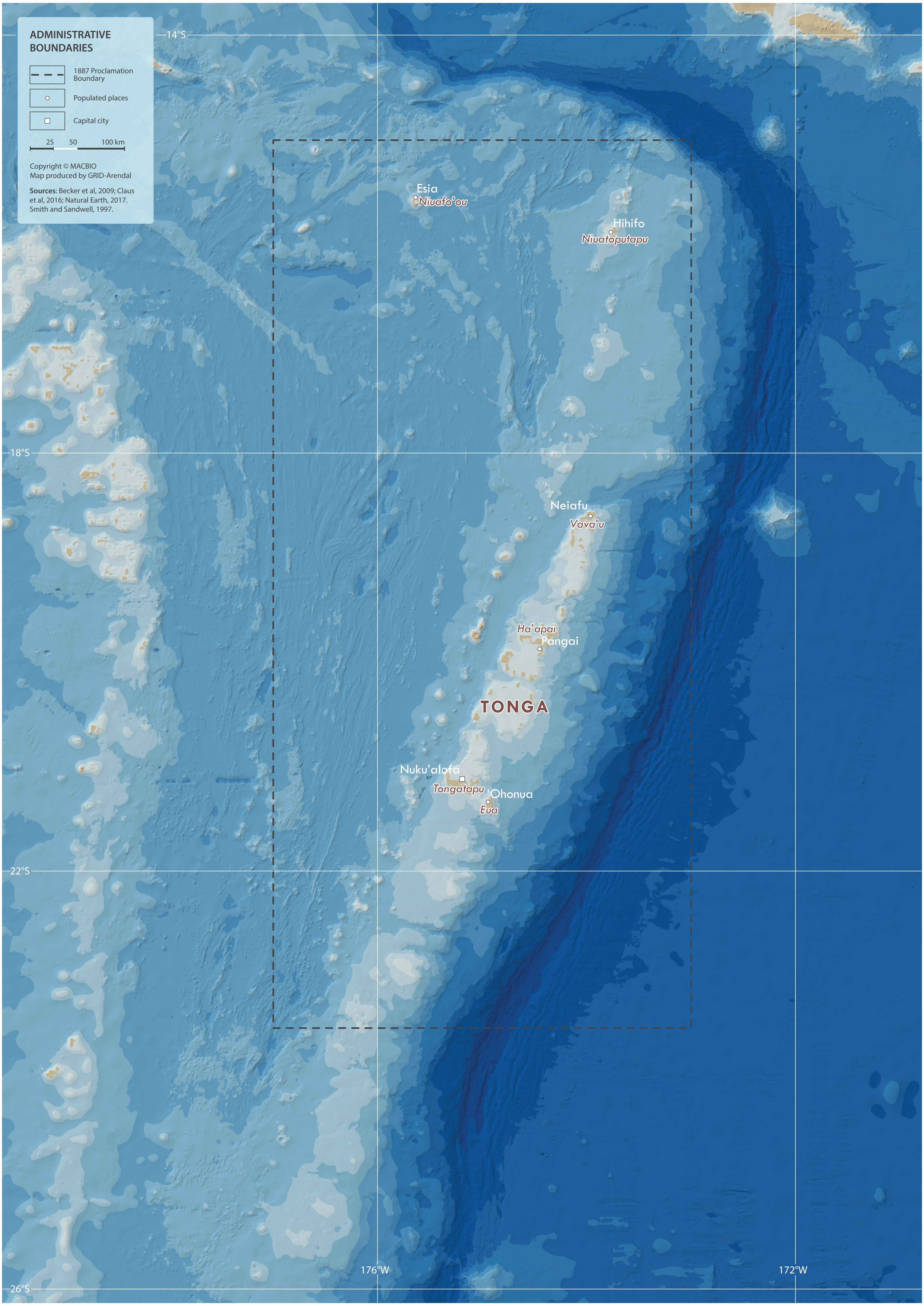

ADMINISTRATIVE BOUNDARIES
1887 Proclamation Boundary
Populated places
Capital city
25
50
100 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Claus et al, 2016; Natural Earth, 2017. Smith and Sandwell, 1997.
14°S
18°S
22°S
26°S
176°W
172°W
Esia
Niuafo'ou
Hihifo
Niuatoputapu
Neiafu
Vava'u
Ha'apai
Pangai
TONGA
Nuku'alofa
Tongatapu
Ohonua
Eua

A LARGE OCEAN STATE: ADMINISTRATION

Tonga's ocean provides a wealth of services to the people of Tonga, and beyond. The ocean and its resources govern daily life, livelihoods, food security, culture, economy and climate.

Tonga and its rich marine values are governed on various levels—from the national government to the provincial and local levels—taking Tonga's traditional structures and close connection to the sea into account.

The South Pacific is a sea of islands (see previous map). While these Pacific Island countries are often referred to as small island states, the map shows that they are in fact large ocean states, with Tonga's marine area covering over 700,000 km^2. Tonga's waters are home to a wealth of marine resources and more than 170 islands, with a total land area of 747 km^2.

The western islands, such as 'Ata, Fonuafo'ou, Tofua, Kao, Lata'iki, Late, Fonualei, Toku and Niuatoputapu, make up the Tongan Volcanic Arc and are all of volcanic origin. They were created by the subduction of the western-moving Pacific plate under the Indian-Australian plate at the Tonga Trench.

Special rights

An exclusive economic zone (EEZ) is a sea zone that extends up to 200 nautical miles (nmi) from a country's baseline. Tonga's EEZ, prescribed by the United Nations Convention on the Law of the Sea (UNCLOS), gives Tonga sovereign rights regarding the exploration and use of marine resources below the surface of the sea. The territorial sea, within 12 nmi from the baseline, is regarded as the sovereign territory of Tonga, in which it has full authority.

The Tongan islands sit on the Indian-Australian plate, just west of the Tonga Trench. These volcanoes are formed when materials in the descending Pacific plate heat up and rise to the surface. With the exception of Niuatoputapu, there is only limited coral reef development on these islands.

The eastern islands are non-volcanic and sit above the mostly submerged Tonga Ridge that runs parallel to the Tongan Volcanic Arc and the Tonga Trench. Of these islands, only 'Eua has risen high enough to expose its underlying Eocene volcanic bedrock; the rest are either low coral limestone islands (Tongatapu, Vava'u, Lifuka) or sand cay islands ('Uoleva, 'Uiha). These islands are surrounded by a protective and resource-rich labyrinth of fringing, apron and offshore barrier reefs that have supported most of the human settlement in Tonga ever since the first Lapita people arrived circa 900 B.C.E. (Burley 1998).

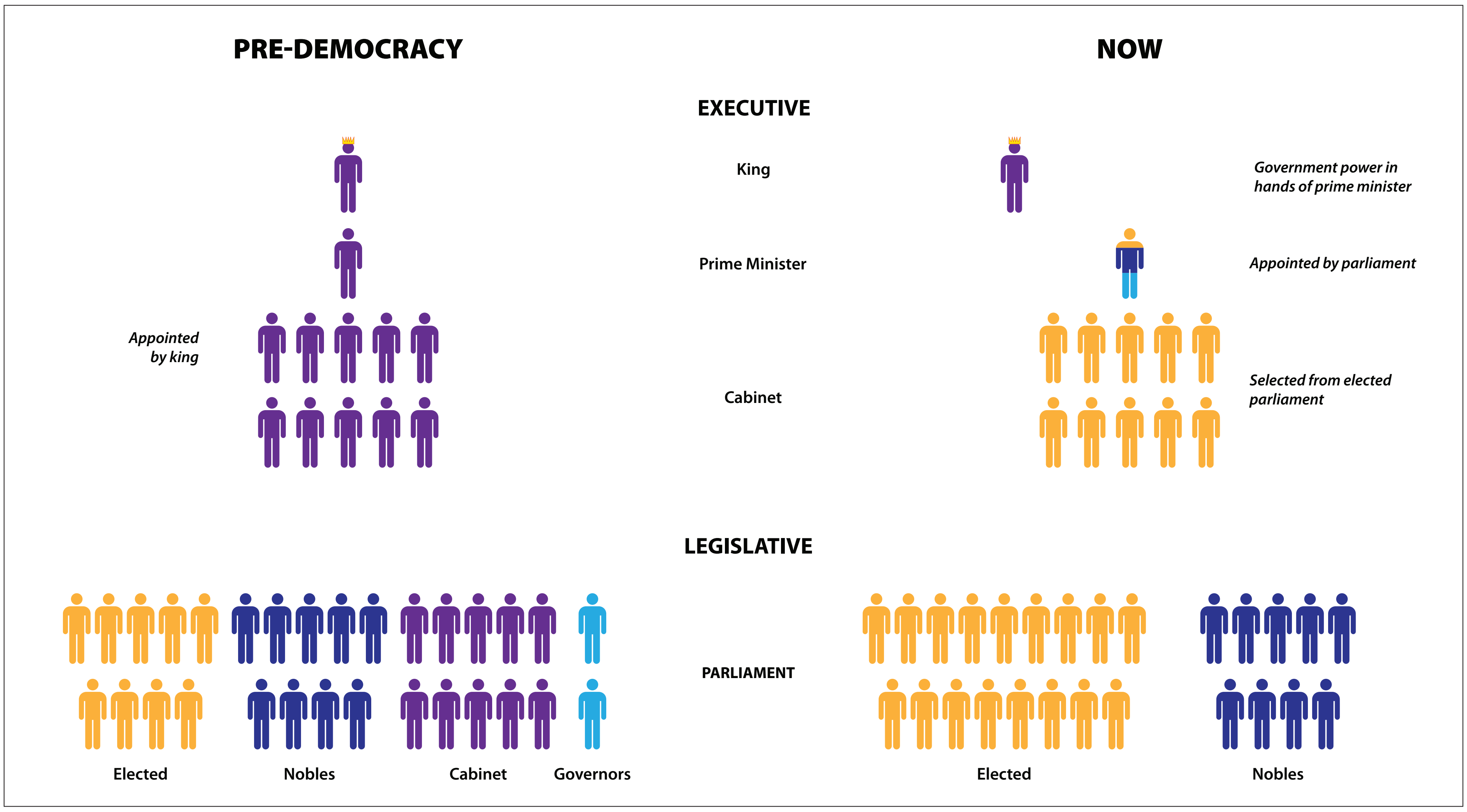
The Tongan Volcanic Arc has played an important role in supplying the islands on the Tonga Ridge with an andesite tephra soil, an extremely rich soil capable of supporting a high-yield, short-fallow agricultural system (Wilson and Beecroft, 1983). The andesite/basalt from the volcanoes was also traditionally used for hammerstones, weaving weights, cooking stones, and decorative pebbles for grave decoration, and Niuatoputapu island in the far north provided volcanic glass to initial human settlers (Burley 1998).

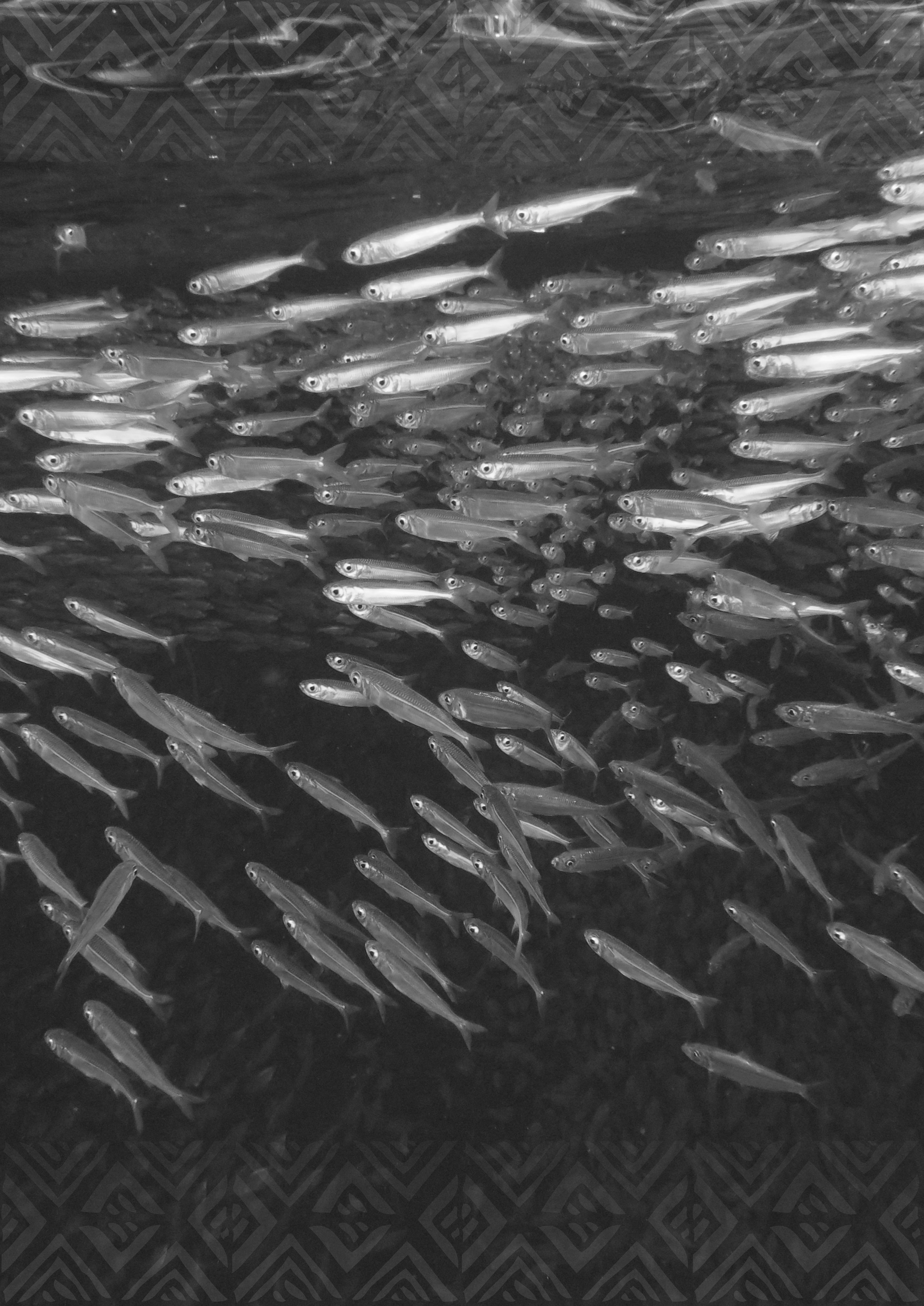
The "Friendly Islands" archipelago, as it was formerly known, was united to form the Polynesian Kingdom of Tonga in 1845. Tonga is unique in the Pacific Island region in the sense that it never lost its traditional ruling system and is the only remaining monarchy. According to 2017 estimates, Tonga is home to approximately 107,746 inhabitants, spread

across four main island groups. The official language, Tongan, is spoken by the entirety of the population. Tonga has no municipal councils, however, there are various town and district officers elected by residents to represent the government at the local level.

The longest claim

Interestingly, the Kingdom of Tonga has the longest continuous legal claim of historic title to maritime domain in the world. This claim dates back to 24 August 1887, with the Royal Proclamation instrument issued by His Majesty George Tupou I. This is noteworthy because this title sets the national jurisdiction of the Kingdom of Tonga, defining the islands, rocks, reefs, coasts and offshore areas within Tonga's EEZ.





VALUING

Marine ecosystems in Tonga provide significant benefits to society, including livelihoods and nutrition for the people of Tonga, the Pacific and around the world. Limited land resources and the dispersed and isolated nature of communities make Tongans heavily reliant upon the benefits of marine ecosystems.

These benefits, or ecosystem services, include a broad range of connections between the environment and human well-being and can be divided into four categories:

1. Provisioning services are products obtained from ecosystems (e.g. fish).
2. Regulating services are benefits obtained from the regulation of ecosystem processes (e.g. coastal protection).
3. Cultural services are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences (e.g. traditional fishing and traditional marine resource management systems).
4. Supporting services are necessary for the production of all other ecosystem services (e.g. nutrient cycling, biodiversity).

The maps in this chapter showcase, firstly, the biophysical prerequisites underpinning the rich values and benefits provided by marine ecosystems. These range from the volcanism at the depths of the ocean that formed the islands and atolls that now provide a home to many, to the prevailing flow of currents and the role of plankton in the ocean's life cycle, among many others.

Based on the combinations of biophysical conditions, the ocean provides a home to many different species, from coral-grazing parrotfish on the reefs to the strange and mysterious animals of the deep. These and many other species and the unique marine ecosystems on which they rely are featured in the maps to follow.

Appreciating the rich diversity of marine ecosystems helps in understanding their importance to Tonga. Quantifying the benefits of marine ecosystems in the Pacific makes it easier to highlight and support appropriate use and sustainable management decisions. Despite the fact that more than 95 per cent of Pacific Island territory is ocean, the human benefits derived from marine and coastal ecosystems are often overlooked. For example, ecosystem services are usually not visible in business transactions or national economic accounts in Pacific Island countries. Assessments of the economic value of marine ecosystem services to Pacific Islanders can help make society and decision makers alike aware of their importance.

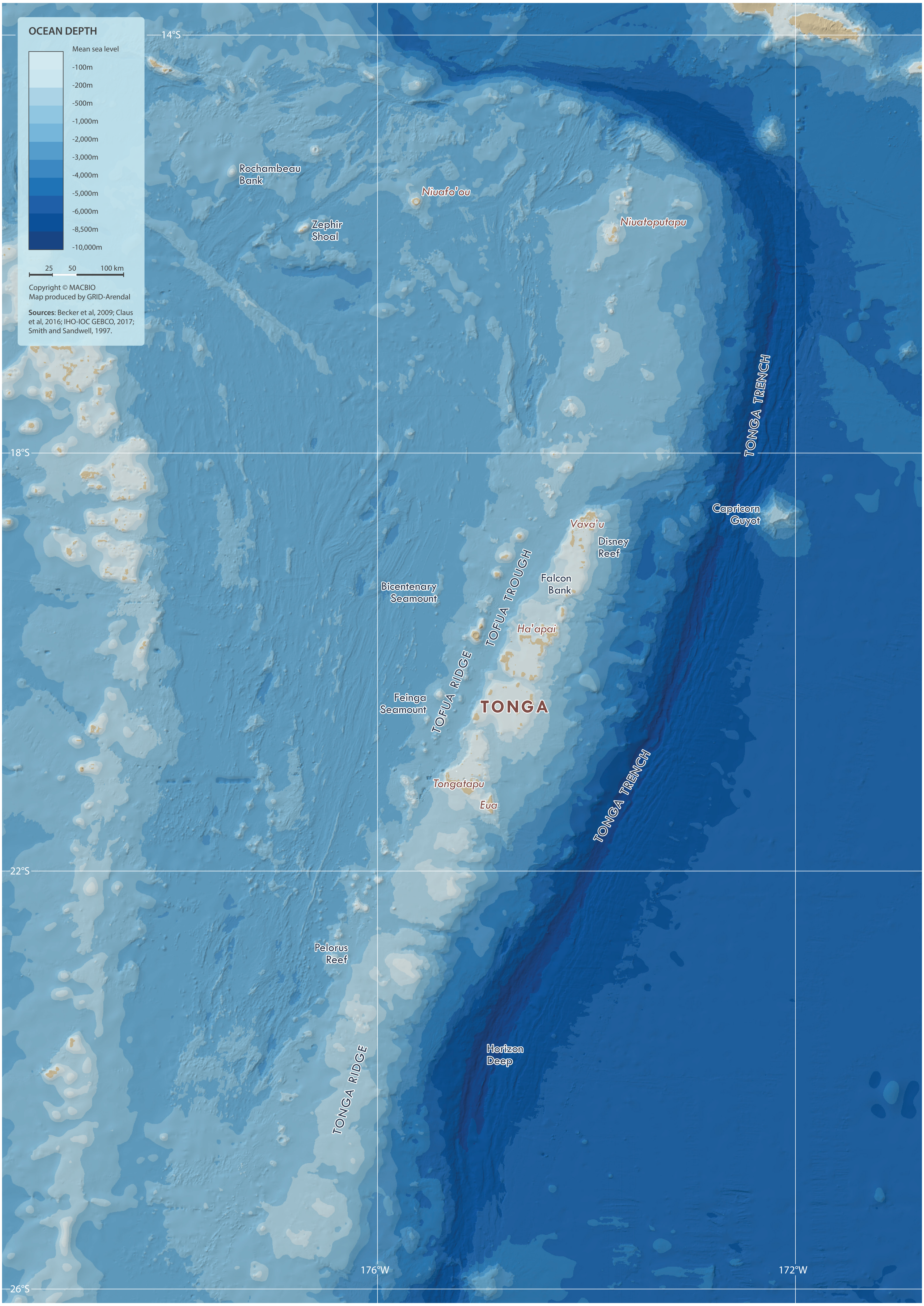
Tonga has therefore undertaken economic assessments of its marine and coastal ecosystem services, and is working on integrating the results into national policies and development planning. These economic values are also featured in the maps of this atlas, to help maximize benefits for Tonga.

For further reading, please see **http://macbio-pacific.info/marine-ecosystem-service-valuation/**

The **goods and services** provided by Tonga's **marine ecosystems** are **huge**. They are **larger** than the country's **total export.**

Tonga's **marine ecosystem services** are **valuable** and **diverse**, yet often **hidden**.

Tonga's **marine ecosystem services** need to be fully recognized and sustainably managed or they **may be lost forever**.


OCEAN DEPTH
Mean sea level
-100m
-200m
-500m
-1,000m
-2,000m
-3,000m
-4,000m
-5,000m
-6,000m
-8,500m
-10,000m
25 50 100 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Claus et al, 2016; IHO-IOC GEBCO, 2017; Smith and Sandwell, 1997.
14°S
18°S
22°S
26°S
176°W
172°W
Rochambeau Bank
Zephir Shoal
Niuafo'ou
Niuatoputapu
TONGA TRENCH
Capricorn Guyot
Vava'u
Disney Reef
Falcon Bank
Bicentenary Seamount
TOFUA TROUGH
Ha'apai
TOFUA RIDGE
Feinga Seamount
TONGA
Tongatapu
Eua
TONGA TRENCH
Pelorus Reef
Horizon Deep
TONGA RIDGE

SUPPORTING VALUES

STILL WATERS RUN DEEP: OCEAN DEPTH

It is important to understand how ocean depth influences both the distribution of life below the surface and the management of human activities along the coasts of Tonga.

Standing on Tonga's shore and gazing into an alluring turquoise lagoon, it is hard to imagine how deep the ocean truly is. Only 1 per cent of Tonga's national waters are shallower than 200 metres, while the other 99 per cent dive to 10,800 metres deep, and further. Changes in ocean depth, also known as bathymetry, affect many other dimensions of human life and natural phenomena.

Bathymetric maps were originally produced to guide ships safely through reefs and shallow passages (see chapters "Full speed ahead" and "One world, one ocean"). Since ocean depth is correlated with other physical variables such as light availability and pressure, it is also a determining factor in the distribution of biological communities, either those living on the bottom of the sea (benthic), close to the bottom (demersal) or in the water column (pelagic).

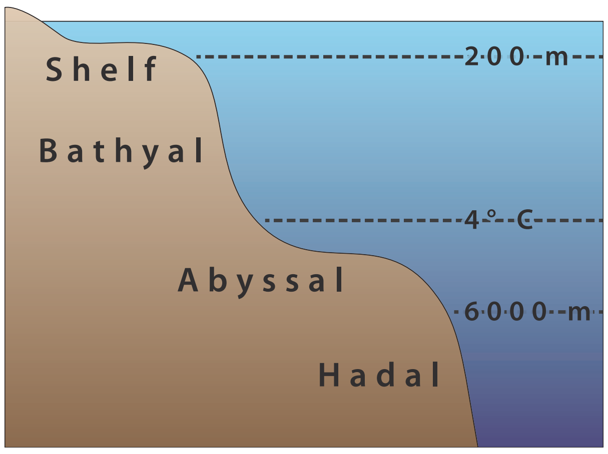
In addition, bathymetry significantly affects the path of tsunamis, which travel as shallow-water waves across the ocean. As a tsunami moves, it is influenced by the sea floor, even in the deepest parts of the ocean. Bathymetry influences the energy, direction and timing of a tsunami. As a ridge or seamount may redirect the path of a tsunami towards coastal areas, the position of such features must be taken into account by tsunami simulation and warning systems to minimize the risk of disaster.

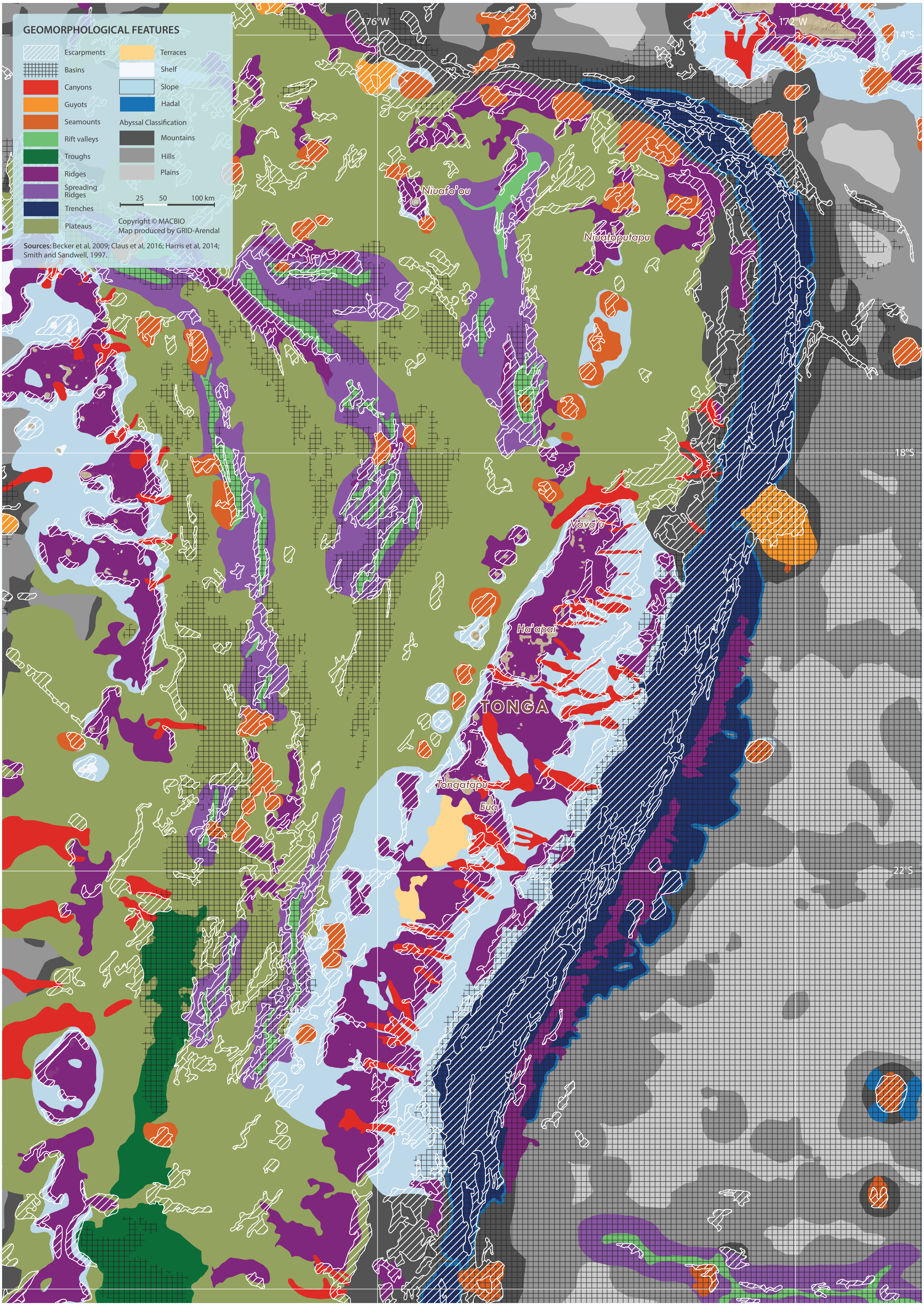
As the bathymetry map shows, Tonga's main islands are located along a large ridge less than 2,000 metres deep, which extends to the south as the Tonga Ridge. To the west lies an area of shallow abyssal sea floor between 2,000 and 3,000 metres deep. To the north and west of the main islands, there are numerous seamounts. Several if these, such as the Zephir Shoal (see also chapter "Underwater mountains"), have peaks approaching the sea surface. To the east of the main Tongan islands lies the Tonga Trench, the second deepest trench in the world. This trench goes to depths in excess of 8,000 metres along much of its length. Horizon Deep, in the southern part of Tonga's waters, is the deepest part, with a maximum depth of 10,880 metres. The abyssal sea floor is much deeper to the east of the Tonga Trench, with depths between 5,000 and 6,000 metres. The Capricorn Guyot, a seamount with a flat top, rises up from this deep-sea floor to within 500 metres of the sea surface.

The sea floor can be divided into several different zones based on depth and temperature: the sublittoral (or shelf) zone, the bathyal zone, the abyssal zone and the hadal zone. The sublittoral zone encompasses the sea floor from the coast to the shelf break—the point at which the sea floor rapidly drops away. The bathyal zone extends from the shelf break to around 2,000 metres. The lower limit of the bathyal zone is defined as the depth at which the temperature reaches 4°C. This zone is typically dark and thus not conducive to photosynthesis. The abyssal zone extends from the bathyal zone to around 6,000 metres. The hadal zone, the deepest zone, encompasses the deep-sea floor, typically only found in ocean trenches.

Horizon Deep

Tonga's ocean is deep. Very deep. It boasts the deepest point in the southern hemisphere and the second deepest on Earth. With a maximum depth of 10,880 metres, Horizon Deep is the deepest point in the Tonga Trench. The submarine trench in the floor of the South Pacific Ocean is about 1,375 kilometres long and 80 kilometres wide and forms the eastern boundary of the Tonga Ridge. Together, the Tonga Ridge and the Tonga Trench constitute the northern half of the Tonga-Kermadec Arc, a structural feature of the Pacific floor, completed to the south by the Kermadec Trench and Ridge. The trench exists where the Pacific plate slips under the Indo-Australian plate. And this is another record: it is the fastest plate tectonic velocity on Earth. While 24 centimetres per year may not seem particularly speedy, for geologists, this is breakneck speed!




GEOMORPHOLOGICAL FEATURES
Escarpments
Basins
Canyons
Guyots
Seamounts
Rift valleys
Troughs
Ridges
Spreading Ridges
Trenches
Plateaus
Terraces
Shelf
Slope
Hadal
Abyssal Classification
Mountains
Hills
Plains
25 50 100 km
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Sources: Becker et al, 2009; Claus et al, 2016; Harris et al, 2014; Smith and Sandwell, 1997.
176°W
172°W
14°S
18°S
22°S
Niuafo'ou
Niuatoputapu
Vava'u
Ha'apai
TONGA
Tongatapu
Eua

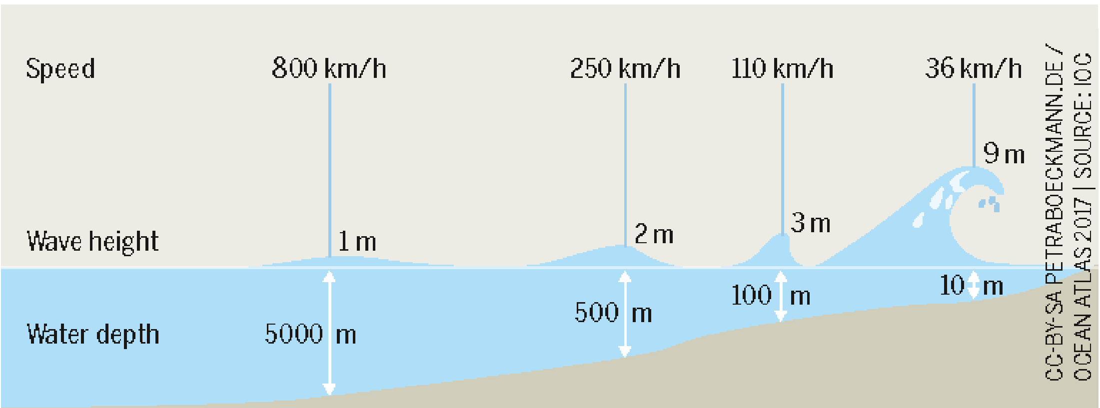
VOYAGE TO THE BOTTOM OF THE SEA: GEOMORPHOLOGY

Tonga's sea floor is rich in physical features of different shapes and sizes that affect the distribution of biodiversity, fishing grounds and deep-sea minerals.

The Samoa Tsunami

One recent example of such effects was the 2009 Samoa Tsunami, which caused substantial damage and the loss of 189 lives in Samoa, American Samoa and Tonga (see graphics). A 76 millimetre rise in sea levels near the earthquake's epicentre transformed into a wave up to 14 metres high when it hit the shallow Samoan coast.

Emerging Giant – A Tsunami Races across the Ocean



The nation's seascape is as diverse underwater as its landscape above, including towering underwater mountains (seamounts) that attract migratory species from hundreds of kilometres away, and deep-sea canyons that carry nutrient-rich water from the deep ocean to the shallow areas. Geomorphology (the study and classification of these physical features) reveals both the geological origin of the features as well their shape (morphology), size, location and slope.

The geomorphology of the sea floor influences the way the ocean moves (see also chapter "Go with the flow"), the way the wind blows and the distribution of water temperature and salinity (see also chapter "Hotter and higher"). These factors affect the distribution of biological communities, resulting in different biological communities being associated with different types of sea-floor geomorphology. For example, seamounts generally have higher biodiversity and a very different suite of species to the adjacent, deeper abyssal areas.

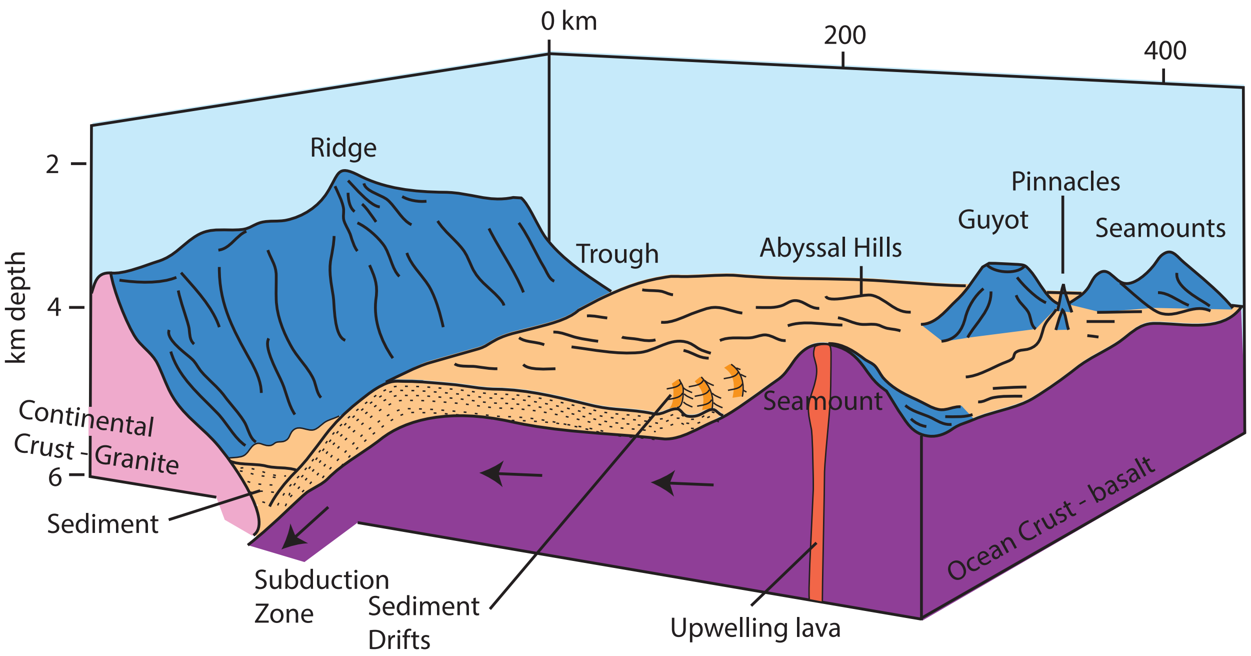
Similarly, different economic resources are often associated with different features. Many fisheries operate on certain features, such as the shelf, slope or over seamounts, based on where their target species occur. In Tonga, important deep-sea snapper is mostly found on outer reef slopes and around seamounts (mainly in depths from 100 to 400 metres; see chapter "Fishing in the dark"). Furthermore, different types of deep-sea mineral deposits are also associated with different features, such as the sea-floor massive sulfide deposits found along mid-ocean ridges (see chapter "Underwater Wild West").

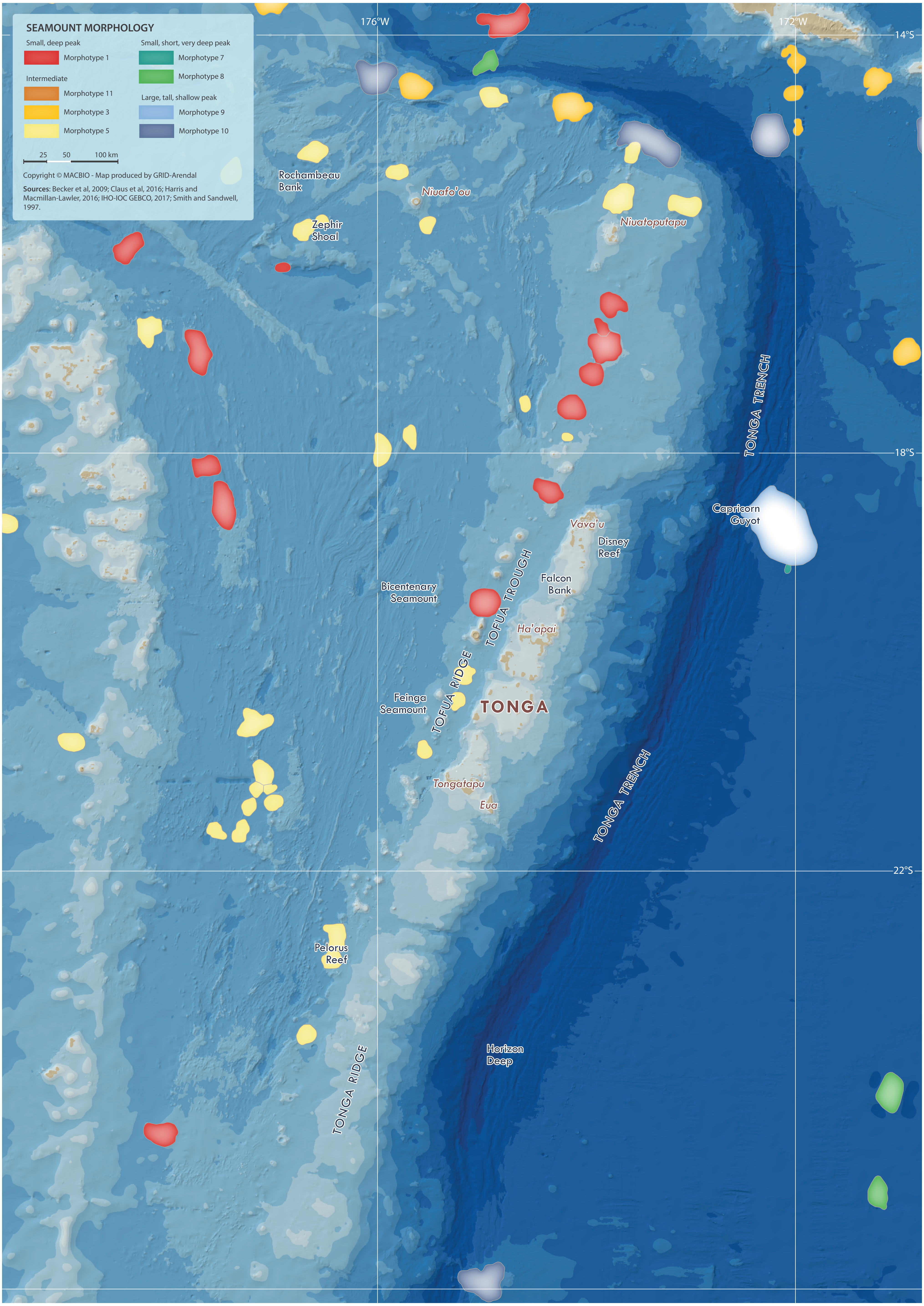
Tonga's waters harbour 18 different geomorphic features, which are presented in this map and associated figures. The distribution of geomorphology reflects many of the patterns observed in the bathymetry map, as geomorphology is primarily a classification of the shape of the sea-floor features. The Tongan islands and the western part of Tonga's waters sit on top of a large plateau—an area of raised sea floor—that perches several thousand metres above the surrounding ocean sea floor. Within this area, there are several small, spreading ridges, with small rift valleys forming in their centres.

There are 43 seamounts in Tonga's waters, with the majority to the west and north of the main islands. A distinct chain of seamounts lies to the immediate west of the main islands, running in a north–south direction. A single large guyot—a seamount with a flat top—lies to the east of the main islands. Seamounts are large (over 1,000 metres high), conical mountains of volcanic origin, while guyots are seamounts with flattened tops (see also chapter "Underwater mountains"). The steep sides of all these features interact with currents and create important habitats for many species.

Immediately to the east of the main islands lies the Tonga Trench, a deep ocean trench reaching depths greater than 8,000 metres. It's deepest point, known as Horizon Deep, measures 10,880 metres. These deep ocean trenches are likely to support a suite of unique species compared with other parts of the sea floor.

The main islands are perched on the large Tonga Ridge, which marks the eastern boundary of a large plateau. Adjacent areas of slope and the margins of the plateau are incised with numerous large submarine canyons. These canyons are characterized as areas of high biodiversity due to their steep sides featuring rocky slopes, strong currents and enhanced access to food. They also act as a conduit between the deep-sea floor and the shallow shelf areas. On all these features, areas of steep sea floor (escarpments) are likely to contain hard substrate which, coupled with increased current flow, create ideal habitats for filter-feeding organisms such as sponges and cold-water corals.





SEAMOUNT MORPHOLOGY
Small, deep peak
Morphotype 1
Intermediate
Morphotype 11
Morphotype 3
Morphotype 5
Small, short, very deep peak
Morphotype 7
Morphotype 8
Large, tall, shallow peak
Morphotype 9
Morphotype 10
25 50 100 km
Copyright © MACBIO - Map produced by GRID-Arendal
Sources: Becker et al, 2009; Claus et al, 2016; Harris and Macmillan-Lawler, 2016; IHO-IOC GEBCO, 2017; Smith and Sandwell, 1997.
176°W
172°W
14°S
18°S
22°S
Rochambeau Bank
Niuafo'ou
Zephir Shoal
Niuatoputapu
TONGA TRENCH
Capricorn Guyot
Vava'u
Disney Reef
Falcon Bank
TOFUA TROUGH
Bicentenary Seamount
Ha'apai
TOFUA RIDGE
Feinga Seamount
TONGA
Tongatapu
Eua
TONGA TRENCH
Pelorus Reef
Horizon Deep
TONGA RIDGE

UNDER WATER MOUNTAINS: SEAMOUNT MORPHOLOGY

Tonga has 44 submarine mountains or seamounts (including guyots). These enhance productivity and act as biodiversity hotspots attracting pelagic predators and migratory species such as whales, sharks and tuna. Vulnerable to the impacts of fishing and mineral resource extraction, seamounts are becoming increasingly threatened.

Underwater mountains

Imagine the shock of the captain who, in 2005, ran his submarine, the USS San Francisco, at full speed (35 knots) into an unknown solid object at a depth of 160 metres (Doehring, 2014). It was neither a whale nor a hostile submarine. The mysterious object in fact turned out to be an underwater island, or seamount. Vessels on the surface can easily look out for islands, either visually or using bathymetric maps (see chapter "Still waters run deep"), and the same applies for submarines. Unfortunately, at the time, the charts did not show the seamount near Guam that the submarine ran into. The fact that this feature was not on the charts is due to the nature of seamounts—mountains rising from the ocean floor that do not quite reach the water's surface.

But how quickly things can change! By 16 January 2015, after a large eruption and ash plumes reaching 10 kilometres high, a former seamount became a new Tongan island, Hunga Ha'apai, now 2 kilometres long and 100 metres high (NASA, 2015).

While some islands are newly born and others disappear amid rising sea levels (see chapter "Hotter and higher"), there is a third kind that seems to come and go. Home Reef, created by another Tongan seamount, surfaced in 2006, sending vast rafts of floating pumice drifting over to Fiji. And yet, by 2008, Home Reef was already gone. A subsequent eruption in 2015 did not bring Home Reef back, but the seamount may yet have another chance to metamorphose into an island (Smithsonian Institution, 2017).

Seamounts are important features of the ocean landscape, providing a range of resources and benefits to Tonga. Many have elevated biodiversity compared to surrounding deep-sea areas. They can therefore function as stepping stones, allowing hard substrate organisms to disperse from one underwater mountain to another, thereby expanding their range across ocean basins. Seamounts are also key locations for many fisheries (see also chapter "Fishing in the dark") and are known to contain valuable mineral resources (see also chapter "Underwater Wild West"). As demand for these resources continues to grow, the need for focused management is increasing. The adverse impacts of mismanaged mineral resources extraction have the potential to severely impact seamount ecosystems.

Just like mountains above the sea, seamounts differ in size, height, slope, depth and proximity, with different combinations of these factors recognized as different morphotypes likely to have different biodiversity characteristics (Macmillan-Lawler and Harris, 2015). The map presents a classification of seamounts identified by Harris et al. (2014) into morphotypes within Tonga's waters. Physical variations such as depth, slope and proximity are known to be important factors for determining the structure of biological communities. For example, many species are confined to a specific depth range (Rex et al., 1999; Clark et al., 2010). Therefore, both the minimum depth (peak depth) and the depth range (height) are likely to be strongly linked to the biodiversity of a given seamount.

Slope is also an important control in the structure of seamount communities, with steep slopes, which are current-swept, likely to support different communities to flat areas, which may be sediment-dominated (Clark et al., 2010). Seamounts in close proximity commonly share similar suites of species with one another and also with nearby areas of the continental margin.

The 43 seamounts and one guyot in Tonga's water represent eight of the 11 global morphotypes. Understanding this distribution of the different morphotypes is important for prioritizing management actions. For example, seamounts with shallow peak depths that fall within the Epipelagic (photic) zone are hotspots for biodiversity. In Tonga's case, this includes the large, tall and shallow peaked seamounts (morphotypes 9 and 10), the majority of which are found north of the main islands, with the exception of the Capricorn Guyot (morphotype 9) to the east of the islands. Over half the seamounts are part of the intermediate seamount group (morphotypes 3, 5 and 11). These are small to medium in size, with medium heights and a gradation in peak depths from moderately shallow through to moderately deep. Of the remaining seamounts, nearly one quarter are small with deep peaks (morphotype 1).

Those with shallow or moderately shallow peak depths are more likely to be exposed to fishing impacts than deeper-peaked ones. The remaining seamount morphotypes are characterized by deep to very deep peak depths, so are less likely to be targeted directly by fishing. However, with the push to explore seabed mineral resources, seamounts—with their associated cobalt-rich crusts—are likely to come under increasing pressure.

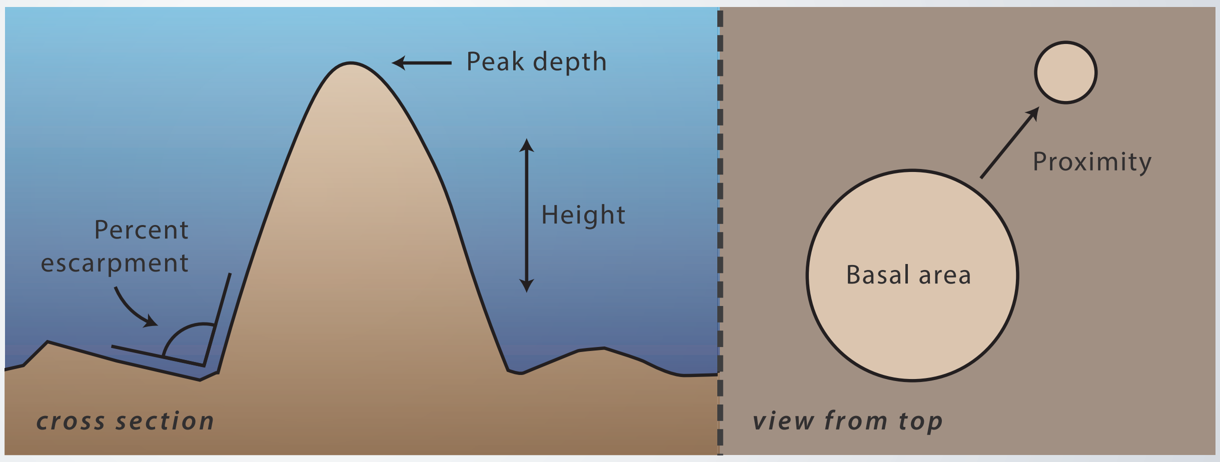
Seamount morphotypes found in Tonga waters

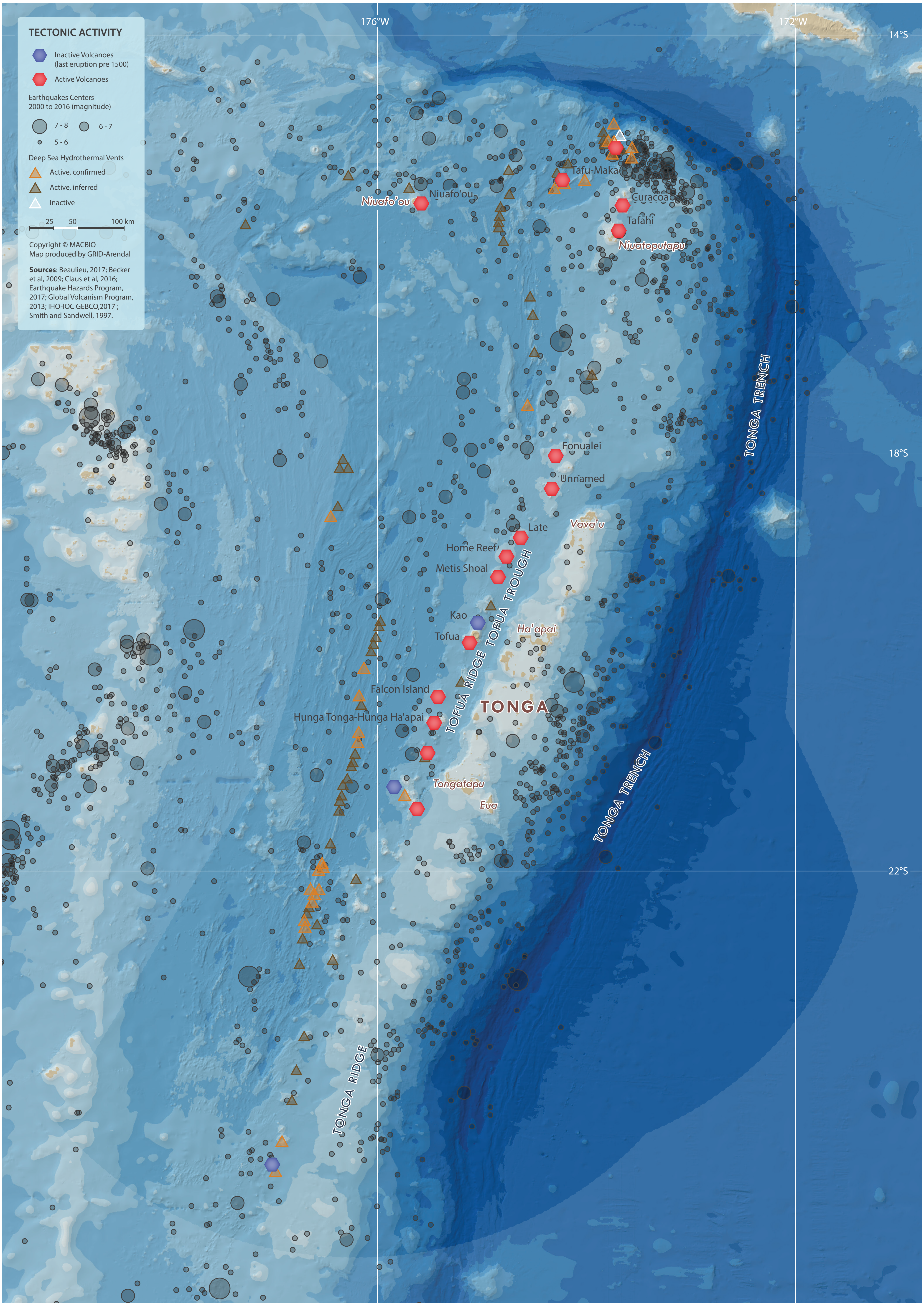
Large and tall seamounts with a shallow peak – *Morphotypes 9 and 10*.

Medium-height seamounts with moderately deep peak depths – *Morphotype 3, 5, and 11*.

Small seamounts with a deep peak – *Morphotypes 1, 2, and 4*.

Small and short seamounts with a very deep peak – *Morphotypes 7 and 8*.




TECTONIC ACTIVITY
Inactive Volcanoes (last eruption pre 1500)
Active Volcanoes
Earthquakes Centers 2000 to 2016 (magnitude)
7 - 8
6 - 7
5 - 6
Deep Sea Hydrothermal Vents
Active, confirmed
Active, inferred
Inactive
25 50 100 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Beaulieu, 2017; Becker et al, 2009; Claus et al, 2016; Earthquake Hazards Program, 2017; Global Volcanism Program, 2013; IHO-IOC GEBCO,2017 ; Smith and Sandwell, 1997.
176°W
172°W
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Tafu-Maka
Niuafo'ou
Niuafo'ou
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Niuatoputapu
Fonualei
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Late
Vava'u
Home Reef
Metis Shoal
Kao
Tofua
Ha'apai
Falcon Island
Hunga Tonga-Hunga Ha'apai
TONGA
Tongatapu
Eua
TOFUA RIDGE
TOFUA TROUGH
TONGA TRENCH
TONGA TRENCH
TONGA RIDGE

SMOKE UNDER WATER, FIRE IN THE SEA: TECTONIC ACTIVITY

Tonga is located on the Pacific Ring of Fire, a highly active tectonic zone. Above water, this tectonic activity means that the people of Tonga are under threat from possible earthquakes and tsunamis. Underwater, the tectonic activity produces magnificent underwater volcanoes and hydrothermal vents that, in turn, spawn unique, complex but fragile ecosystems that contribute to Tonga's rich marine biodiversity. These features also deposit minerals, making them an attractive, if conflicting, target for deep-sea mining exploration and extraction.

The Tongan islands sit on the Tonga-Kermadec Arc, an arc of volcanic islands that stretches from New Zealand to Tonga. This island arc was formed by the subduction of the Pacific plate, which began around 45 million years ago (Ma) (Neall and Trewick, 2008). The western islands, including 'Ata, Fonuafo'ou, Tofua, Kao, Lateiki, Late, Fonualei, Toku, Niuatoputapu and Tafahi, are volcanic in origin. The eastern islands are non-volcanic and instead low coral limestone islands. In 2015, the eruption of the Hunga Tonga volcano created a new island 45 kilometres north-west of Tonga's capital, Nuku'alofa. Evidently, the island-building process is an active and ongoing one and plate tectonics are the driving force behind this process.

Aside from the shallow-water areas surrounding these islands, the majority of Tonga's national waters are deeper than 2,000 metres (with a mean depth of around 3,500 metres) and reach depths exceeding 10,800 metres at the deep ocean floor.

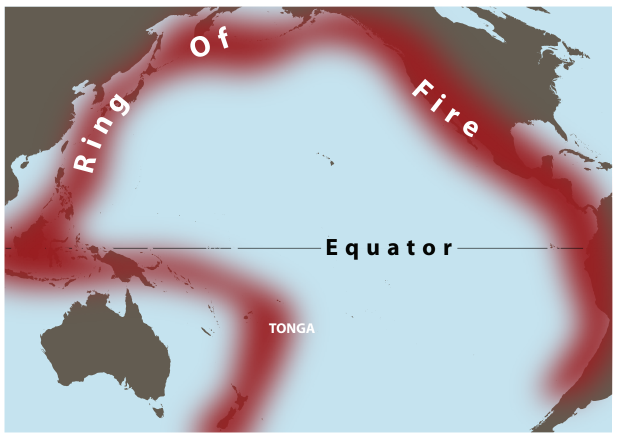
There are still many mysteries around sea-floor hydrothermal vent systems, with their complicated biological, chemical and geological relationships. Only by exploring, recording and monitoring deep-sea hydrothermal systems is there a chance of protecting them and the benefits they provide. But what are hydrothermal vents exactly? They are fissures in the Earth's surface from which geothermally heated water (up to 450°C) escapes. Vents are commonly found in volcanically active areas, such as areas between tectonic plates. Under the sea, hydrothermal vents may develop black or white smokers. These roughly cylindrical chimney structures can reach heights of 60 metres, forming from either black or white minerals that are dissolved in the vent fluid.

The black and white smokers and their mineral-rich warm water attract many organisms and have unique biodiversity. Chemosynthetic bacteria and archaea, both single-celled organisms, form the base of a food chain supporting diverse organisms, including giant tube worms, clams, limpets and shrimp. Some scientists even suggest that life on Earth may have originated around hydrothermal vents. Along with their unique biodiversity, these vents are also a hotspot of minerals. Massive sulfides (including gold and copper), cobalt and rare earth metals occur in high concentrations in vent systems, which are increasingly being explored for their mineral resources (see also chapter "Underwater Wild West").

How deep can you dive?

In an effort to study a variety of marine organisms that have evolved to live in extreme environments, the Japanese QUELLE2013 project (Quest for the Limit of Life) was the first exploration to be undertaken with a manned research submersible in Tonga's waters, in January 2013. QUELLE2013 was a global-scale voyage of scientific surveys and research on ecosystems in hydrothermal vent areas and other unique and extreme environments in the Indian, Atlantic and Pacific Oceans.

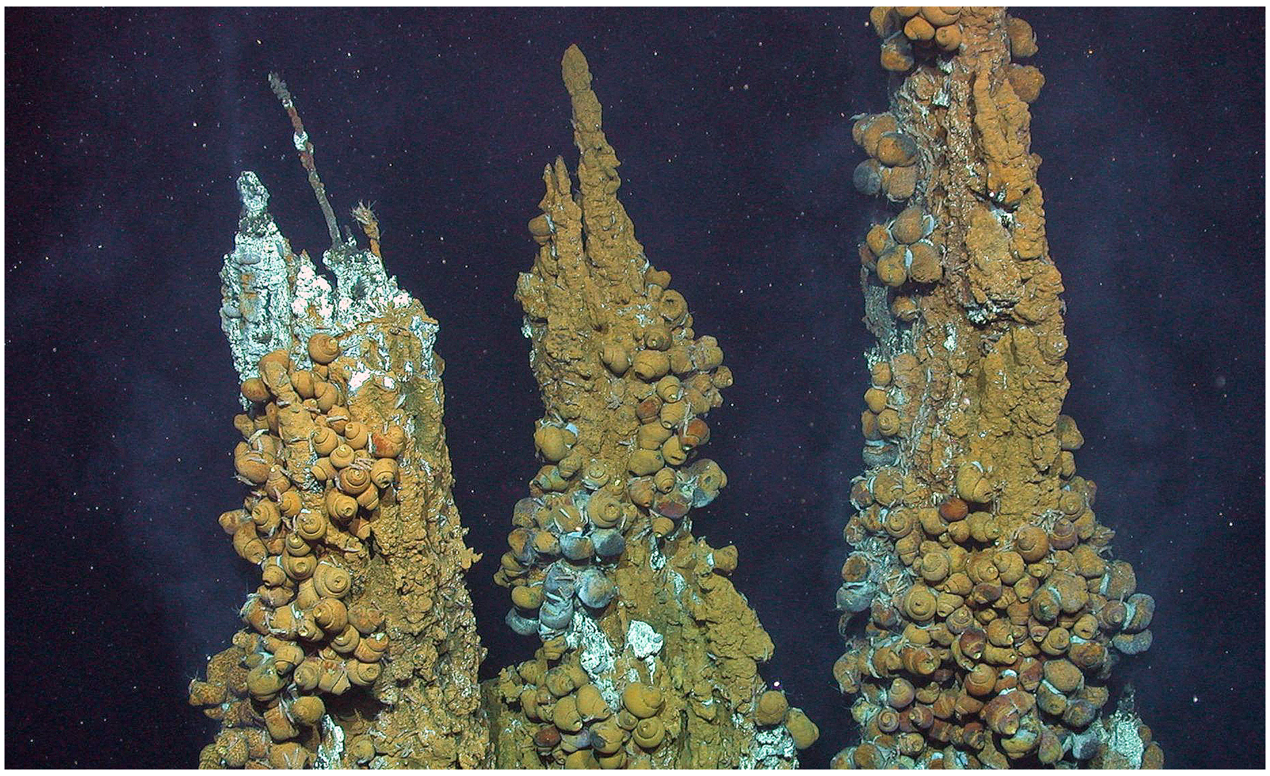
The main survey area was Horizon Deep in the Tonga Trench—the world's second deepest point in the ocean, at 10,850 metres. The objectives of the survey were to: "(i) describe the environmental characteristics of the "hadal zone", including depths of greater than 10,000 meters, and sample the organisms living in this environment, and (ii) find out exactly what is going on there, unravel the correlation between organisms and their habitats, and learn how the trench environment was created."



As the map shows, Tonga's waters harbour not only numerous deep-sea hydrothermal vents, but also 18 volcanoes. The majority of these volcanoes are active, including Hunga Tonga-Hunga Ha'apai. In 2015, Hunga Tonga-Hunga Ha'apai erupted, creating a new island measuring 500 metres across and 250 metres high. This was a demonstration of the dynamic process by which many of Tonga's islands have been created. The volcanoes run in a chain to the west of the main Tongan islands, forming large seamounts rising from the sea floor (see also chapter "Underwater mountains"). The numerous known hydrothermal vents can also be found to the west of the main Tongan islands, where a line of vents runs north to south.

Tectonic activity is key to the creation of the Pacific Islands and atolls, many of which sit upon active or inactive volcanoes (see also chapter "Underwater mountains").

But where does all the heat fuelling vents and volcanoes come from? The Pacific region is one of the most tectonically active regions in the world. The Pacific Ring of Fire, which stretches clockwise from New Zealand all the way around to South America, experiences around 90 per cent of the world's earthquakes. Pacific Island countries such as Tonga are part of the Pacific tectonic plate and are therefore subject to volcanic and seismic activity. Tectonic activity is common around Tonga, with many earthquakes registered in the region, including several of magnitude 7 and above. The earthquakes are concentrated to the west of the Tonga Trench, with a particularly high concentration around the islands in the northern Tongan waters. Earthquakes can, under certain circumstances, generate tsunamis. In 2009, an earthquake measuring 8.1 occurred along the Kermadec-Tonga subduction zone, generating a tsunami that affected Tonga, Samoa and American Samoa. Waves up to 6 metres high struck the northern islands, resulting in extensive damage, injuries and deaths (see also chapters "Still waters run deep" and "Voyage to the bottom of the sea").

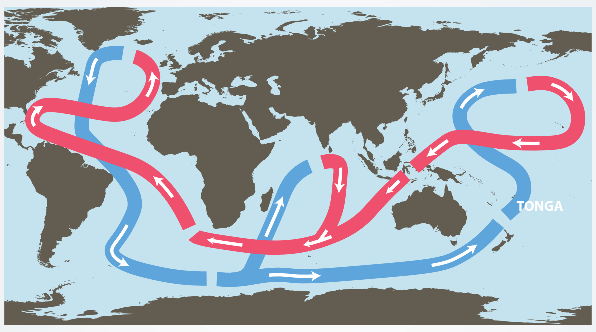


GO WITH THE FLOW: SALINITY AND SURFACE CURRENTS

Ocean currents are driven by a combination of thermohaline currents (thermo = temperature; haline = salinity) in the deep ocean and wind-driven currents on the surface. Ocean currents affect climate, the distribution of biodiversity and the productivity of the seas, particularly during extreme El Niño years.

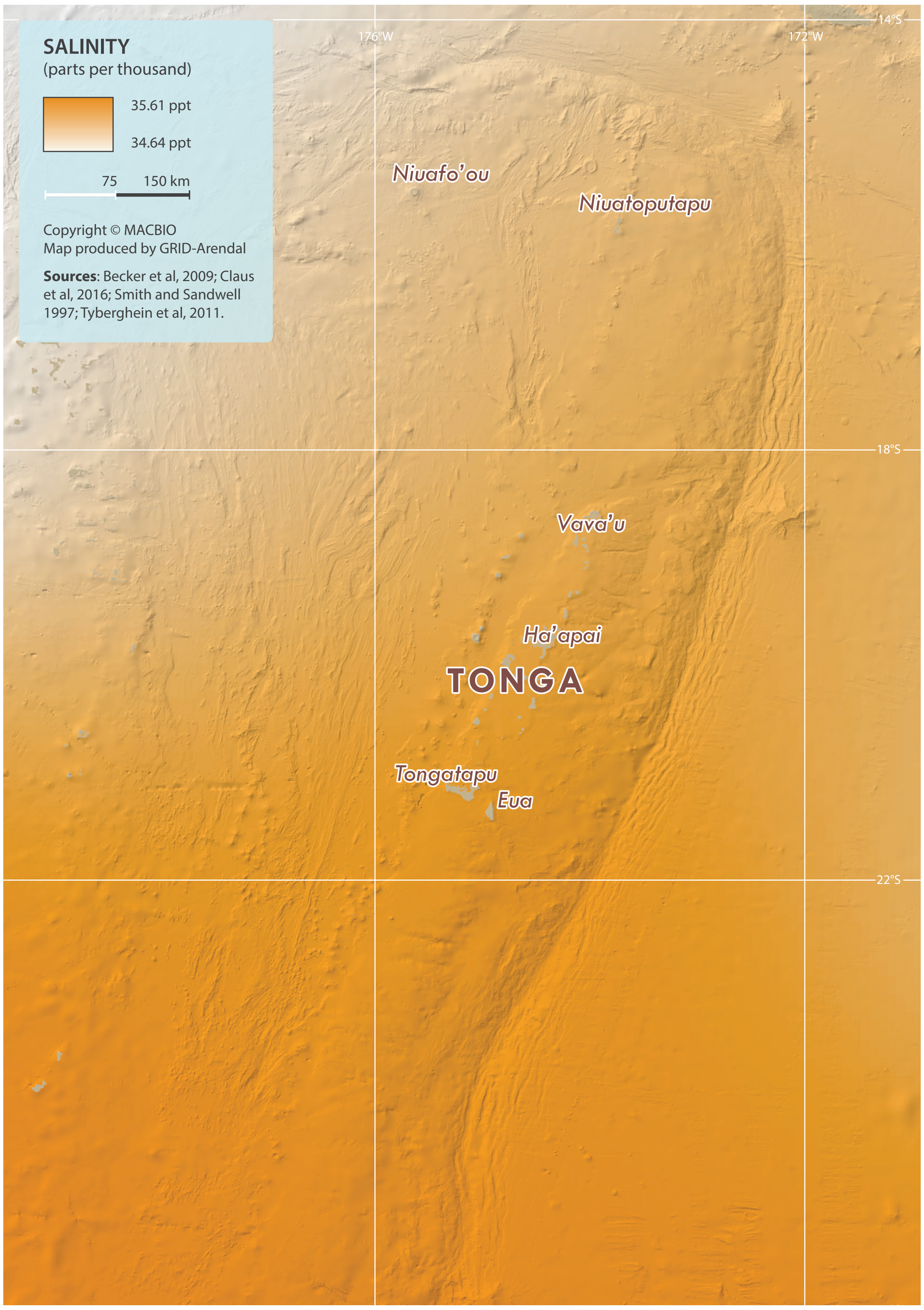
A trip around the world

It took Magellan more than three years (from 1519 to 1522) to be the first person to circumnavigate the Earth. The current record for this trip is 67 hours by plane and 50 days by sailboat. Water in the ocean is not in such a rush, taking much more time on its journey on the global ocean conveyor belt. Within this belt, the ocean is constantly in motion due to a combination of thermohaline currents in the deep, and wind-driven currents at the surface. Cold, salty water is dense and sinks to the bottom of the ocean, while warm water is less dense and remains at the surface.



The global ocean conveyor belt starts in the Norwegian Sea, where warm water from the Gulf Stream heats the atmosphere in the cold northern latitudes. This loss of heat to the atmosphere makes the water cooler and denser, causing it to sink to the bottom of the ocean. As more warm water is transported north, the cooler water sinks and moves south to make room for the incoming warm water. This cold bottom water flows south of the equator all the way down to Antarctica. Eventually, the cold bottom water returns to the surface through mixing and wind-driven upwelling, continuing the conveyor belt that encircles the globe (Rahmstorf, 2003), crossing the Pacific from east to west.

A full circle takes about 1,000 years. No rush at all!

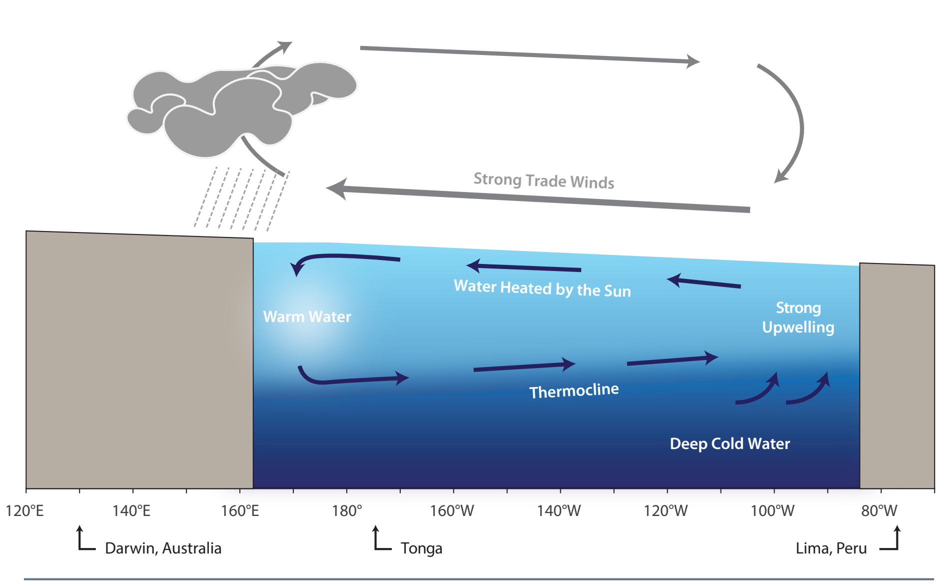


Salinity also greatly influences the distribution of marine life (Lüning, 1990; Gogina and Zettler, 2010). Salinity is the concentration of dissolved salt, measured as the number of grams of salt per kilogram of seawater. The salinity of the global oceans is generally around 35, with a maximum salinity of over 40 found in the Mediterranean and Red Seas, and a minimum salinity of less than five in parts of the Baltic and Black Seas. Generally, salinity is higher in the warmer low-latitude waters and lower in the cooler high-latitude waters. The salinity of Tonga's waters has a narrow range—between 34.9 in the northern part of the EEZ and 35.5 in the southern part of the EEZ. Salinity also varies by depth, with a strong salinity gradient forming in the upper layers, known as a halocline.

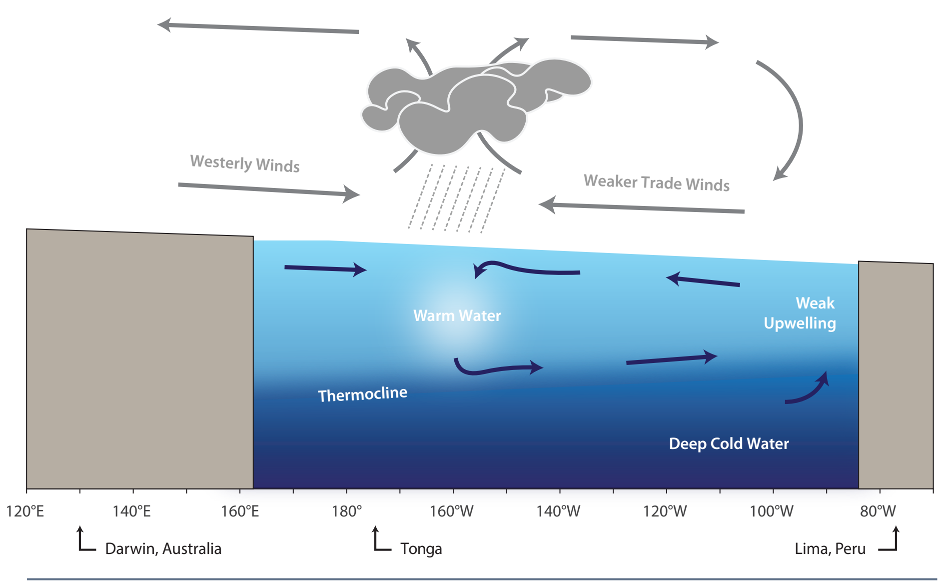
In contrast to the deep-sea currents, Tonga's surface currents are primarily driven by wind. Their direction is determined by wind direction, Coriolis forces from the Earth's rotation, and the position of landforms that interact with the currents. Surface wind-driven currents generate upwelling in conjunction with landforms, creating vertical water currents. The westward flowing South Equatorial Current, which is strongest in Tonga's northern waters, around the islands of Niuafo'ou and Niuatoputapu, is driven by the southeast trade winds. This current turns further southward and becomes weaker through the central part of the main islands and then flows in a south-westerly direction in Tonga's southern waters. Currents are also influenced by topography. Interaction with the Tonga island arc creates a complex current structure, with a weak zonal jet occurring north of Tonga's islands (Webb, 2000).

Both kinds of currents—the thermohaline ones in the deep water and the wind-driven one on the surface—are very important to Tonga. On their journey, water masses transport two things around the globe and through Tonga's waters. Firstly, matter such as solids, dissolved substances and gases are carried by the currents, including salt, larvae (see also chapter "Travellers or homebodies"), plastics and oil (see also chapters "Plastic oceans" and "Full speed ahead"). Secondly, currents transport energy in the form of heat. Currents therefore have a significant impact on the global climate.

Normal conditions



El Niño conditions

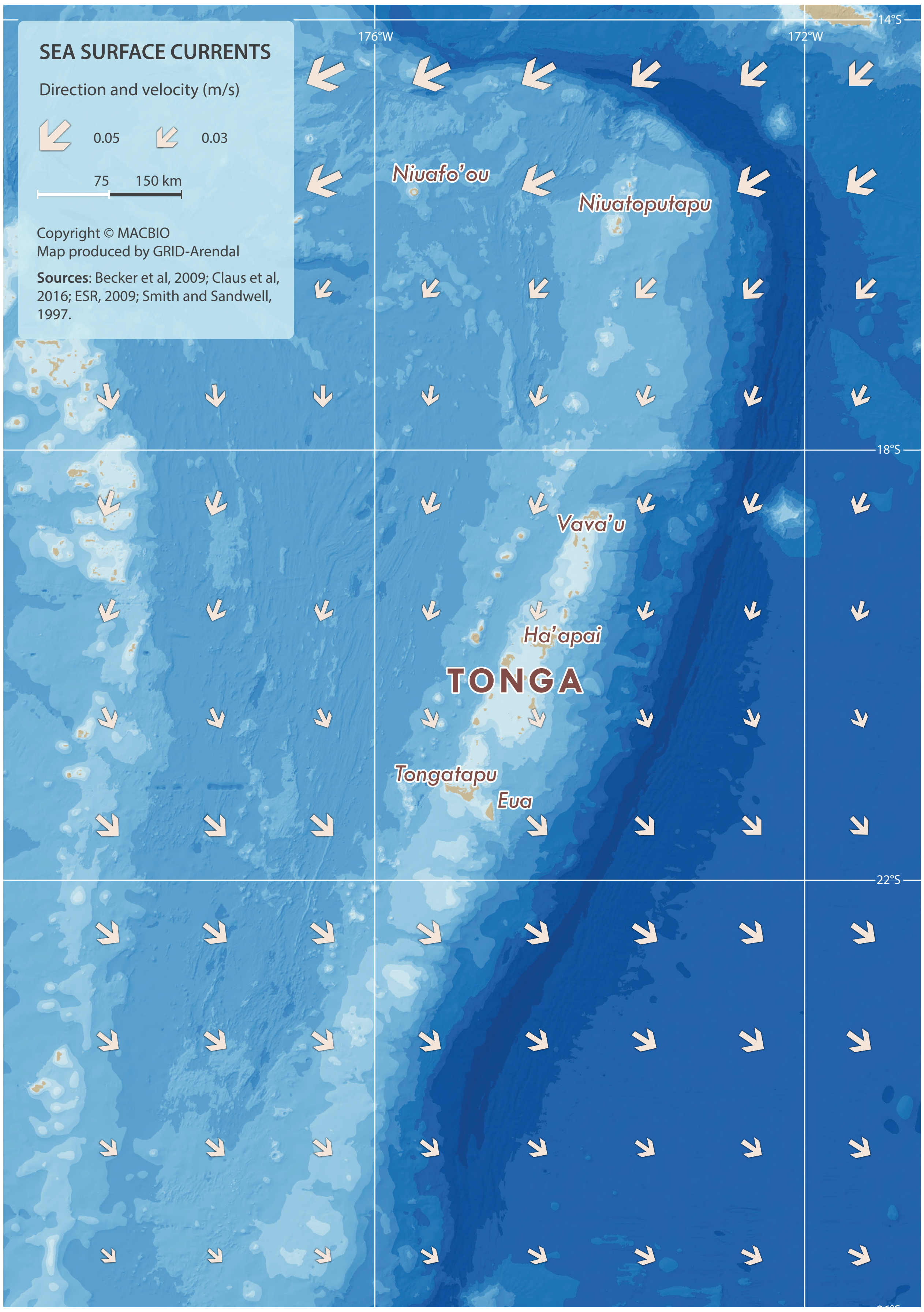


El Niño is an example of the big impact that regional climate variability related to ocean currents has on Tonga (see graphs and chapter "Hotter and higher"). Normally, strong trade winds blow from east to west across the Pacific Ocean around the equator. As the winds push warm surface water from South America west towards Asia and Australia, cold water wells up from below in the east to take its place along the west coast of South America. This creates a temperature disparity across the Pacific, which also keeps the trade winds blowing. The accumulation of warm water in the west heats the air, causing it to rise and create unstable weather, making the western Pacific region warm and rainy. Cool, drier air is usually found on the eastern side of the Pacific.

In an El Niño year, the trade winds weaken or break down. The warm water that is normally pushed towards the western Pacific washes back across, piling up on the east side of the Pacific from California to Chile, causing rain and storms and increasing the risk of cyclone formation over the tropical Pacific Ocean (Climate Prediction Center, 2005).

On the other side, the western Pacific experiences particularly dry conditions. The periods 1997–1998 and 2014–2016 witnessed some of the most extreme events on record in the region. Between 2015 and 2017, Tonga experienced its worst and most sustained drought in decades. Many of the worst affected areas were also those severely hit by Cyclone Pam, itself one of the worst natural disasters in the history of Tonga. Throughout this period, a food security crisis loomed that saw many communities struggle to survive, with young children the most acutely affected. Moreover, El Niño contributes to an increase in global temperatures. In the particularly hot year of 2015, El Niño was responsible for about 10 per cent of the temperature rise. In turn, rising global and ocean temperatures may intensify El Niño (Cai et al., 2014).

In summary, sea currents driven by wind, heat and salinity influence not only Tonga's marine biodiversity, but also its rainfall patterns and temperature on land.

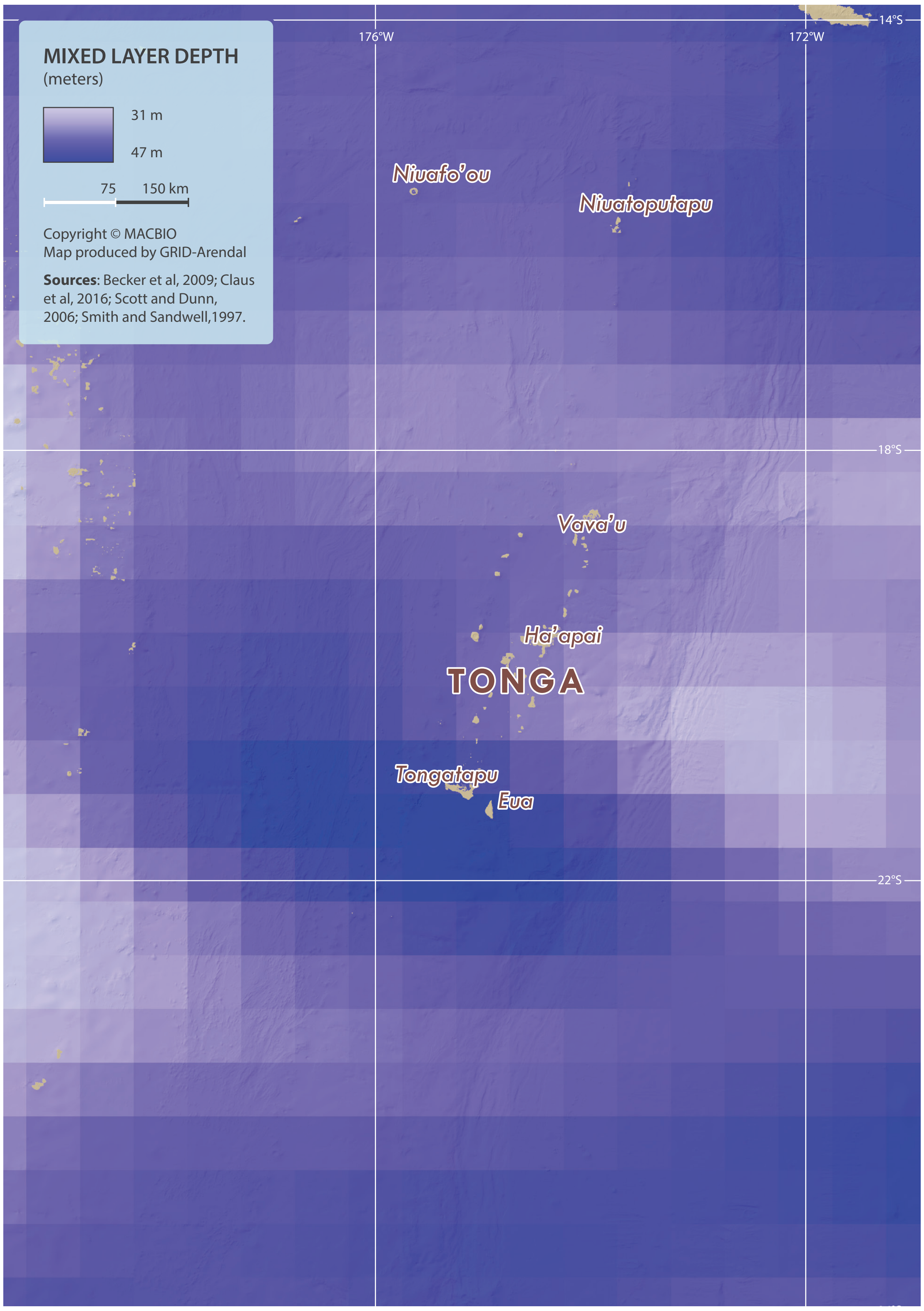


STIR IT UP: MIXED LAYER DEPTH

Tonga's waters are stirred by winds and heat exchange. How deep this disturbance goes influences both the climate and the marine food chain.

The waters surrounding Tonga are often choppy and turbulent, creating a 'mixed layer' in the upper portion of sea surface where active air–sea exchanges cause the water to mix and become vertically uniform in temperature and salinity, and thus density.

The mixed layer plays an important role in the physical climate, acting as a heat store and helping regulate global temperatures (see also chapter "Hotter and higher"). This is because water has a greater capacity to store heat compared to air: the top 2.5 metres of the ocean holds as much heat as the entire atmosphere above it. This helps the ocean buffer global temperatures, as the heat required to change a mixed layer of 25 metres by 1°C would be sufficient to raise the temperature of the atmosphere by 10°C. The depth of the mixed layer is thus very important for determining the temperature range in Tonga's waters and coastal regions.



In addition, the heat stored within the oceanic mixed layer provides a heat source that drives global variability, including El Niño (see also chapter "Go with the flow").

The mixed layer also has a strong influence on marine life, as it determines the average level of light available to marine organisms. In Tonga and elsewhere in the tropics, the shallow mixed layer tends to be nutrient-poor, with nanoplankton and picoplankton supported by the rapid recycling of nutrients (e.g. Jeffrey and Hallegraeff, 1990; see also chapters "Soak up the sun" and "Travellers or homebodies"). In very deep mixed layers, the tiny marine plants known as phytoplankton are unable to get enough light to maintain their metabolism. This affects primary productivity in Tonga's waters which, in turn, impacts the food chain. Mixed layer depth can vary seasonally, with consequential impacts on primary productivity. This is especially prominent in high latitudes, where changes in the mixed layer depth result in spring blooms.

The depth of the mixed layer in Tonga's waters ranges from 33 metres to a maximum of 47 metres, with a mean depth of around 39 metres. The shallowest mixed layer depths occur to the east of the main islands, while the deepest occur in the north—corresponding to the strong South Equatorial Current—and also south of the main islands. Globally, mixed layer depths range from 4 metres to nearly 200 metres depth. The deepest mixed layer depths are generally found in the sub-Antarctic regions and the high latitudes of the North Atlantic.

PUMP IT: PARTICULATE ORGANIC CARBON FLUX

Tonga's sea has valuable ocean pumps that control nutrients, fuel marine life and affect carbon storage.

Oceanic carbon naturally cycles between the surface and the deep via two pumps of similar scale (see graphic). The solubility pump is driven by ocean circulation and the solubility of carbon dioxide (CO_2) in seawater. Meanwhile, the biological pump is driven by phytoplankton (see also chapter "Soak up the sun") and the subsequent settling of detrital particles or the dispersion of dissolved organic carbon.

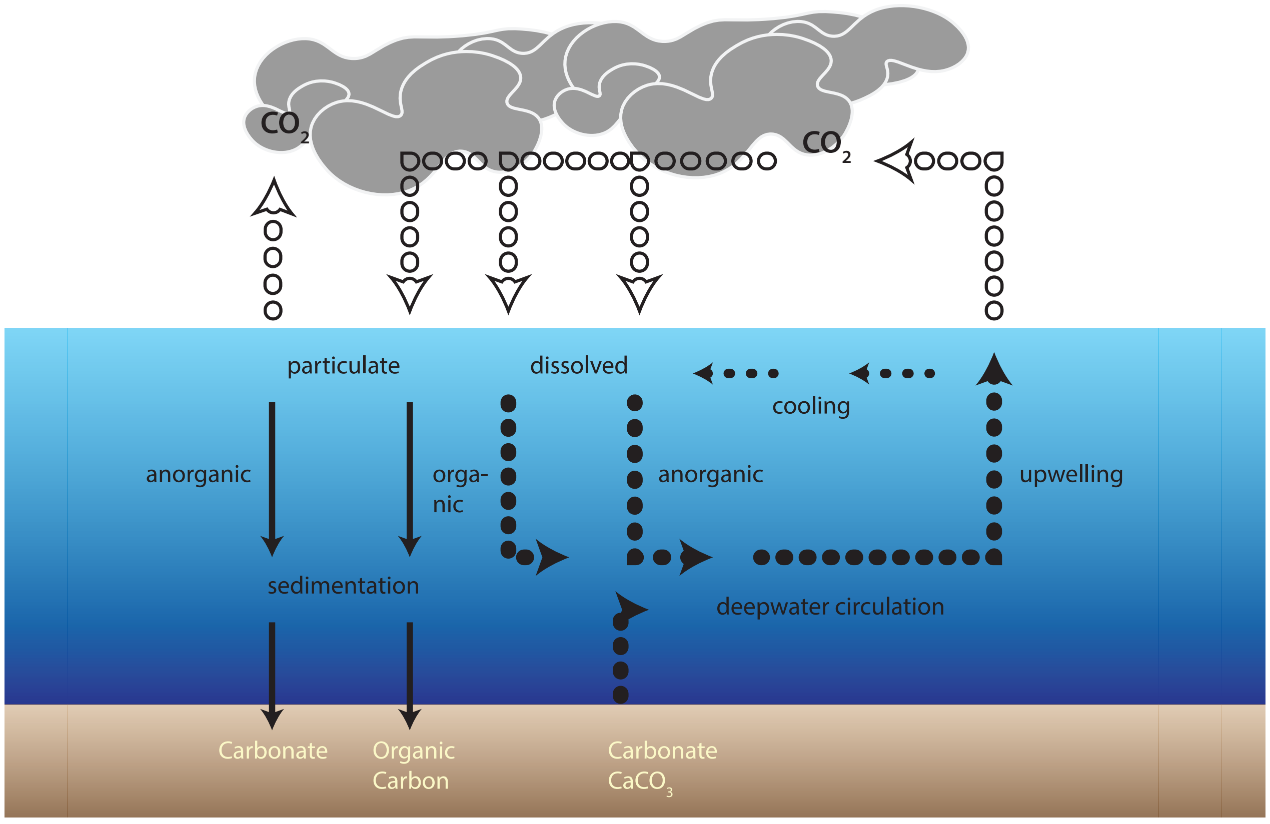
Tonga's ocean pumps are measured by particulate organic flux (the total amount of organic carbon reaching the sea floor) as seen on the map. Organic detritus passing from the sea surface through the water column to the sea floor controls nutrient regeneration, fuels benthic life and affects the burial of organic carbon in the sediment record (Suess, 1980). As the ocean's biological pump is a direct pathway that allows carbon from the atmosphere to be sequestered in the deep-sea floor, it is one of the mechanisms that moderates climate change.

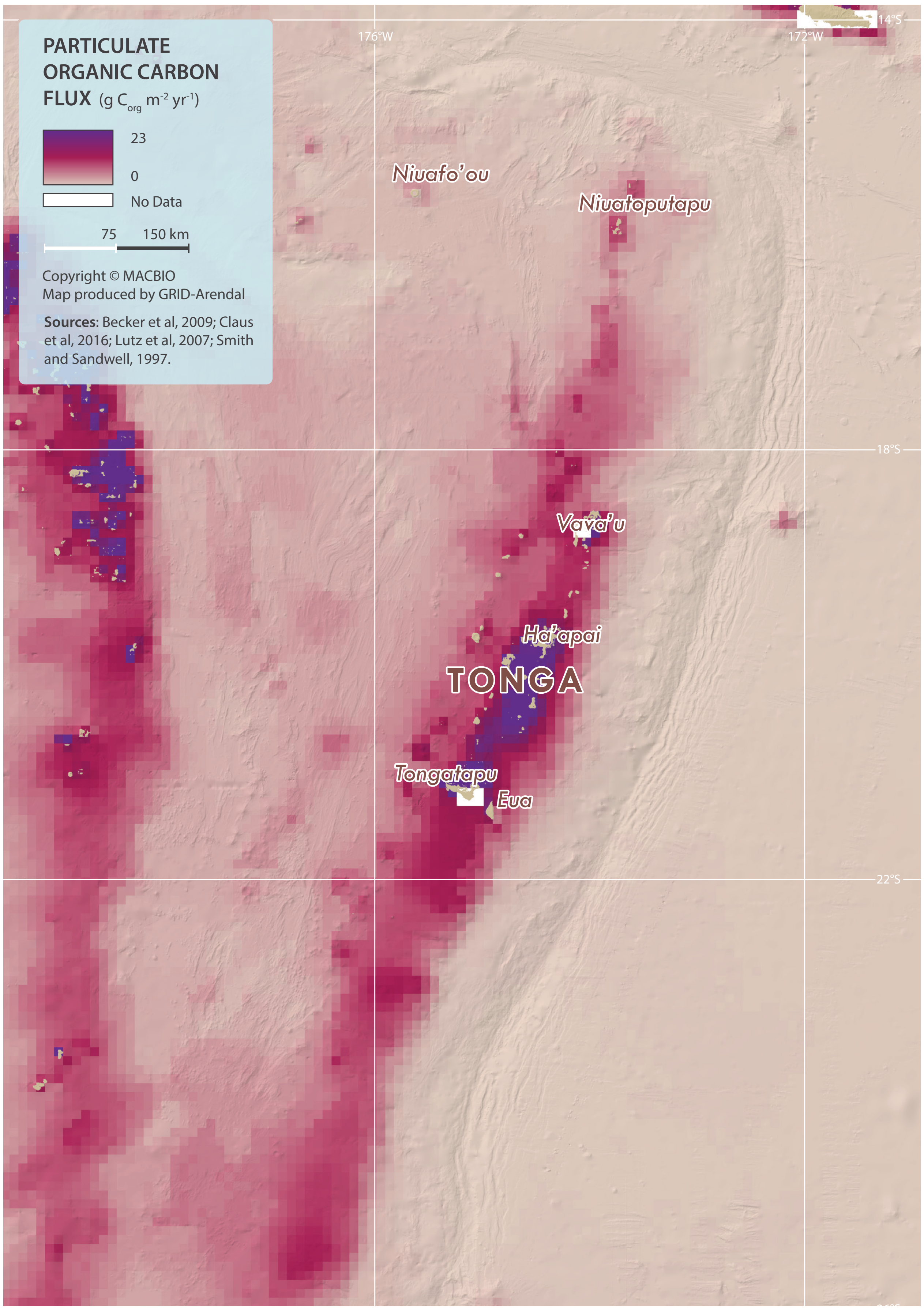
In fact, Tonga's ocean pumps are a key part of blue carbon—the carbon captured by the world's oceans and coastal ecosystems. The carbon captured by living organisms in the oceans is stored as biomass and can be trapped in sediment. Key carbon-capturing ecosystems include mangroves, salt marshes, seagrasses and potentially algae (see also chapter "Home, sweet home"). The social value of carbon sequestration by mangroves and seagrasses in Tonga has been estimated to be worth up to US$1.4 million per year (Pascal et al., 2015).

The patterns of particulate organic carbon flux in Tonga's waters closely reflect the depth of the sea floor, with higher rates in the shallow water compared with the deep. Particulate organic carbon flux is low throughout the majority of Tonga's waters, with rates of less than 1 gram of organic carbon/m2/year reaching much of the deep-sea floor. This is consistent with deep-sea rates globally. The maximum rates of particulate organic carbon flux occur in the shallow coastal zones, where rates are generally above 5 grams/m2 /year and up to a maximum of 23 grams/m2/year.

Whale falls

Whales have cultural significance in Tonga, but they also play an important role in the marine food chain, even after they have died. When a whale passes away, its carcass sinks to the bathyal or abyssal zone, deeper than 1,000 metres (Russo, 2004; see also chapter "Still waters run deep"). On the sea floor, it can create complex localized ecosystems that can sustain deep-sea organisms for decades. Moreover, a whale carcass contains a lot of carbon, which it transports to the bottom of the sea. This transport is part of the biological pump—the flux of organic material from the surface ocean to depth. Food falls (such as whale carcasses) may contribute up to 4 per cent of the total carbon flux to the deep ocean (Higgs et al., 2014).





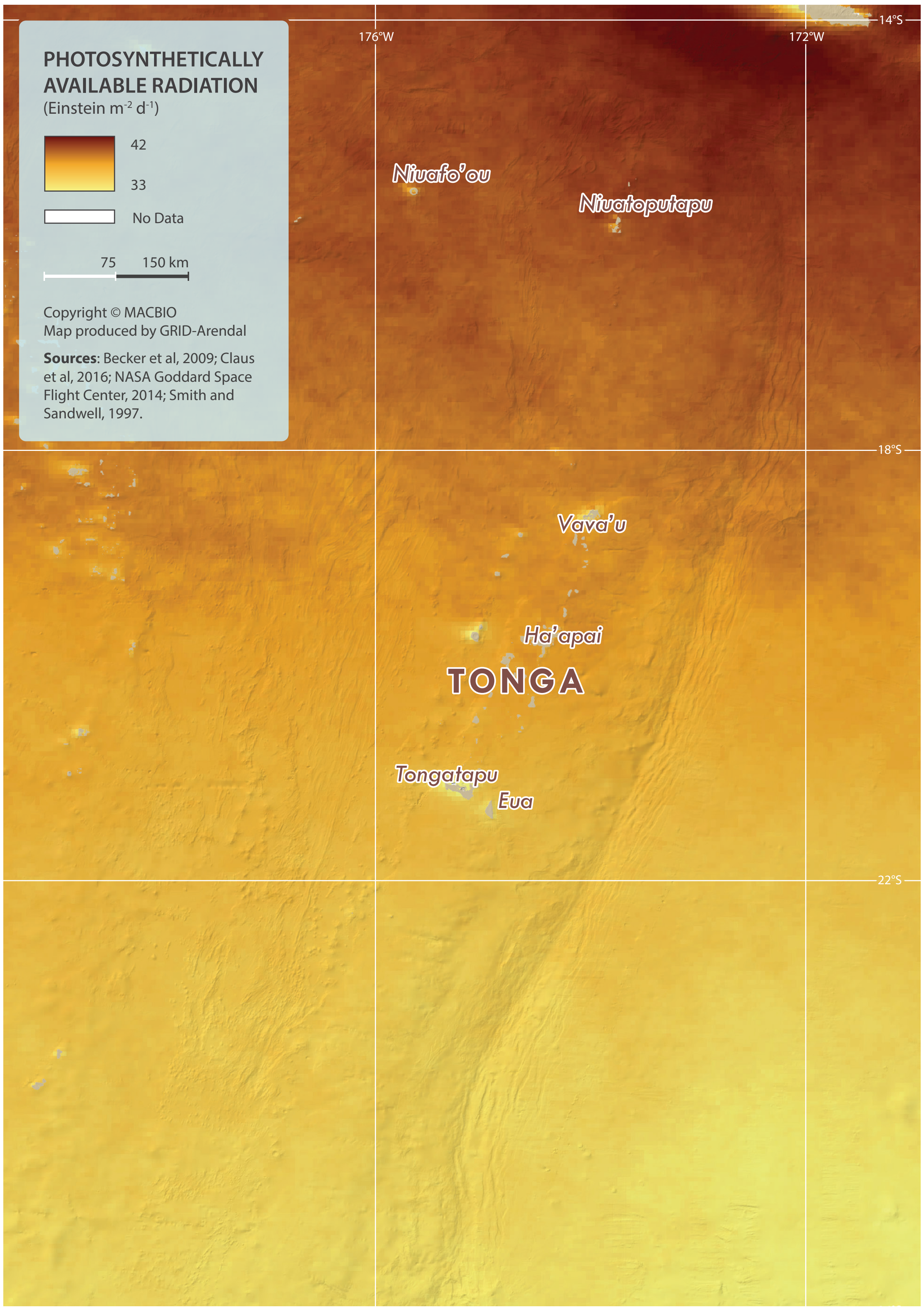
SOAK UP THE SUN: PHOTOSYNTHETICALLY AVAILABLE RADIATION

The amount of light available in Tonga's waters determines the growth of plants, including tiny phytoplankton—the basis of the marine food chain—and thus the rate of carbon capture.

However, in Tonga's coastal waters, increased nutrients from land-based activities, such as farming and wastewater treatment, can result in harmful algal blooms. These blooms can affect coastal habitats, for example, the growth of macroalgae can smother coral reefs and limit light availability, both of which can lead to rapid declines in reef biodiversity (Fabricius, 2005). Blooms can therefore have a detrimental impact on living creatures and ecosystems, resulting in fish die-offs, water being unsafe for human consumption, or the closure of fisheries.

Marine phytoplankton, however, play a key role in the global climate system and in supporting Tonga's complex marine food webs. Understanding their spatio-temporal variability by analysing chlorophyll-a concentrations is an important goal of present-day oceanography. Consequently, chlorophyll-a concentration is routinely measured in the ocean and is also considered to be an important parameter of global physical-biological oceanic models.

Globally, photosynthetically available radiation is highest in the tropics and decreases at high latitudes, with some variation due to cloud cover and other atmospheric conditions. As a result, photosynthetically available radiation is moderately high in Tonga's waters and mirrors the global pattern, with higher levels in the northern parts of Tonga's waters compared with further south. Within this overall trend, there are other variations: for example, photosynthetically available radiation is highest directly north and west of the main islands, and significantly lower to the direct south and east. This is a reflection of the local climatic conditions, with the predominantly easterly trade winds (see also chapter "Go with the flow") resulting in less cloud cover over the leeward side of the larger islands (Tonga Meteorological Service, 2016).



Ocean gardens

For plants to thrive, they need three things: water, sunlight and nutrients. In Tonga's sea, the first is obviously not an issue. The second is also not a problem, with the sun shining on Tonga's tropical waters year-round. Thus, there is always radiation available for photosynthesis—the process used by a plant to convert light energy into chemical energy that can later be released to fuel its activities. However, the third requirement, nutrients, is often the limiting factor in the seas of Tonga.

The energy from sunlight is absorbed by green chlorophyll pigments that transform sunlight into energy. Only sunlight of a specific wavelength range (400 to 700 nanometres) can be converted into energy. This wavelength range is referred to as photosynthetically available radiation, also known as photosynthetically active radiation.

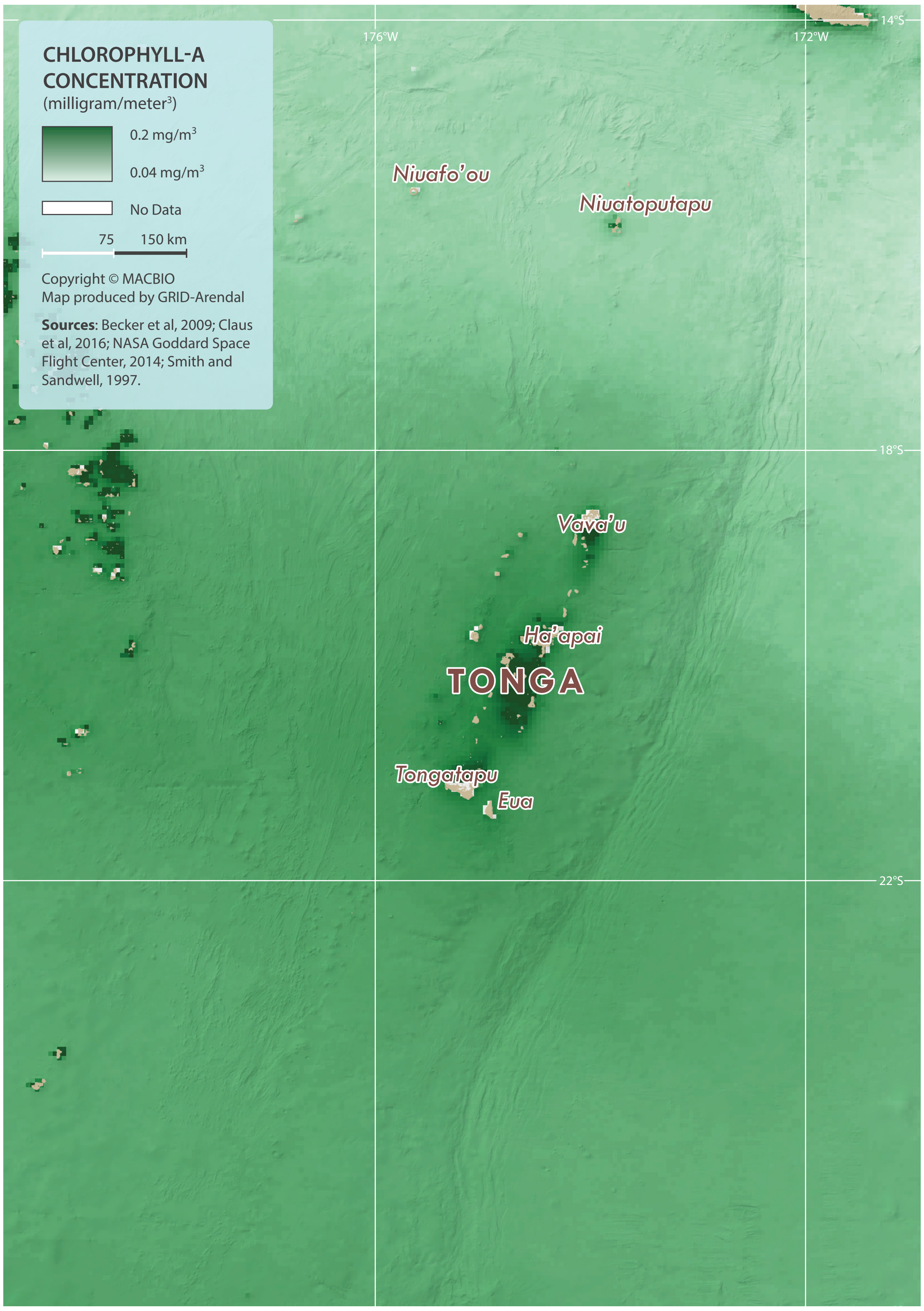
Growing in Tonga's sunlit surface waters is a myriad of tiny plants called phytoplankton, which literally means drifter plants (see also chapter "Travellers or homebodies"). They are full of chlorophyll, which gives them their greenish colour. Chlorophyll absorbs most visible light, but reflects some green and near-infrared light. There are six different types of chlorophyll molecules, with chlorophyll-a the most common type in phytoplankton. Measuring chlorophyll-a concentration gives a good indication of primary productivity in the oceans.

Nevertheless, marine plants cannot live off water and light alone. They also require nutrients, including iron, nitrate and phosphate (see also chapter "The dose makes the poison"). Since these nutrients are generally low in Tonga's waters, phytoplankton quickly consume nutrients whenever they do become available. There is a school of thought that fertilizing areas of ocean may stimulate phytoplankton growth, capturing carbon that may sink to the ocean floor (see also chapter "Pump it"). Could this be the solution to climate change (see also chapter "Hotter and higher")? However, the many ocean fertilization experiments worldwide using iron, phosphate or nitrate have yet to show feasibility on a scale large enough to reduce global emissions (Matear, 2004).

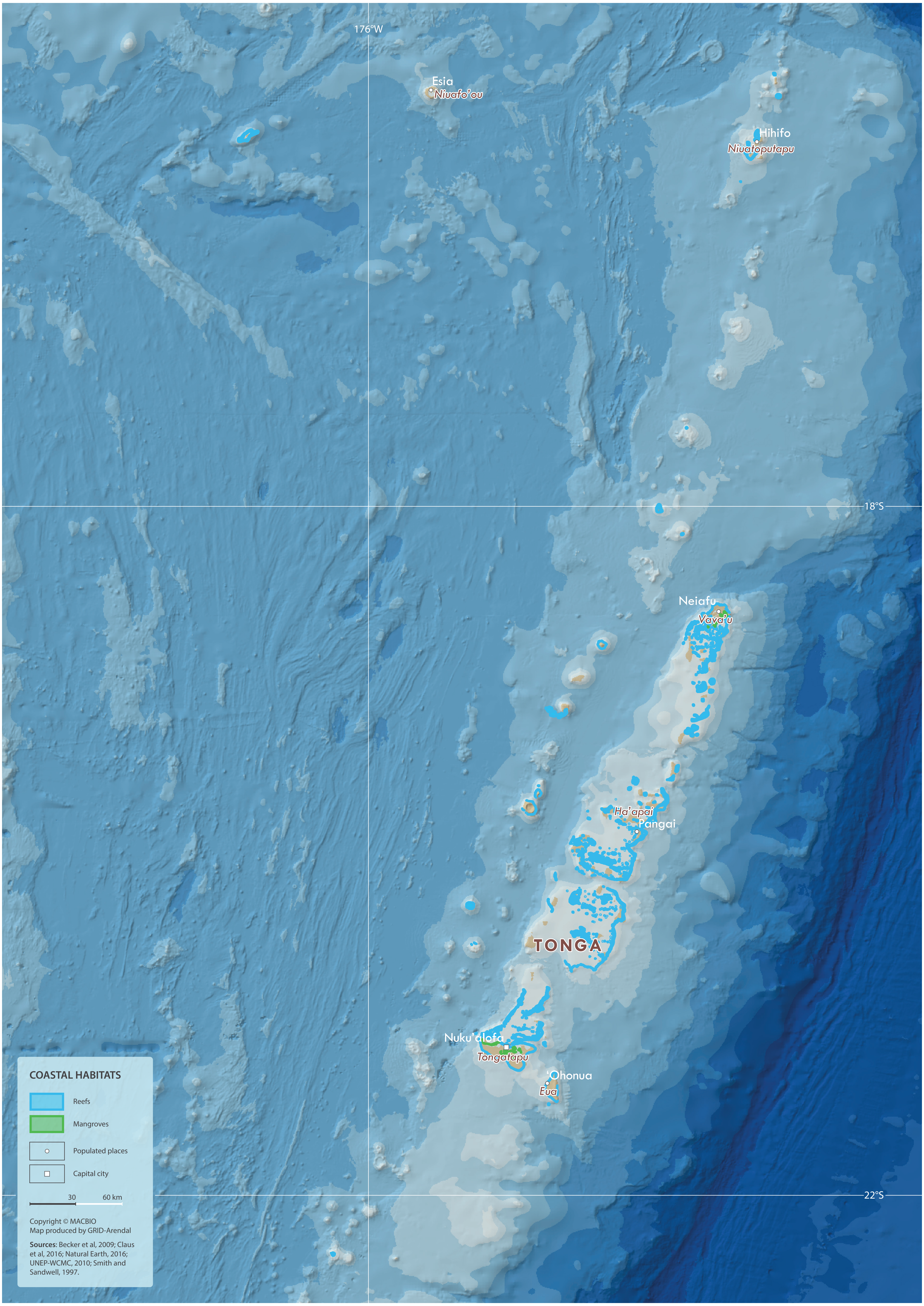
There is also seasonal variation in photosynthetically available radiation in Tonga. The greatest variation occurs around the islands and in the very northern part of Tonga's waters, where photosynthetically available radiation varies by up to 15 per cent throughout the year. This is in part due to changes in atmospheric conditions, such as cloud cover. In Tonga, the average percentage of the sky covered by clouds experiences significant seasonal variation over the course of the year, with the cloudiest days occurring from December to March and the least cloudy days from July to September.

The chlorophyll-a concentration in Tonga's waters is generally very low, with concentrations in the offshore waters less than 0.1 gram per m3 of seawater. Most of the tropical regions of the open oceans have similarly low chlorophyll-a concentrations. In contrast, within temperate and arctic regions, these concentrations can approach 1 gram per m3 of seawater. The shallow coastal regions have increased chlorophyll-a concentrations, with up to 2.2 grams per m3 of seawater. Again, this is low compared to many coastal regions around the world, where chlorophyll-a concentrations can reach over 10 grams per m3 of seawater. The low concentrations of chlorophyll-a in Tonga's waters reflect the low availability of key nutrients. Compared to large continental landmasses, with large river discharges that can carry nutrients into the sea, Tonga is a small island nation with comparatively small nutrient inputs into the marine environment. However, at the local or bay scale, nutrient inputs may still be significant.

In the south-western tropical Pacific Ocean, strong seasonal and inter-annual variabilities in the chlorophyll-a concentration have been observed (Dupouy et al., 2004). Strong chlorophyll-a enrichments have been documented around the Solomon Islands, and between New Caledonia and Vanuatu, with weaker enrichments found around Fiji or Tonga. The annual variation in chlorophyll-a around Tonga is up to 2 grams per m3 of seawater in some coastal areas.



Euphausia superba, phytoplankton from the Antarctic, is an example of the basis of the marine food chain.



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Ohonua
Eua
COASTAL HABITATS
Reefs
Mangroves
Populated places
Capital city
30
60 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Claus et al, 2016; Natural Earth, 2016; UNEP-WCMC, 2010; Smith and Sandwell, 1997.

HABITAT VALUES

HOME, SWEET HOME: COASTAL HABITATS

Tonga's famous hospitality extends to the thousands of species that call its coral reefs, mangroves and seagrasses home. These habitats are home to countless plants and animals that store carbon and help protect Tonga's coastal inhabitants.

The previous set of maps in the "Supporting values" section of this report took us on a journey from the ocean floor all the way to the surface, demonstrating the colourful biophysical features of Tonga's waters. While they are fascinating in their own right, the combination of features such as bathymetry, geomorphology, currents, nutrients or plankton are also important factors in the distribution and the health of Tonga's coastal habitats.

These habitats can be highly valuable, as residents of many Tongan islands came to realize in February 2018. Cyclone Gita struck Tonga as a category four, causing devastation to buildings, widespread power outages and flooding. However, without the protection that coral reefs and mangroves provide to most of Tonga's islands, the outcome could have been a lot worse. Every year, reefs and mangroves mitigate damage to houses and hotels across Tonga's islands; coastal protection is valued at TOP 20 million every year (Salcone, 2015), demonstrating just how valuable marine and coastal ecosystem services are to Tonga.

Aerial view of Tongatapu island's coastline in Tonga.

Coast protection, a key marine and coastal ecosystem service, has two components: the prevention of erosion and the mitigation of storm surges. Healthy coastal ecosystems prevent coastal erosion by reducing the effects of waves and currents and they also help regulate the removal and deposition of sediment (erosion and accretion). They also provide increased short-term protection against episodic events, including coastal floods and storm surges. The benefits of this protection against extreme weather events include minimizing damage to homes, buildings and other coastal infrastructure and to important resources such as crops.

Coastal habitats such as mangrove forests, seagrass beds and coral reefs play an important role in stabilizing shorelines. As human density increases, however, so too does the impact on these important habitats.

The role of mangroves in coastal stabilization is well known. They protect coastal areas from erosion, storm surges (especially during cyclones) and tsunamis. Their massive root systems are efficient at dissipating wave energy and slow down tidal water so that suspended sediment is deposited as the tide comes in, with only the fine particles resuspended as the tide recedes. In this way, mangroves help build their own environment. Given the uniqueness of mangrove ecosystems and the protection they provide against erosion, they are often the subject of conservation programmes and are commonly included in national biodiversity action plans.

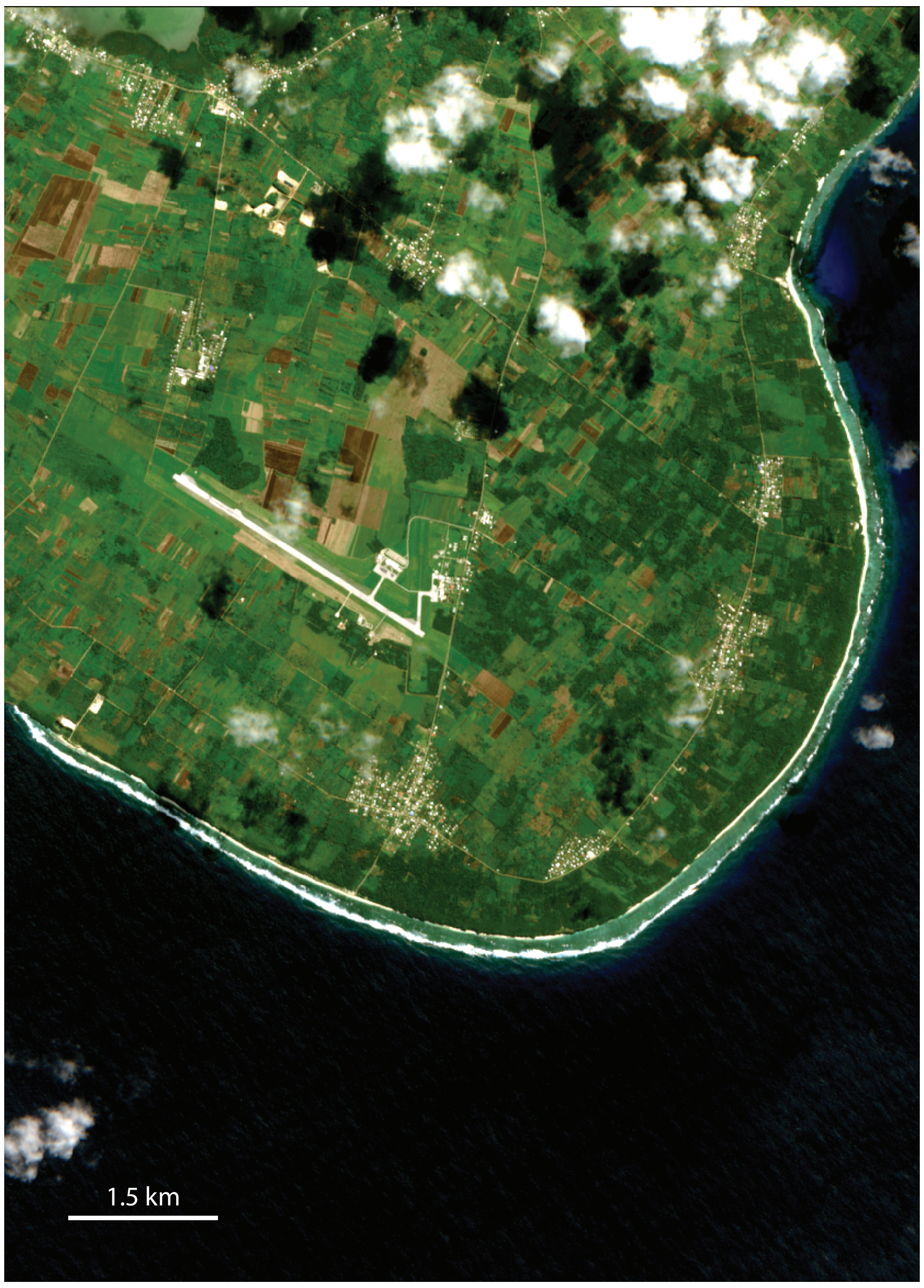
Seagrasses are another important coastal habitat that form extensive meadows in the coastal areas they colonize. Their leaves can also slow currents, and their roots and rhizomes trap the sediments in which they grow, thereby enhancing the stability of the substrate. Seagrasses can also dissipate the energy of waves by up to 40 per cent, which can in turn increase the rate of sedimentation. As such, seagrass beds effectively help protect against waves and limit coastal erosion.

In addition to protecting the coast, Tonga's coastal habitats also act as nursery areas for fish and support food security, livelihoods, tourism and other human activities. Tonga is a known whale-watching destination because migration paths take humpback whales through the islands, where they seek shelter in coastal habitats to breed and give birth. Seagrass meadows and mangroves are also recognized as important carbon stores, with the preservation of healthy mangrove systems contributing to climate change action. Mangroves are sparsely distributed across Tonga, with the main areas found in the Tongatapu and Vava'u groups of islands. Eight species of mangroves occur in Tonga, the main species being *Rhizophora mangle, Rhizophora stylosa, Bruguiera gymnorrhiza, Excoecaria agallocha* and *Lumnitzera littorea*.

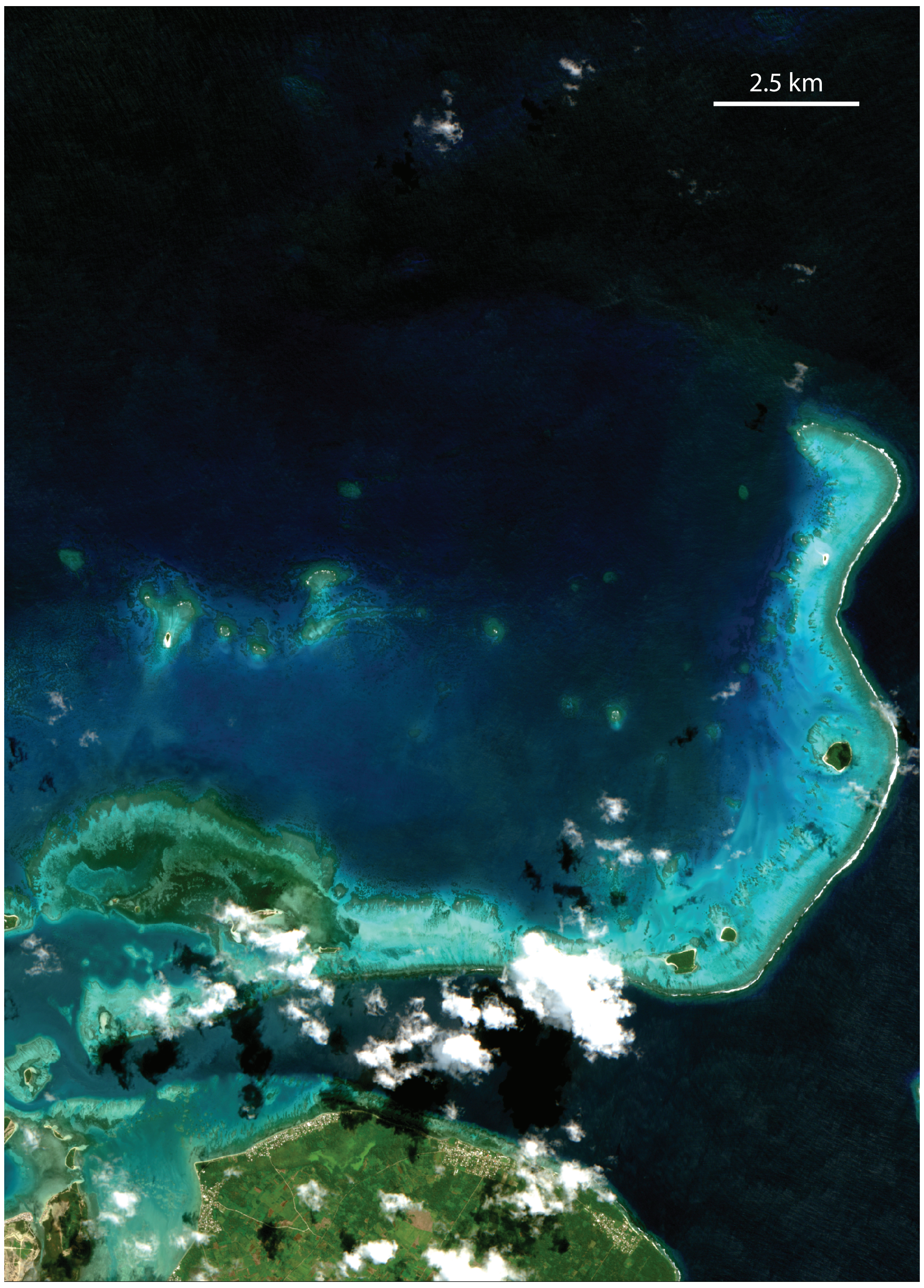
While coastal habitats are some of the most productive and valuable marine habitats, they are, by the same token, some of the most vulnerable to human activities (see also chapters "Reefs at risk" and "Turning sour"). Tonga's mangrove area has declined significantly in recent decades, from an estimated 1,000 hectares in 1983 to 336 hectares in 2010 (MESCAL, n.d.), under threat chiefly from urban development, waste disposal and agricultural expansion.

The map of coastal habitats presents the distribution of coral reefs and mangroves. Shallow coral reefs form some of the most diverse ecosystems on Earth. Despite occupying less than 0.1 per cent of the world's ocean surface, they provide a home for at least 25 per cent of all marine species, including fish, molluscs, worms, crustaceans, echinoderms, sponges, tunicates and other cnidarians. Coral reefs provide many benefits to people living in coastal areas, including food provision, supporting artisanal and commercial fisheries, tourism opportunities and coastal protection. Tonga is home to a diversity of coral reefs, with most of the islands surrounded by fringing coral reefs. There are also several barrier reefs, with the largest of these on the eastern side of the Ha'apai group of islands.

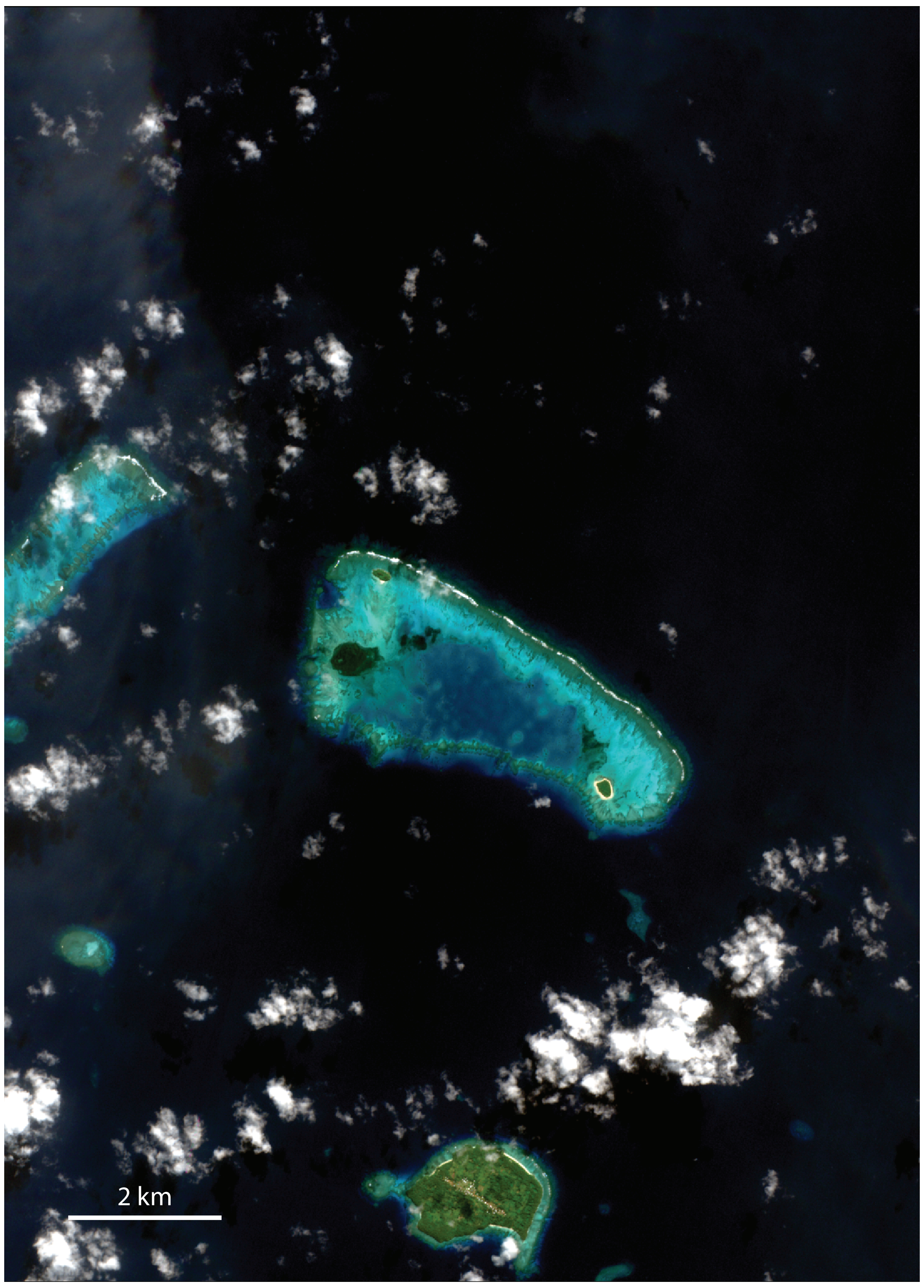
Seagrass beds are highly diverse and productive ecosystems that can harbour hundreds of associated species from all phyla, for example, juvenile and adult fish, epiphytic and free-living macroalgae and microalgae, molluscs, bristle worms and nematodes. These beds occur in the sheltered waters of many of Tonga's islands. However, seagrass maps have not been presented in the map of coastal habitats as there are currently no publicly available data that adequately capture the distribution of seagrass in Tonga.



Fringing reef south of Nuku'alofa



Barrier reef north of Nuku'alofa



Atolls north of Lofanga Island

Patch reefs north west of Nuku'alofa

SHAPING PACIFIC ISLANDS: CORAL REEFS

Tonga's reefs are not only important coastal habitats; they are also transforming and shaping Tonga's coastlines, islands and atolls.

Corals play a fundamental role in the development of island nations such as Tonga, with coral reefs having helped transform and shape the very outline of Tonga's coasts, islands and atolls. But how do coral reefs do this, especially considering that corals are tiny animals, belonging to a group of animals known as cnidaria, which also includes jellyfish and sea anemones?

Firstly, corals secrete hard calcium carbonate exoskeletons, which support and protect their coral polyps. The resulting calcium carbonate structures hold the coral colonies together. Most coral reefs are built from stony corals, which consist of polyps that cluster together and grow best in warm, clear, sunny, nutrient-poor, agitated water, which also needs to be shallow, as corals are dependent on light. But where does the shallow water come from in the middle of the ocean?

Charles Darwin was wondering the same. Following his voyage of the world on HMS Beagle in 1842, he set out his theory of the formation of atoll reefs. He theorized that uplift and subsidence of the Earth's crust under the oceans was responsible for atoll formation (see also chapter "Smoke underwater, fire in the sea"). Darwin's theory, which was later confirmed, sets out a sequence of three stages for atoll formation, starting with a fringing reef forming around an extinct volcanic island. As the island and ocean floor subsides, the fringing reef becomes a barrier reef, and ultimately an atoll reef as the island subsides below sea level.

A fringing reef can take 10,000 years to form, while an atoll can take up to 30 million years. When an island is undergoing uplift, fringing reefs can grow around the coast, but if the coral is raised above sea level, it will die and become white limestone. If the land subsides slowly, the fringing reefs keep pace by growing upward on a base of older, dead coral, forming a barrier reef enclosing a lagoon between the reef and the land. A barrier reef can encircle an island, and once the island sinks below sea level, a roughly circular atoll of growing coral continues to keep up with the sea level, forming a central lagoon. Barrier reefs and atolls do not usually form complete circles, but are broken in places by storms. Like sea level rise (see also chapter "Hotter and higher"), a rapidly subsiding bottom can overwhelm coral growth, killing the coral polyps and the reef through "coral drowning". Corals that rely on their symbiotic zooxanthellae can drown when the water becomes too deep for their symbionts to adequately photosynthesize due to decreased light exposure (Spalding et al., 2001).

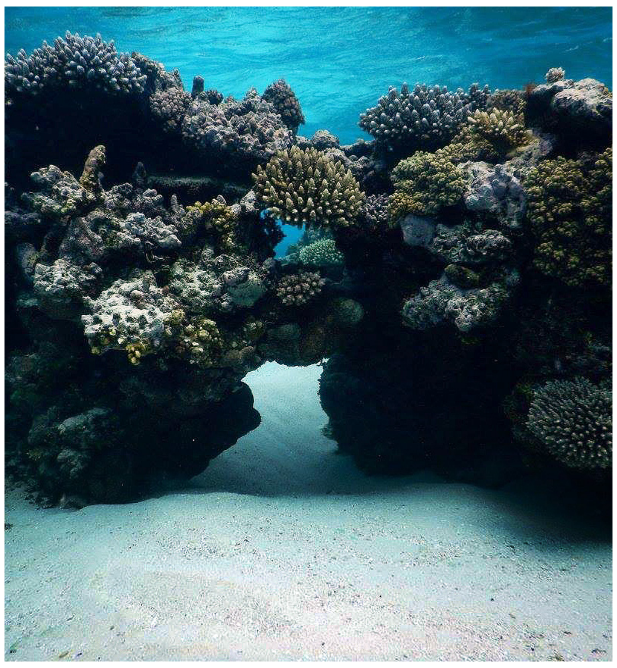
According to Spalding et al. (2001), Tonga has around 1,500 km^2 of coral reef, with the most extensive reef found around the Ha'apai group of islands. Coral reefs are common in the eastern islands, with fringing reefs surrounding most coasts, while platform and barrier-type structures are also located in most of the main island groups (Spalding et al., 2001). In contrast, many of the western islands are too tectonically active to allow significant coral reef development (Spalding et al., 2001). There have been 189 species of coral recorded on Tonga's coral reefs (Lovell and McLardy, 2008), which include fringing reefs, barrier reefs and platform reefs (Spalding et al, 2001).

The maps show examples of the four prevailing reef types in Tonga.

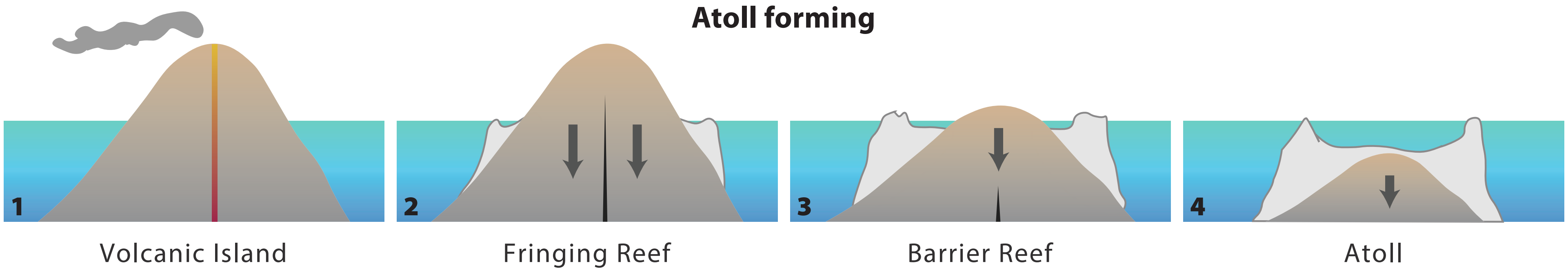
- Fringing reef (e.g. south of Nuku'alofa): Directly attached to a shore or borders it with an intervening shallow channel or lagoon.
- Barrier reef: Separated from a mainland or island shore by a deep channel or lagoon, such as north of Nuku'alofa.
- Atoll reef (e.g. north of Lofanga Island): More or less circular or continuous barrier reef that extends all the way around a lagoon without a central island.
- Patch reef (e.g. north-west of Nuku'alofa): Common, isolated, comparatively small reef outcrop, usually within a lagoon or embayment, often circular and surrounded by sand or seagrass.

Underwater rainforests

Tonga's sea features the proverbial "rainforests of the sea", coral reefs. These reefs are rich in biodiversity and harbour many more plants and animals than Tonga's forests above sea level. Such a diverse ecosystem is very valuable to Tonga, providing habitat, shelter and tourism opportunities (see also chapters "Home, sweet home" and "Beyond the beach").



Atoll forming



TRAVELLERS OR HOMEBODIES: MARINE SPECIES RICHNESS

Tonga's marine environment hosts two types of animals: pelagic species and benthic species, both of which are important and biologically interconnected.

Pelagic species are those that live in the water column away from the sea floor and coast. Often these species migrate across vast areas of ocean, driven by oceanic conditions and seasonal food availability (see also chapter "Go with the flow"). On the other hand, benthic species are those that live on or close to the sea floor. Unlike pelagic species, which migrate large distances, benthic species are often associated with specific sea-floor features and are either attached to the substrate or very site-specific.

Both pelagic and benthic species contribute to Tonga's rich marine biodiversity, are part of complex food chains and form important habitats. Furthermore, many commercially important species of both types are found in Tonga's waters. According to Tonga's National Biodiversity Strategy and Action Plan, there are 38 identified pelagic fish, 12 species of whales and six species of turtles found within Tonga's waters. Commercially important pelagic species include several species of tuna, such as albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) tuna, and several important commercial billfish species, such as blue marlin (*Makaira nigricans*), black marlin (*Makaira indica*), striped marlin (*Kajikia audax*) and swordfish (*Xiphias gladius*). There are also some pelagic shark species. including the blue shark (*Prionace glauca*), oceanic whitetip (*Carcharhinus longimanus*), shortfin mako shark (*Isurus oxyrinchus*) and silky shark (*Carcharhinus falciformis*).

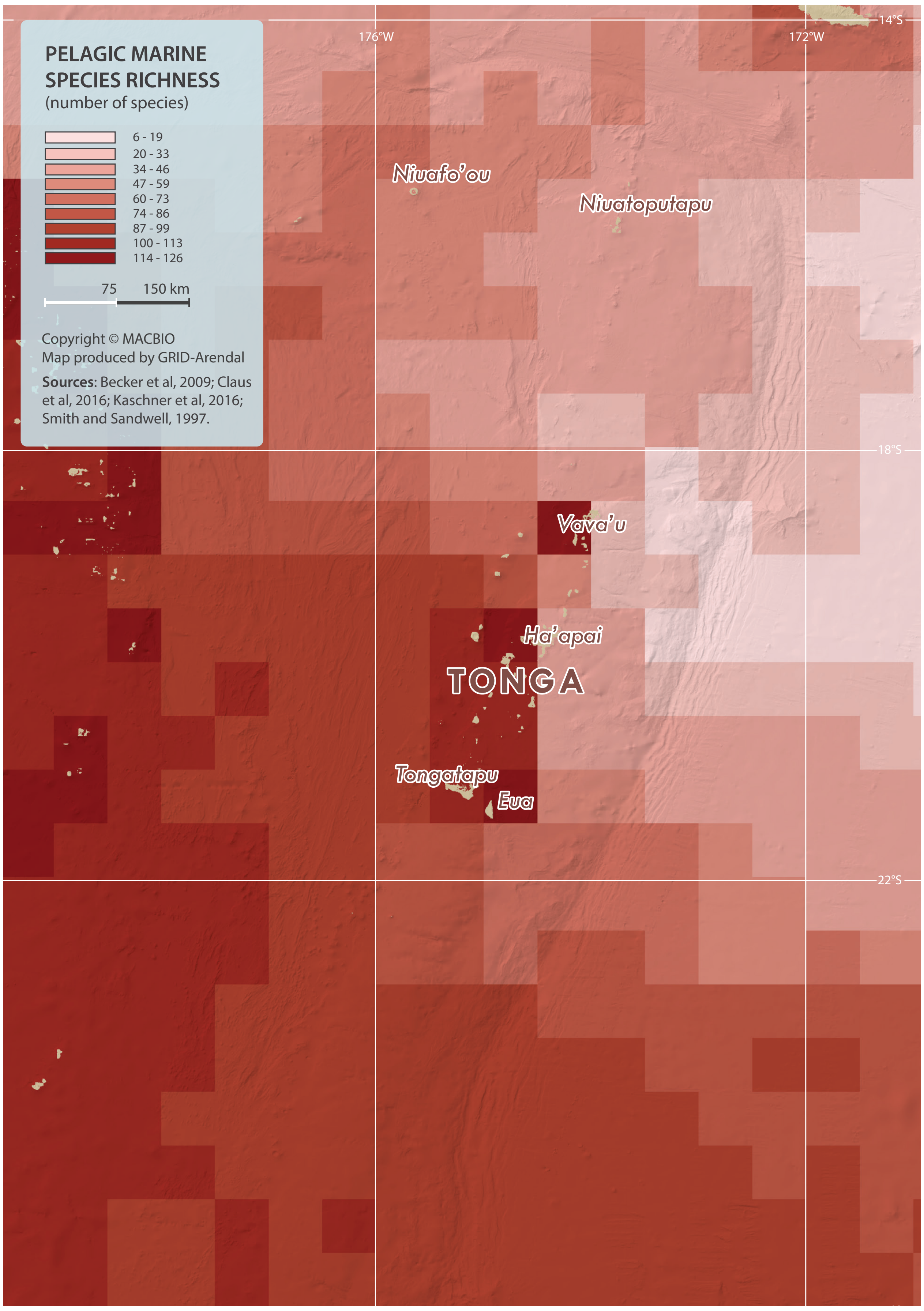
Tonga is also one of a handful of places in the world where tourists can dive with humpback whales (*Megaptera novaeangliae*), which attract countless dive tourists and revenue to Tonga (see also chapter "Beyond the beach"). Pelagic species also include the smaller species that support these large, commercially important species (see also chapter "Fishing in the dark"). The routes these species take to migrate, and thus the connectivity of their habitats, are an important consideration for marine management and conservation planning.

Pelagic or benthic?

Some marine species move from one place to another, while others tend to stay in the same location. These species are described as either "pelagic" or "benthic" (see also chapter "Still waters run deep").

As for Tonga's numerous benthic species, many invertebrates (those without a backbone) are found in soft sediment habitats. According to its National Biodiversity Strategy and Action Plan, Tonga has numerous marine invertebrates, including 192 species of hard corals, 150 species of molluscs, including bivalves (such as oysters and mussels) and gastropods (such as snails and slugs), 26 crustaceans (such as crabs, lobsters and shrimps) and 33 echinoderm species (including starfish, sea urchins and sea cucumbers). Many benthic species form habitats in Tonga's shallow waters, including corals, seagrass, mangroves and algae (see also chapter "Home, sweet home").

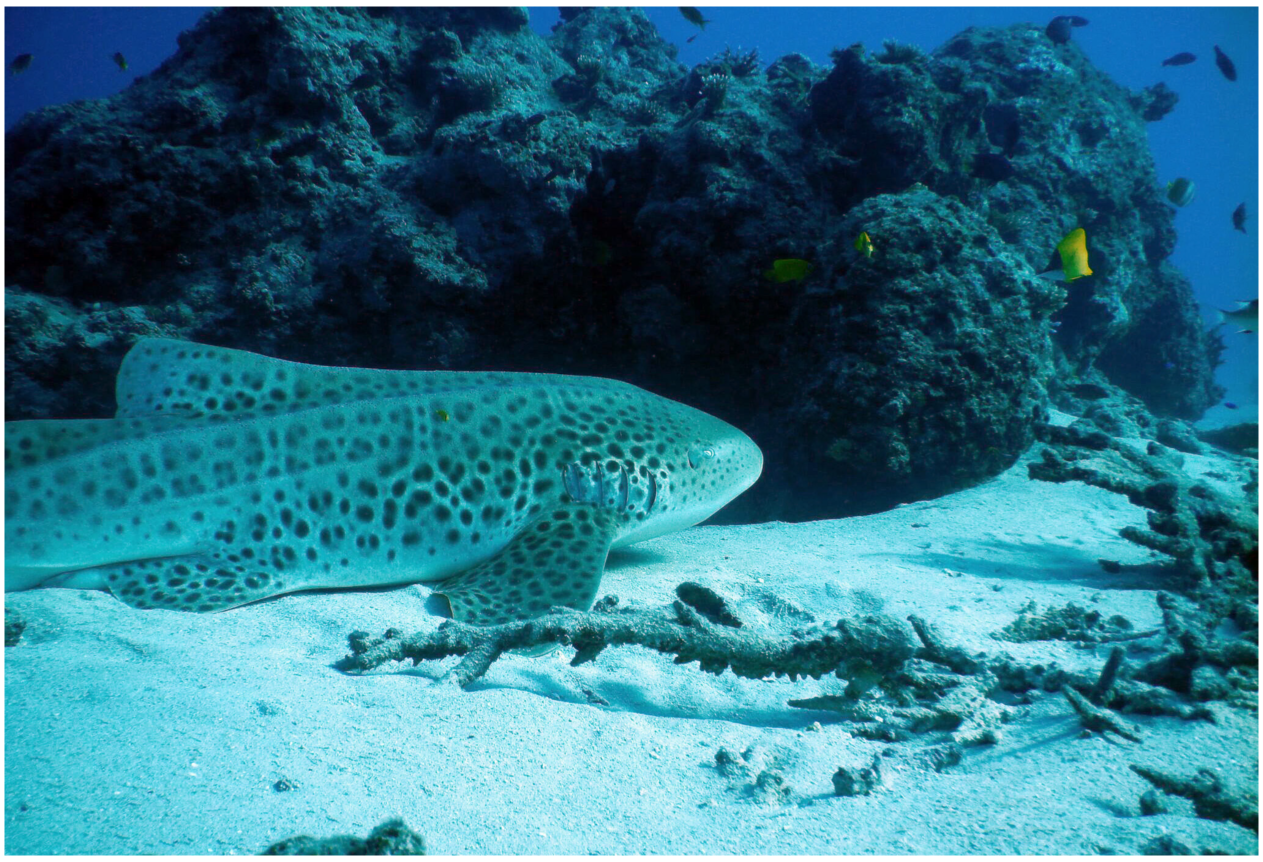
In general, species richness can be used as an indicator of conservation significance. It does not, however, provide information on species compo-



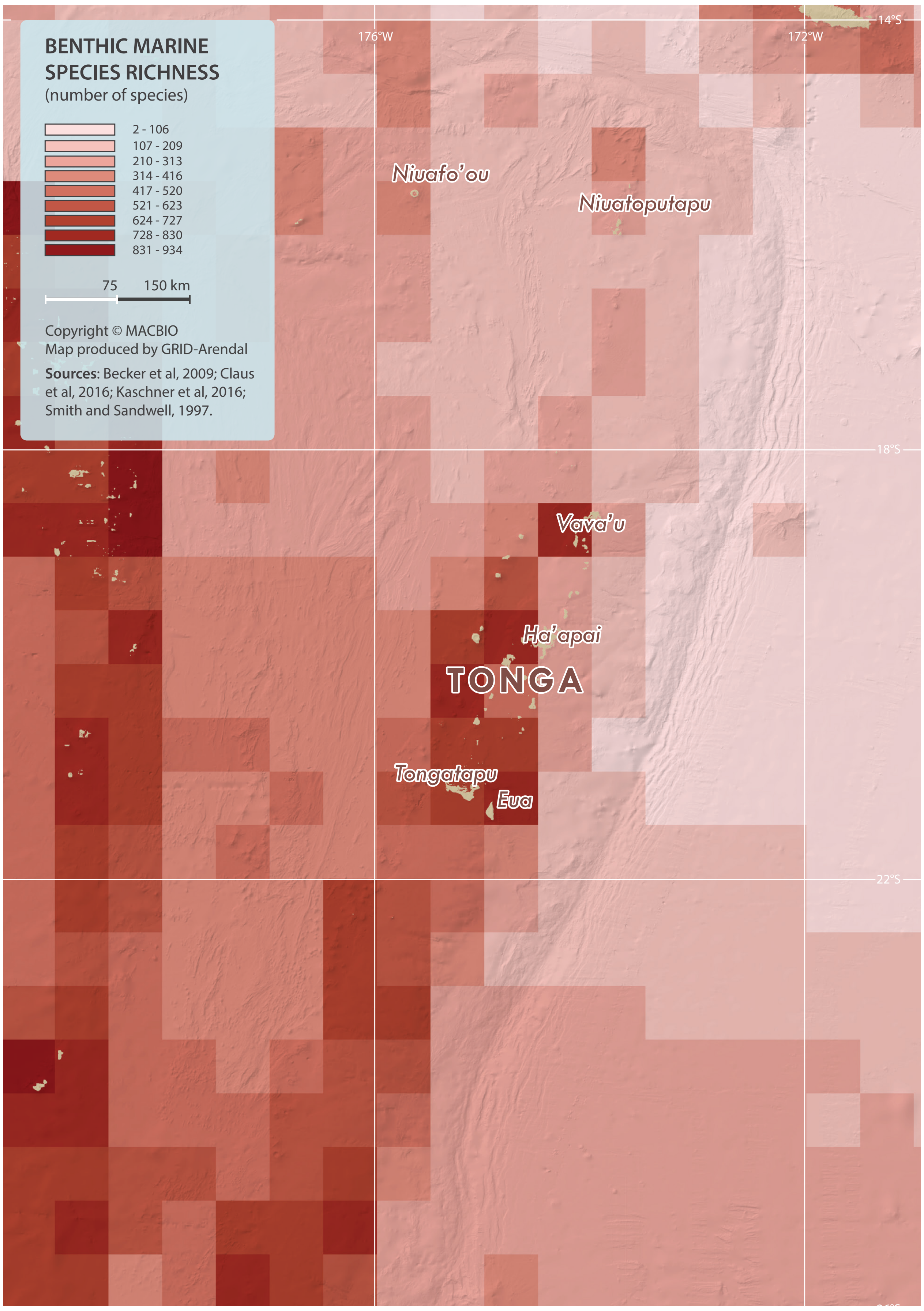
sition, nor does it identify whether there are rare or priority species in an area. Further, areas with similar species richness may have very different species present, which would affect the conservation and management measures required.

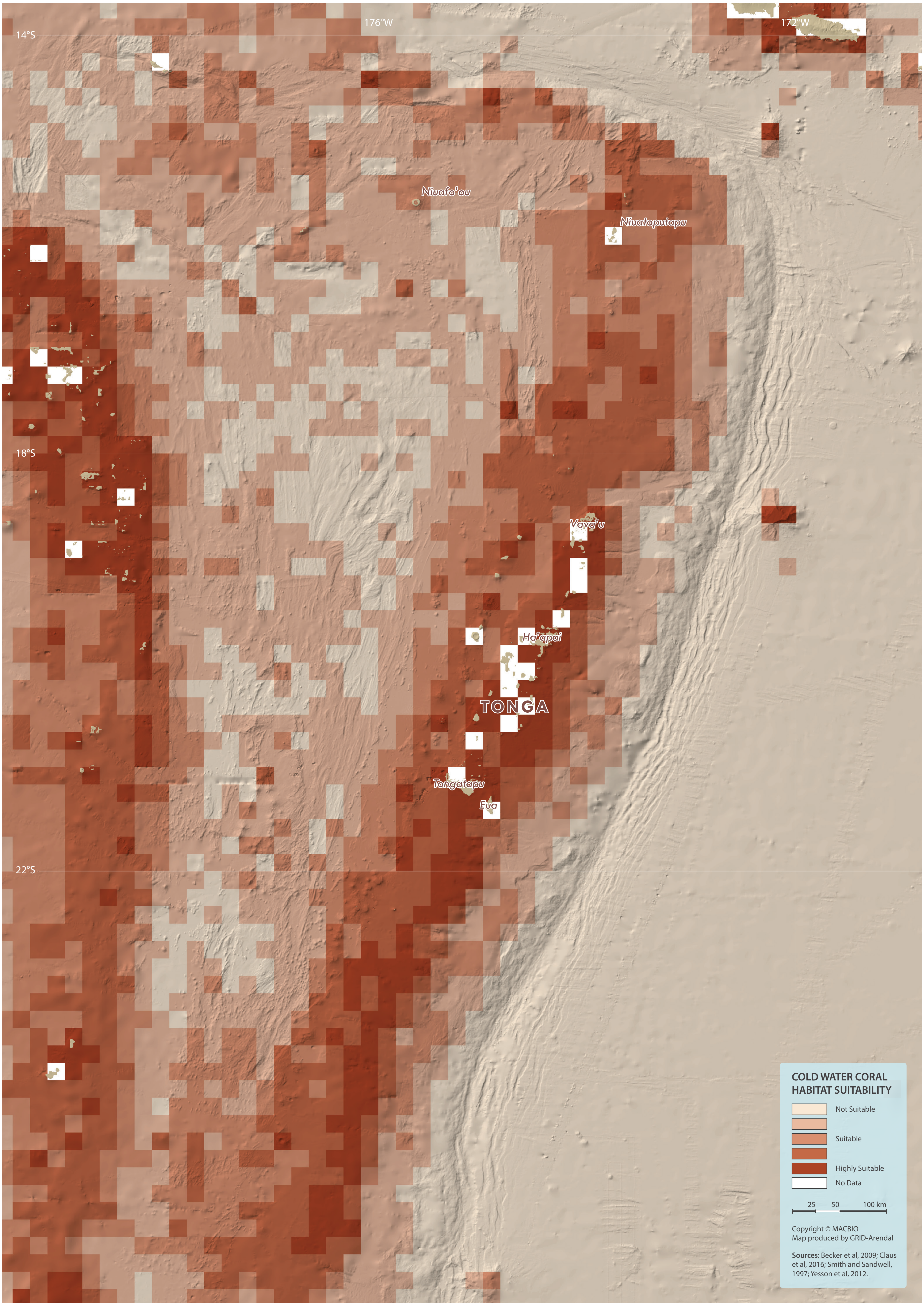
Globally, pelagic fish are generally more abundant in tropical waters and decrease as latitude increases. As the map shows, within Tonga's waters, there is a trend for higher species richness around the islands and to the west of the islands. Lower species richness to the east of the islands may reflect the different sea-floor complexity, with the deep, relatively featureless sea floor to the east resulting in less upwelling (see also chapter "Voyage to the bottom of the sea"). Large geographic features that rise off the sea floor, such as the Tonga Ridge, interact with currents and create upwellings (see also chapter "Go with the flow"). Pelagic fish abundance and biomass can, therefore, peak deep in the water column in association with abrupt bathymetric features such as seamounts and mid-ocean ridges (Sutton et al., 2010). Furthermore, migrating species, including whales, frequently pause over seamounts and other shallow geographical features (Garrigue et al., 2015).

Similarly, tropical waters tend to have a higher benthic species richness than waters at higher latitudes. Again, in Tonga's waters, there is a trend for higher species richness around the islands. Benthic species richness is higher in shallow water compared with deep water, both in Tonga and globally. The highest benthic species richness is found around Tonga's main islands and extending south along the Tonga Ridge. Benthic species richness is particularly low to the east of the main islands, where the sea floor is more than 5,000 metres deep.



The Zebra shark is found throughout the tropical Pacific, but listed as endangered species.




14°S
18°S
22°S
176°W
172°W
Niuafo'ou
Niuatoputapu
Vava'u
Ha'apai
TONGA
Tongatapu
Eua
COLD WATER CORAL HABITAT SUITABILITY
Not Suitable
Suitable
Highly Suitable
No Data
25
50
100 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Claus et al, 2016; Smith and Sandwell, 1997; Yesson et al, 2012.

HOW MUCH DO WE REALLY KNOW? COLD WATER CORAL HABITATS

While quite a lot is known about Tonga's inshore environment, some habitats are hard to explore and map, especially those found deep below the surface where research is both expensive and complicated. To map Tonga's important, cold-water coral communities, scientists use habitat suitability models that guide us to where they are likely to be found.

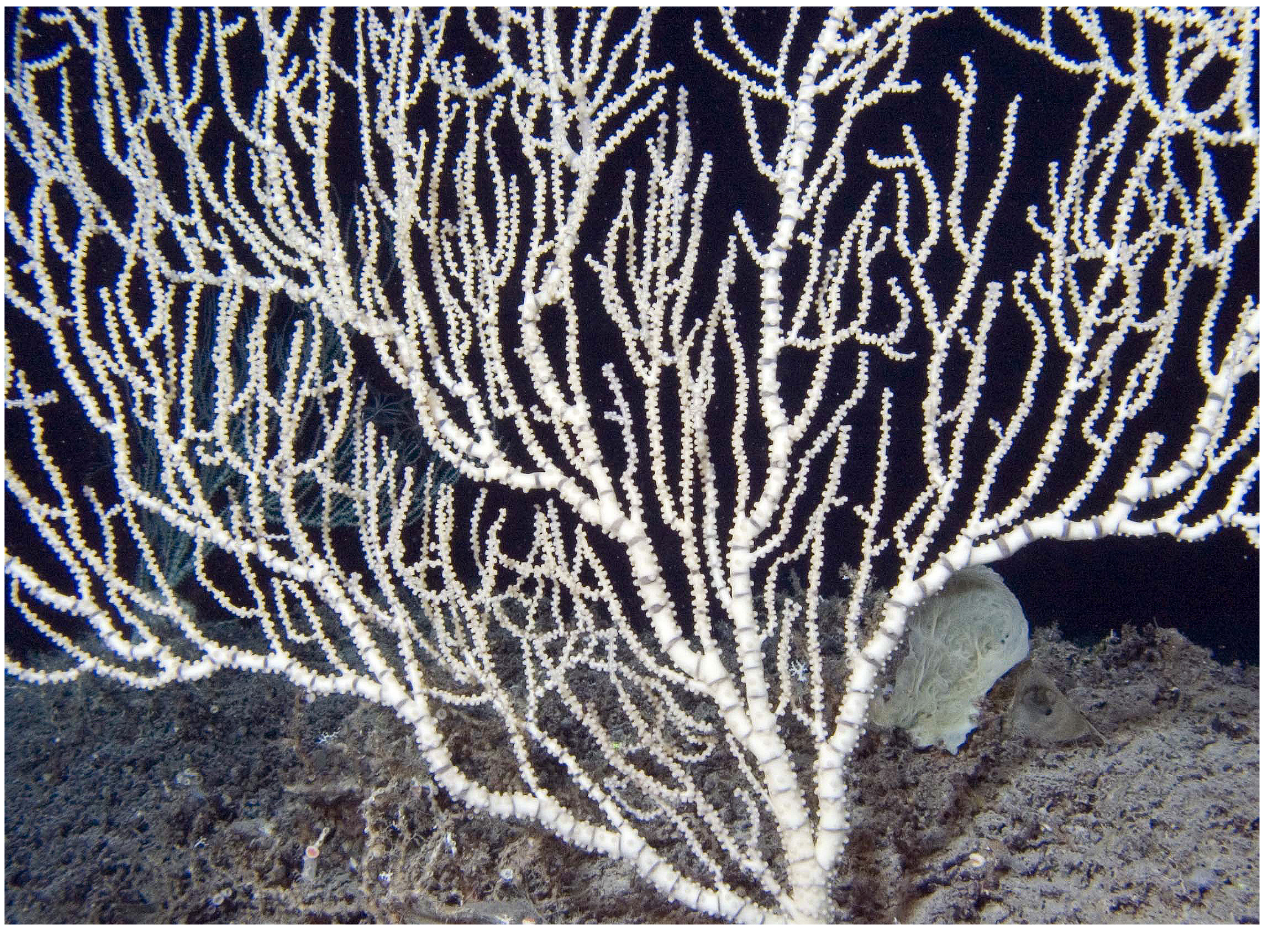
The Moon or the sea?

There is a common misconception that we know more about the surface of the Moon than the ocean floor and that 95 per cent of the ocean is unexplored. The chapter "Voyage to the bottom of the sea" showed that we actually know a lot about the ocean floor. The entire ocean floor has been mapped to a maximum resolution of around 5 kilometres, unveiling most features larger than 5 kilometres across (Sandwell, 2014). However, only 0.05 per cent of the ocean floor has been mapped to a high level of detail, meaning Tonga's waters undoubtedly hold a lot of secrets, including deep-water or cold-water corals. These corals have a depth range extending from around 50 metres to beyond 2,000 metres deep, where water temperatures may be as cold as 4°C (see also chapter "Still waters run deep"). While there are nearly as many species of cold-water corals as shallow-water corals, only a few cold-water species develop into traditional reefs. This is also why they are much harder to discover and map than their shallow-water counterparts. Nevertheless, scientists have created habitat suitability models that use information on the physical environment to predict their distribution and provide an understanding of their ecological requirements.

Corals are not restricted to shallow-water tropical seas. Deepwater or cold-water corals are regarded as occurring deeper than 50 metres and include five taxa and over 3,300 more species than their better known tropical coral reef counterparts: order Scleractinia (hard, stony corals), order Zoanthidea (zoanthids, gold corals), order Antipatharia (black corals), subclass Octocorallia (soft corals, gorgonians, bamboo corals) and family Stylasteridae (lace corals) (Roberts et al., 2009). They are widespread throughout the Pacific Ocean.

At present, cold-water corals have no economic importance for Tonga. However, many of them have been recognized as playing important ecological roles in the deep sea, since they can form large reef-like structures or have complex growth forms which in turn, provide habitat for many associated invertebrate and fish species. They are potentially common on seamounts in the southern part of Tonga, which are of commercial interest for deepwater snapper and bluenose fisheries.

The map shows the predicted suitability of habitat where octocoral species could occur. Octocorals are a highly diverse group, with soft corals, gorgonians, sea fans, sea whips, sea feathers, precious corals, pink coral, red coral, golden corals, bamboo corals, leather corals, horny corals and sea pens among their estimated 2,000-plus species (Roberts et al., 2009). Globally accessible data for offshore corals are sparse in many Pacific Islands, including Tonga. In recent years, there have been deep-sea mineral exploration surveys, as well as research voyages (e.g. RV Falkor, 2017) that have generated images and samples of many species of cold-water coral from Remotely Operated Vehicle dives (Raineault et al., 2018). General species composition is likely to be similar to that known of the northern Kermadec Ridge off New Zealand.



However, at this stage, because of the limited published data, habitat suitability modelling has been used to predict the likely occurrence of corals in the area.

Habitat suitability was high in a continuous band along the main Tonga Ridge and island slopes. The distribution largely follows depth, with topography also a factor. The ridge is shallower than much of the abyssal plains offshore, with higher food availability. The steep topography also provides hard rocky substrate which the corals need for attachment. Cold-water corals are sparse on the abyssal plains and are not predicted to occur at all in the hadal depths of the Tonga Trench.

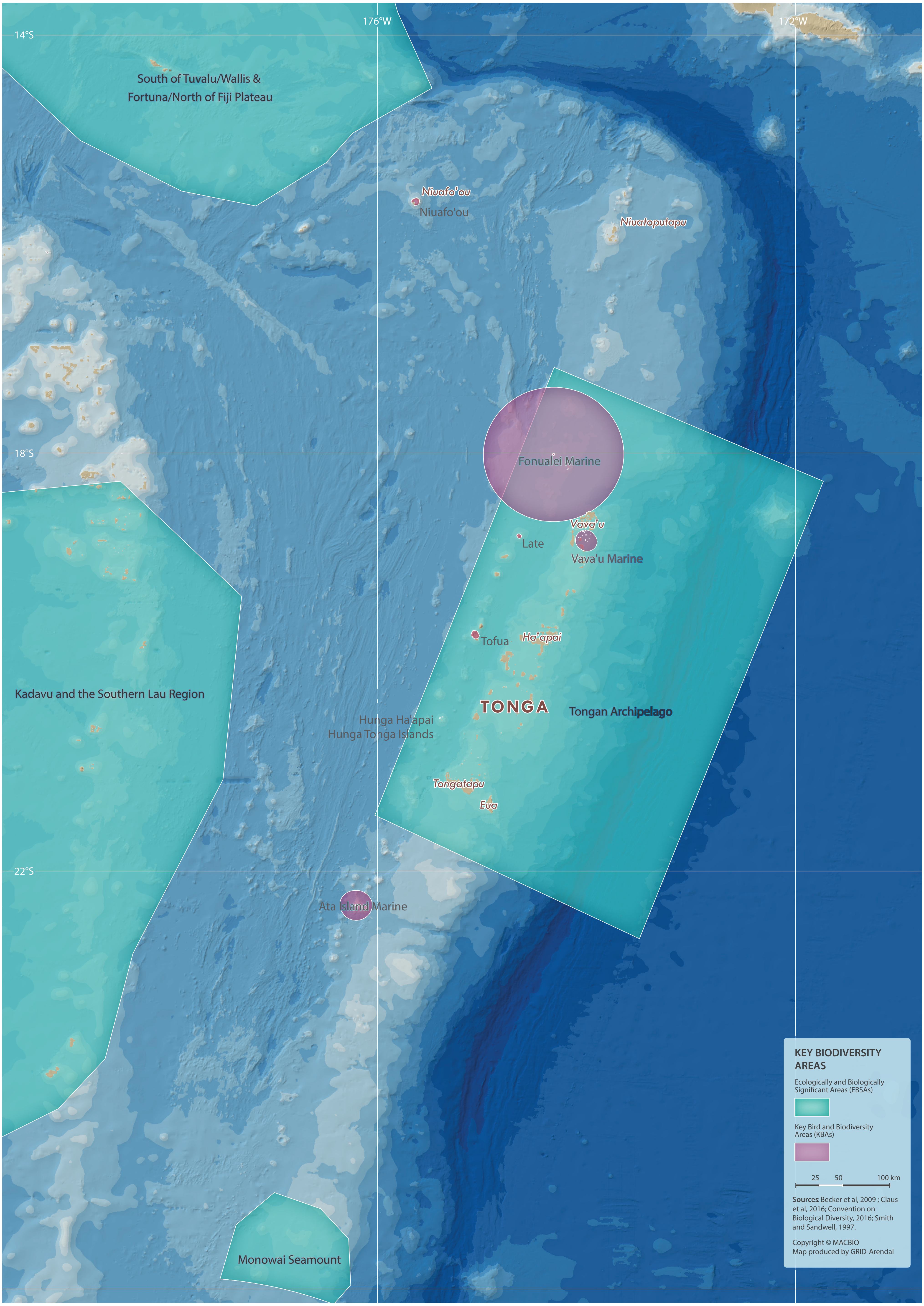
Although not presented, similar analyses have been carried out for five species of stony coral (order Scleractinia) (Davies and Guinotte, 2011). Depth, temperature, aragonite saturation state and salinity were the key environmental drivers for this taxonomic grouping. Their results indicate high suitability for some stony corals, such as Enallopsammia rostrata, especially in southern parts of the Tongan EEZ.

Cold-water corals are widely regarded as being susceptible to damage from human activities, such as the direct effects of fishing and deep-sea mining and more indirect impacts from pollution and climate change. Many species of cold-water coral are structurally fragile and hence easily broken. They can also be long-lived and slow-growing, meaning that any recovery from damage or changing environmental conditions is slow. This could have long-term effects on deep-sea ecosystems. Octocorals are one of the groups listed by the Food and Agriculture Organization of the United Nations (FAO) as potentially Vulnerable Marine Ecosystems (FAO, 2009), and which are required under United Nations resolutions to be protected from deep-sea fishing.

The presence of cold-water corals can be an important indicator for managing human activities to avoid or minimize impacts on deep-sea ecosystems. The habitat suitability map, although based on presence–absence, not on abundance, gives an indication of which areas may need protection from disturbance of the sea floor or climate change.

Habitat suitability modelling examines the relationship between where the corals are known to occur and key environmental conditions at that location. This relationship enables extrapolation into areas that have not been sampled, based on the suitability of a range of globally recognized environmental factors. For octocorals, temperature, salinity, slope of the sea floor, ocean productivity, dissolved oxygen levels and calcite saturation state were important factors controlling habitat suitability (Yesson et al., 2012).

The bamboo coral Keratoisis grandiflora, which has been recorded in Tongan waters.



176°W
172°W
14°S
18°S
22°S
South of Tuvalu/Wallis &
Fortuna/North of Fiji Plateau
Niuafo'ou
Niuafo'ou
Niuatoputapu
Fonualei Marine
Vava'u
Late
Vava'u Marine
Tofua
Ha'apai
TONGA
Tongan Archipelago
Kadavu and the Southern Lau Region
Hunga Ha'apai
Hunga Tonga Islands
Tongatapu
Eua
Ata Island Marine
Monowai Seamount
KEY BIODIVERSITY AREAS
Ecologically and Biologically Significant Areas (EBSAs)
Key Bird and Biodiversity Areas (KBAs)
25
50
100 km
Sources: Becker et al, 2009 ; Claus et al, 2016; Convention on Biological Diversity, 2016; Smith and Sandwell, 1997.
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Map produced by GRID-Arendal

NATURE'S HOTSPOTS: KEY BIODIVERSITY AREAS

Tongan waters host a large variety of habitats, which are important breeding or feeding grounds for a number of marine and seabird species. The characteristics of Key Biodiversity Areas (KBAs) mapped here can support the further development of management options to balance human needs and protect vulnerable species and ecosystems.

Marine conservation in Tonga is guided by the goals and objectives laid out in its Environment Management Act (2010) and an earlier National Biodiversity Strategy and Action Plan (2006). These link national action with more global and regional initiatives such as the Convention on Biological Diversity (CBD) process for designating Ecologically or Biologically Significant Areas (EBSAs), the IUCN's KBAs and Birdlife International's Important Bird Areas (IBAs). These areas are defined as sites that contribute significantly to regional or global persistence of biodiversity and consider attributes such as uniqueness or rarity; importance for life-history stages of key species; threatened, endangered or declining species; vulnerability to, or slow recovery from, disturbance; productivity; diversity and/or naturalness. These definitions can operate at all levels of biodiversity (genetic, species, ecosystem).

There is growing recognition worldwide that marine ecosystems need to be managed to prevent or minimize harm from human activities. Conservation areas or plans can benefit a country's tourism potential, as well as improving consumer acceptance of products if they are proven to be sustainable. Whale-based tourism is already an important source of income in the winter season. As knowledge of the characteristics of such prospective areas develops, they can become critical elements of an integrated protected area network that ensures key ecological sites are protected, while still allowing human activities to occur in an environmentally sustainable way.

The map shows the distribution of EBSAs and KBAs in island and offshore areas of Tonga, although it should be noted that there are also a number of localized coastal marine protected areas (MPAs) that are not included on the map.

In November 2011, the Secretariat of the Convention on Biological Diversity hosted a regional workshop to facilitate the description of EBSAs for the western South Pacific Ocean (CBD, 2012). Two EBSAs were subsequently approved by the CBD:

1) The Tongan Archipelago is a large EBSA encompassing the central waters of the provisional Tongan EEZ. It covers diverse topography, with shallower waters around the islands, seamounts (e.g. Capricorn seamount) and peaks along the Tonga Ridge, and most notably the Tonga Trench,

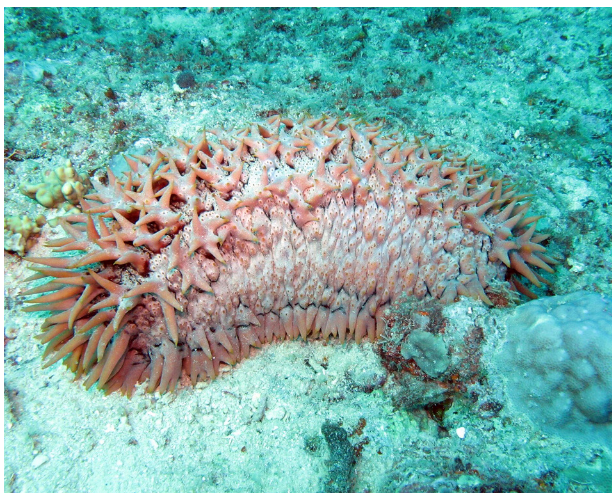
which at its deepest point (Horizon Deep), is 10,880 metres. The region is a key breeding location for the Oceania population of humpback whales. It also supports globally significant populations of eight seabird species and is generally important for seabird nesting and foraging.

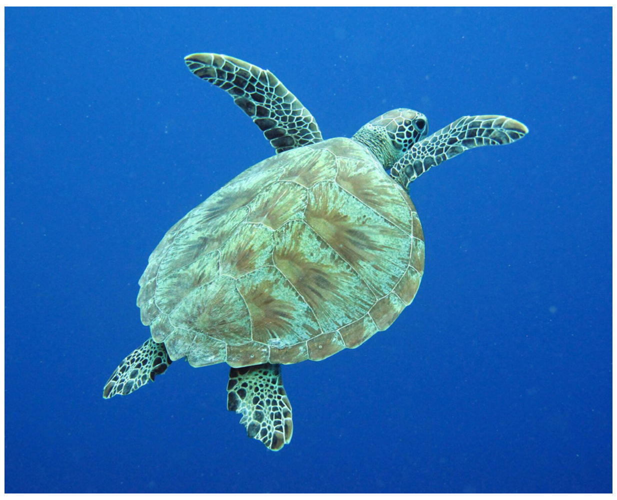
2) Monowai Seamount comprises an active volcanic cone with a large caldera that has extensive areas of hydrothermal vents at depths of 1,200 metres. These host localized mussel, tubeworm, shrimp and crab species that are found in the venting areas.

There are four significant IBAs in Tonga: the largest is the Fonualei Marine Area (15,887 km^2), which is an important breeding site for sooty terns; Vava'u Marine is a black noddy breeding location; Late Island hosts a breeding black noddy population; and Ata Island is a breeding site for wedge-tailed shearwater, red-footed booby and brown booby (Birdlife International, 2018a).

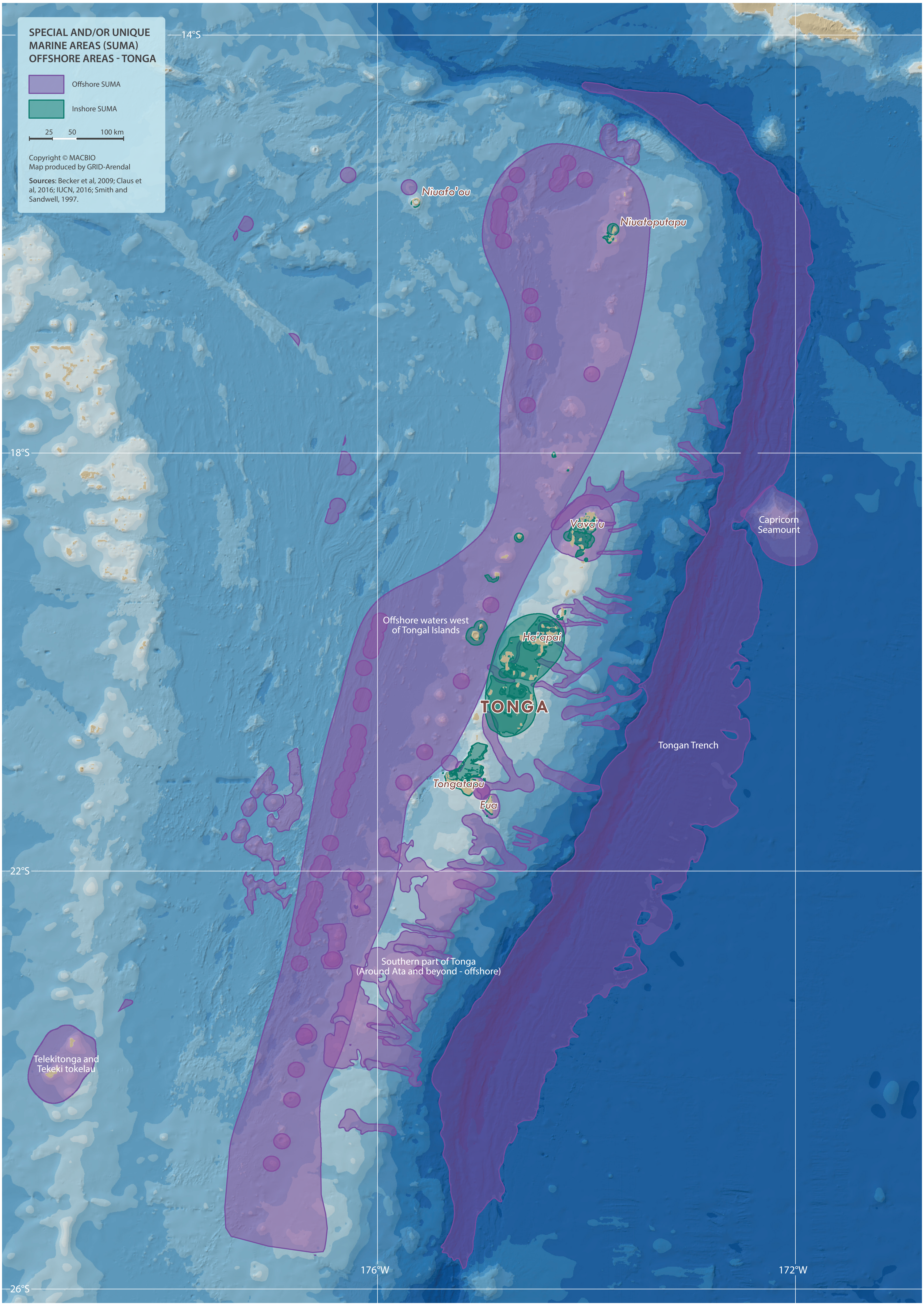
There are 11 recognized KBAs in Tongan waters (Birdlife International, 2018b), including the above IBAs, and these are listed largely because of their potential importance for seabird species. 'Ata Island, Ata Island Marine, Eua Island, Fonualei, Fonualei Marine, Hunga Ha'apai-Hunga Tonga islands, Late, Maninita-Taula-Lualoli, Niuafo'ou, Tofua-Kao and Vava'u Marine EBSAs and KBAs have no official management status, but are components of efforts by the CBD and IUCN to identify species that should be prioritized for conservation based on their ecological roles, cultural significance, uniqueness (e.g. endemics) and rarity (e.g. threat status on IUCN Red List), and to describe the marine habitats in which these species are likely to be found, and which may therefore need protection.

In conjunction with the 10 official marine reserves and protected areas, KBAs and EBSAs can help develop an appropriate network of multiple-use managed areas.





Tonga's KBAs are important habitats, e.g. for bird nesting, and benthic and pelagic species.



SPECIAL AND/OR UNIQUE MARINE AREAS (SUMA) OFFSHORE AREAS - TONGA
Offshore SUMA
Inshore SUMA
25 50 100 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Claus et al, 2016; IUCN, 2016; Smith and Sandwell, 1997.
14°S
18°S
22°S
26°S
176°W
172°W
Niuafo'ou
Niuatoputapu
Vava'u
Capricorn Seamount
Offshore waters west of Tongal Islands
Ha'apai
TONGA
Tongan Trench
Tongatapu
Eua
Southern part of Tonga (Around Ata and beyond - offshore)
Telekitonga and Tekeki tokelau

SPECIAL AND UNIQUE MARINE AREAS

To prioritize management and/or protection of Tonga's waters, local marine experts came together to identify areas in Tonga's waters that are special and/or unique.

Tonga's KBAs (see previous chapter) emphasize not only the importance of marine biodiversity to Tonga, but also to the world. Much of Tonga's waters contain very diverse physical and ecological environments, which in turn support a huge range of marine life, yet a great deal of these environments remains undocumented. As the resources of both the nearshore and offshore marine environments are vital to the well-being and prosperity of the country and its people, their sustainable management and conservation are in the interests of both resource managers and the general population.

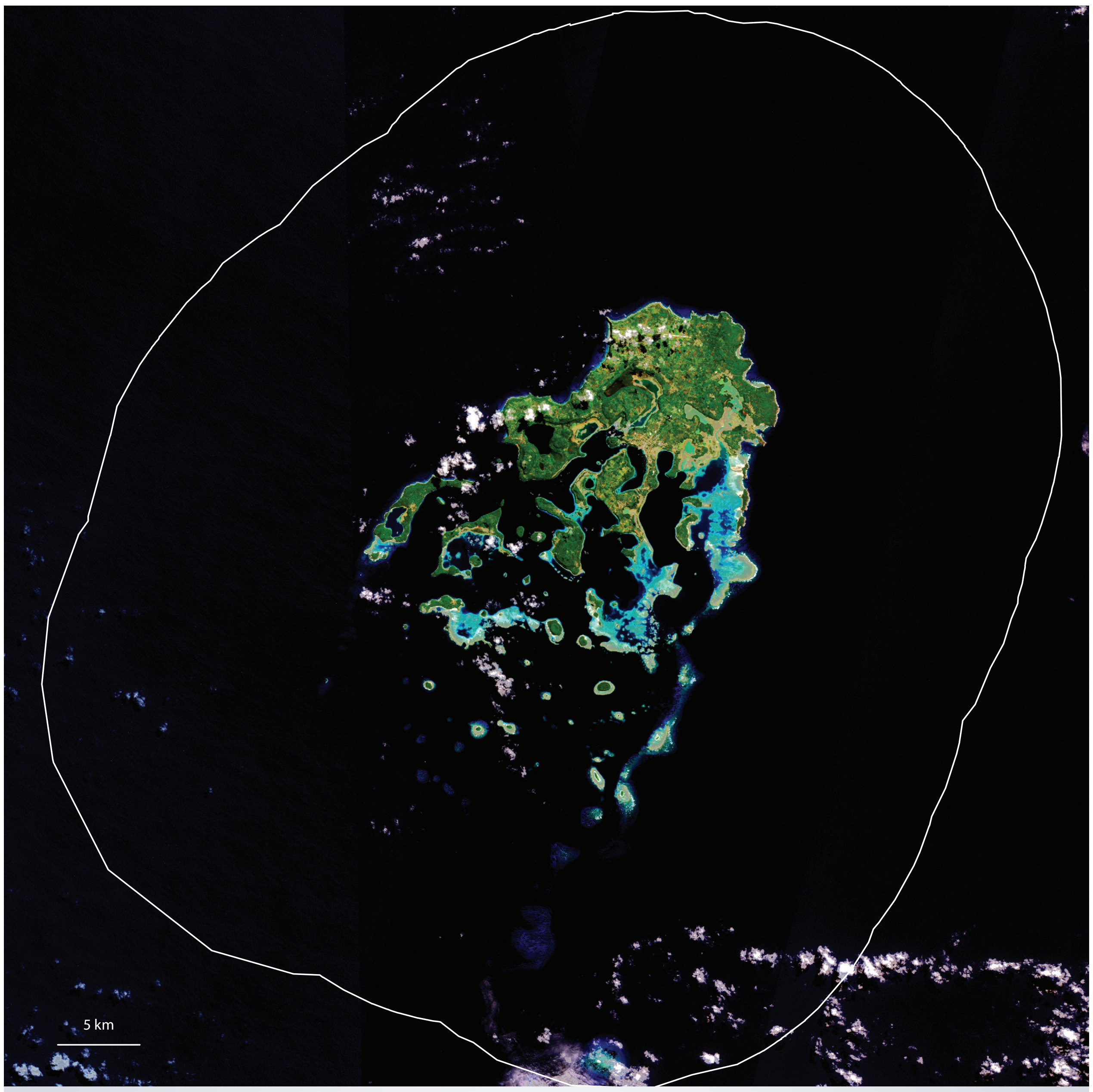
So how can sustainable management be achieved? One requirement is to set agreed management priorities, which allow for an incremental, inclusive and sustainable management and conservation approach to Tonga's valuable biodiversity. To help achieve this, the important concept of KBAs was complemented and extended by the identification of Special and Unique Marine Areas (SUMAs) and bioregions (see "Beyond the hotspots").

SUMAs are areas that are particularly important in maintaining Tonga's biodiversity. They can serve as priority areas for management actions within Tonga's marine environment. It is important that these areas are identified and agreed upon by a broad cross section of local users and experts to ensure they have validity in relevant decision-making processes. In 2015, the Tongan Cabinet decided to embark upon a national Marine Spatial Planning (MSP) process (Cabinet Decision 716). It consequently established a Marine Spatial Planning Technical Working Group (the "Ocean 7"), comprised of the seven key ministries with responsibilities relating to the use, development and management of Tonga's ocean. On 18 May 2016, the Ocean 7, supported by MACBIO, co-hosted a technical workshop to define the biophysically SUMAs of Tonga (Ceccarelli et al., 2017).

The local users and subject experts contributed their local knowledge of the area and were guided by four criteria in identifying SUMAs in Tonga's waters: biophysical justification, geographic explicitness, availability of information sources and international and national obligations.

Ranging from mangroves and seagrasses to deep-sea trenches, canyons and seamounts, these marine areas are some of Tonga's most biologically important. These sites, together with the corresponding report "Biophysically Special, Unique Marine Areas of Tonga", will assist in the selection of marine managed protected areas, to achieve 10 per cent coverage of Tonga's waters (see also chapter "Tonga's commitment to marine conservation"). Moreover, they provide site-specific information for local or national-level decisions, policies, plans or analyses that refer to marine places. Information relating to each site is intended to inform the following management responses:

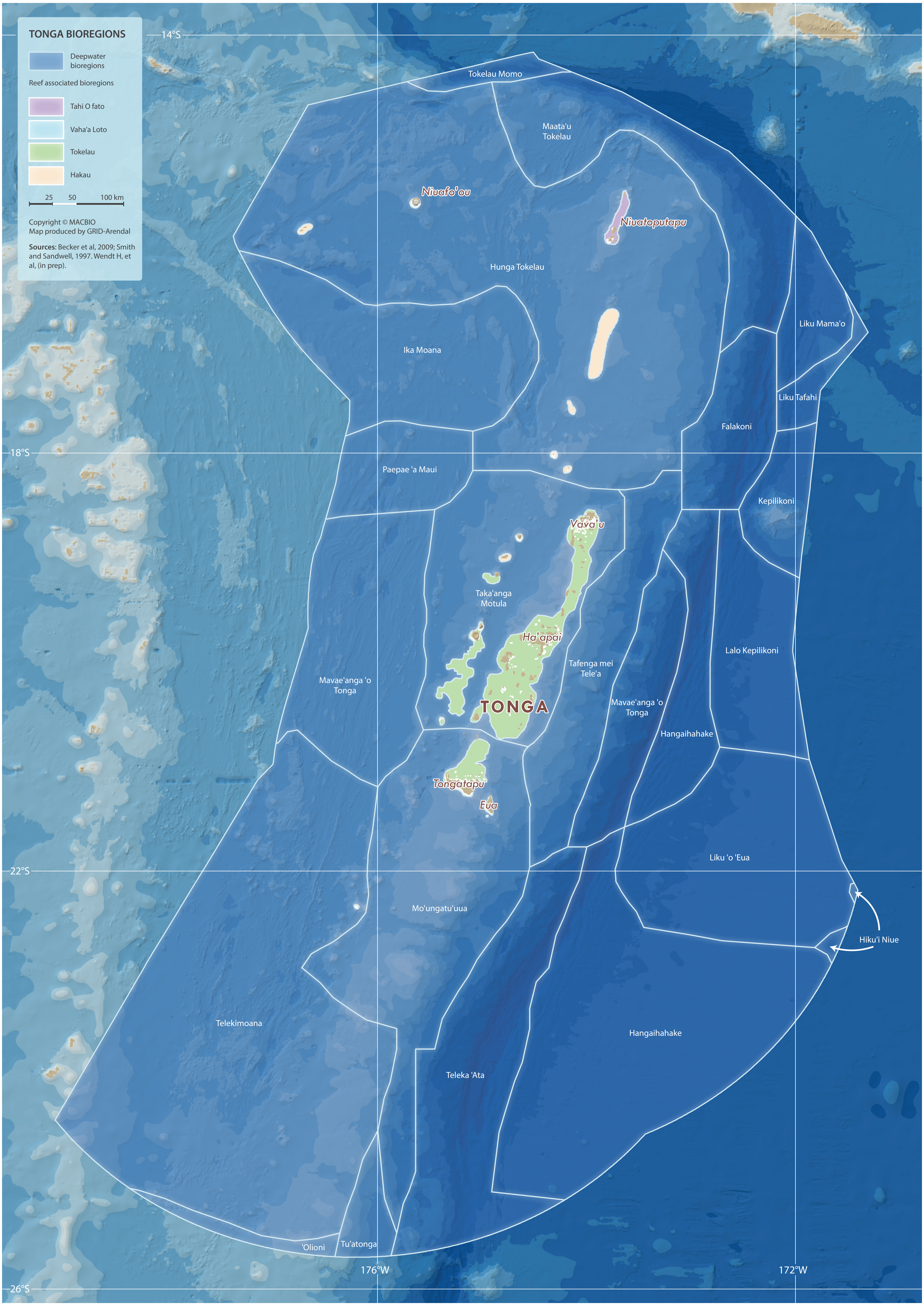
1. Permitting and licencing decisions
2. Environmental impact assessments
3. National and local development planning decisions
4. Decisions by communities and at various levels of government about where to locate marine protected/managed areas



Special and unique: Vava'u waters

The Vava'u group of islands lies in the northern waters of the Kingdom of Tonga. It consists of a main island and 40 smaller islands, as well as numerous rocky islets, sandbars and reefs. Vava'u is surrounded by diverse marine habitats, including inshore coral reefs, seagrass beds, mangroves, shallow soft-bottom communities, deep channels, oceanic waters and deep sea-floor topography, with at least 206 species of hard corals, 249 species of macroinvertebrates and 406 fish species. There are also 14 marine mammal species officially confirmed as occurring in Tonga, including two baleen whales, nine dolphins and one sperm whale—many of these occur in Vava'u. The island group is well known as an important area for calving of humpback whales. Vava'u is special and unique indeed.

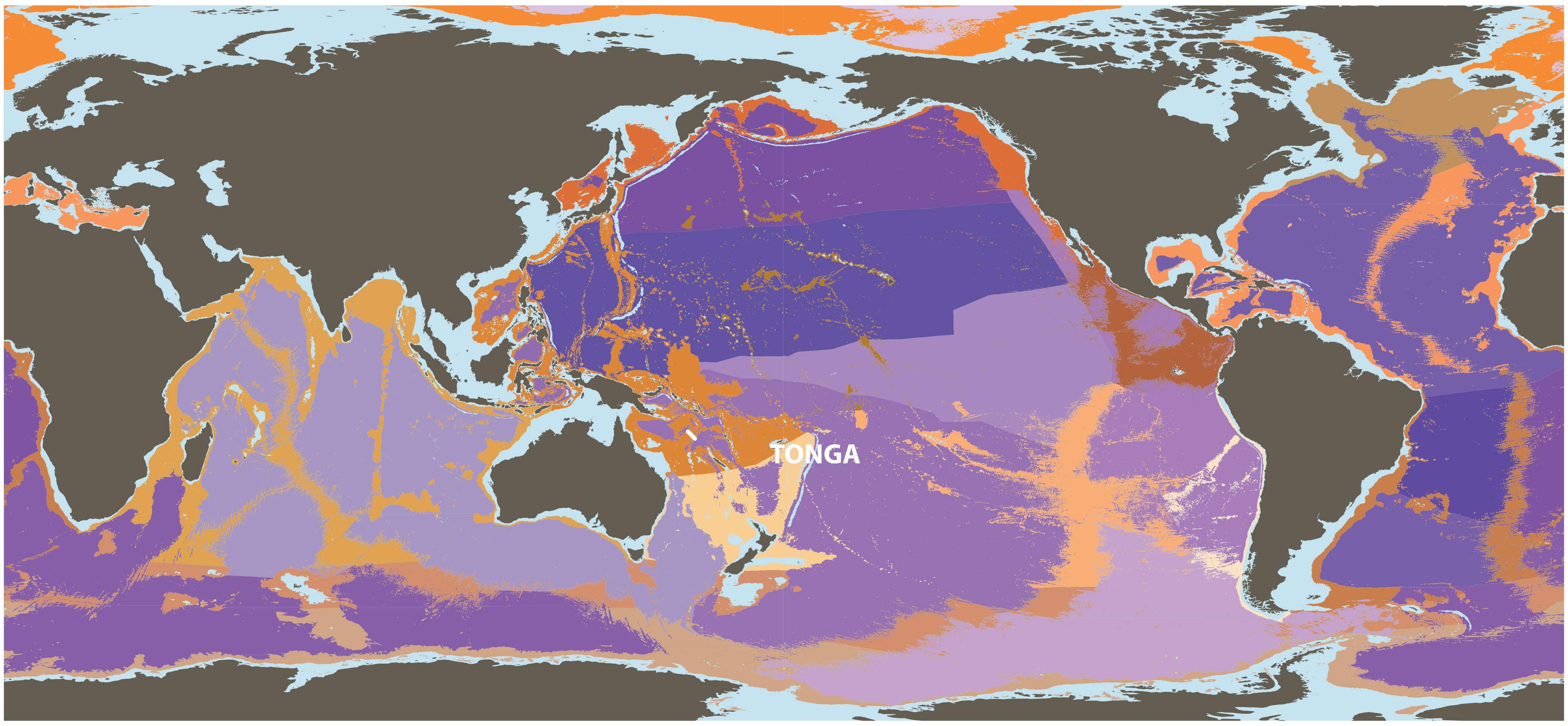
The maps show a total of 50 areas defined as large-scale/offshore and fine-scale/inshore SUMAs in Tongan waters. The large-scale SUMAs capture large sea-floor features such as seamounts, canyons, ridges and troughs, areas of high productivity such as the Ha'apai high-productivity zone, sea-floor hydrothermal vents and important areas for whales off Tongatapu and 'Eua. The fine-scale SUMAs include a range of nearshore habitats and ecosystems important for biodiversity (Ceccarelli et al., 2017). The SUMAs were also identified by the experts as being special, unique marine environments, reflecting the immense variety of marine habitats within the Tongan islands, reefs and surrounding oceans. Much of this information has been published in formal papers and reports, but there is also a great vein of local knowledge held by the traditional resource owners themselves, which should be taken into account for describing what is special and unique.



TONGA BIOREGIONS
Deepwater bioregions
Reef associated bioregions
Tahi O fato
Vaha'a Loto
Tokelau
Hakau
25 50 100 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Smith and Sandwell, 1997. Wendt H, et al, (in prep).
14°S
18°S
22°S
26°S
176°W
172°W
Tokelau Momo
Maata'u Tokelau
Niuafo'ou
Niuatoputapu
Hunga Tokelau
Ika Moana
Liku Mama'o
Liku Tafahi
Falakoni
Paepae 'a Maui
Kepilikoni
Vava'u
Taka'anga Motula
Ha'apai
Tafenga mei Tele'a
Lalo Kepilikoni
Mavae'anga 'o Tonga
TONGA
Mavae'anga 'o Tonga
Hangaihahake
Tongatapu
Eua
Liku 'o 'Eua
Mo'ungatu'uua
Hiku'i Niue
Telekimoana
Hangaihahake
Teleka 'Ata
'Olioni
Tu'atonga

BEYOND THE HOTSPOTS: BIOREGIONS

Ideally ecosystem-based marine planning should be based on comprehensive data that represents all of Tonga's marine plants and animals. This data, however is rarely available for any country. To overcome this limitation, surrogates can be used to classify the marine environment into spatial units, or bioregions, that host similar plants and animals.



The GOODS biogeographic classification from 2009 is an example of a global bioregionalization.

To sustainably manage and protect Tonga's rich marine resources, the government is committed to delivering a comprehensive, ecologically representative network of managed and protected marine areas (see also chapter "Tonga's commitment to marine conservation"). Ideally, ecosystem-based marine planning should be based on comprehensive biodiversity data that represent all of Tonga's marine plants and animals in its entire marine environment.

While a lot of data are accessible—as the maps in this atlas show—comprehensive data are not available for any country, including Tonga. To overcome this limitation, surrogates must be used to classify the marine environment into spatial units, or bioregions, that can host similar plants and animals. These surrogates include factors such as salinity (see also chapter "Go with the flow"), pH (see chapter "Turning sour") or phosphate concentration (see chapter "The dose makes the poison"). Analysing and clustering such data results in spatial units, called marine "bioregions". These bioregions present comprehensive descriptions of the marine biodiversity of Tonga and can be used for conservation, management and planning.

Such marine classification and the use of bioregions is not a new concept, as bioregions have been produced before at various scales in other countries, regions and globally, including some that encompass Tonga. The graphic provides one example of a global bioregionalization, the Global Open Oceans and Deep Seabed (GOODS) biogeographic classification, undertaken by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2009.

Classifications such as GOODS are very useful on a global scale. However, Tonga's large EEZ is divided into merely three bioregions, making the existing classifications of the marine environments, both coastal and offshore, too coarse to inform most national planning processes in Tonga. This calls for more detailed bioregions to inform marine planning. The MACBIO project has developed draft marine bioregions across the South-West Pacific for use by Pacific Island countries, including Tonga, in their national planning process for MSP and MPAs. In total, 262 deepwater bioregions and 102 reef-associated bioregions were defined across the South-West Pacific, which included 33 deepwater and four reef-associated bioregions in Tongan waters (Wendt et al., 2018). In 2017, in-country experts came together to consider and help verify the location, boundaries, name and description of these draft bioregions within Tongan waters. As a result, the four reef-associated bioregions were modified to reflect the participants' knowledge of the coral reef ecosystems and associated biodiversity in Tongan waters. The deepwater bioregions were also refined, based on knowledge of fish assemblages and biophysical attributes, with the original 33 draft deepwater bioregions being recombined into 21 deepwater bioregions (Wendt et al., 2018).

Using these bioregions as substitutes to describe the suite of marine biodiversity in Tonga, an ecologically representative system of managed and protected areas can be built. This is done by representing an example of every bioregion within an area, as well as examples of all known habitats and ecosystems (see also chapters "Nature's hotspots" and "Special and Unique Marine Areas"). The bioregional approach assists planners with the fact that not all habitats and ecosystems are known and mapped.

PLANNING

The previous section on "Valuing" revealed the diversity and richness of Tonga's biophysical features, the ecosystems they underpin and the many goods and services they provide to Tonga. This section will look at how the many human uses of these values interact and how these uses can be planned.

More than 98 per cent of Tonga's total jurisdiction is ocean. The ocean is vitally important to Tonga, providing food and income, coastal protection, carbon storage and essential habitat for marine plants and animals. Furthermore, coasts and oceans are heavily intertwined with Tonga's cultures, traditional knowledge and practices, while the economic, social and ecological benefits provided by marine ecosystems are worth billions of dollars to Tongans every year.

Despite the high value of the ocean to Tongans, to date, national development and conservation planning has largely focused on land. However, recent studies show that better planning for oceans can bring significant economic, social and environmental benefits. Marine Spatial Planning (MSP) can help Tonga realize and maintain these benefits.

MSP is most useful if countries:

- have (or expect) human activities that adversely affect biodiversity in marine areas
- have (or expect) competing human activities within a given marine area
- need to decide which marine spaces are most suitable for new or additional economic development activities such as tourism, deep-sea mining or mariculture
- want to prioritize marine resource management efforts in parts of, or all, marine areas
- need a vision or scenarios of what marine areas could or should look like in another 10, 20 or 30 years

MSP can help address these issues. Similar to land-use planning but relating instead to the sea, it is a tool in the marine resource management toolbox that also includes input controls (e.g. on fishing effort), process controls (e.g. permits) and output controls (e.g. quotas). MSP is an intersectoral and participatory planning process that seeks to balance ecological, economic and social objectives, aiming for sustainable marine resource use and prosperous blue economies.

The concept of MSP is not new and countries are already applying aspects of it, such as designated shipping lanes, fishing areas, locally managed marine areas or MPAs. However, some of these existing examples have, at times, been declared opportunistically without an overarching and integrated planning process. When declared in isolation, individual spatial planning tools may not secure the ecosystem services that people rely on in the medium and long term.

A more comprehensive and integrated MSP process can support and guide sectoral planning efforts, but does not replace sectoral planning. A more holistic MSP process will reduce the conflicts between the marine environment's different users and uses, while maximizing the social, economic and ecological benefits people receive from the ocean.

The maps in this chapter show how Tonga can plan the uses of the rich values its marine ecosystems provide, be it fishing, tourism, mining or vessel traffic. At the same time, MSP is also a powerful tool for avoiding conflicts and managing threats, such as marine debris, pollution or impacts from climate change, as featured in the maps.

Further reading: **www.macbio-pacific.info/marine-spatial-planning**

USES

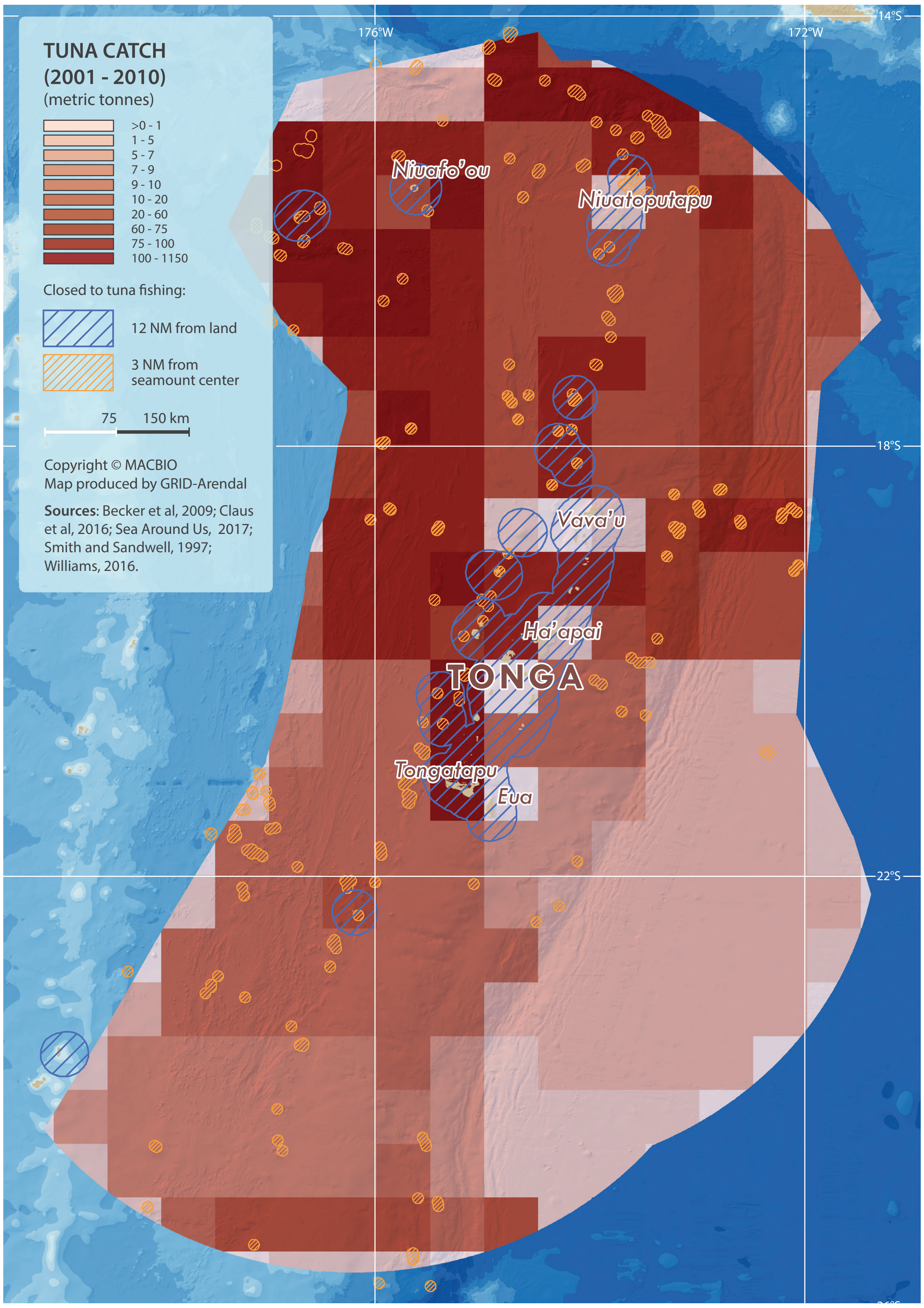
FISHING IN THE DARK: OFFSHORE FISHERIES

Underpinned by Tonga's ecosystems, offshore fisheries are an important contributor to Tonga's economy. Like all human developments, offshore fisheries need to be planned and sustainably managed.

Tuna are the basis of important commercial fisheries for many island nations in the South-West Pacific. Typically, four main species are taken: skipjack (*Katsuwonus pelamis*), albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*), and yellowfin (*Thunnus albacares*). The abundance of these species varies throughout the region, as do fishing methods. The tuna fishery is associated with the capture of a number of valuable, non-target species as well as numerous by-catch species including sharks, turtles and sea birds. The fisheries are managed by the Western and Central Pacific Fisheries Commission (WCPFC) and cover the entire western Pacific Ocean to longitudes of 150°W in the North Pacific and 130°W in the South Pacific. Typically, there are 3,000–4,000 vessels operating each year, and the total tuna catch exceeds 2 million tons per year.

Commercial offshore fisheries are primarily based on tuna harvest and produce a total of TOP 4 million per year. Interestingly, inshore fisheries yield a higher amount, with a total of TOP 12 million per year (Salcone, 2015). Tuna fishing in Tonga is solely longline and lacks the large volume of purse seine catches of other islands to the north. Nevertheless, the commercial tuna fishery in Tonga is an important source of income to the country through the licencing of vessels to catch tuna within the EEZ, the export of most of the domestic catch and employment for local fishermen. Tuna is the largest marine export, making the industry the highest contributor to fisheries-based revenue for Tonga.

The map shows the distribution of all tuna catches over the 2001–2010 period in Tonga's EEZ.



Longline fisheries over this period were highly variable, with between five and 35 vessels per year reported to be involved in longlining (WCPFC, 2017), targeting albacore, yellowfin and bigeye tuna. Following large catches in 2001 and 2002, a strong El Niño event reduced the abundance and availability of fish and resulted in all foreign vessels leaving Tonga in 2005 (Likiliki et al., 2005; Gillett, 2009). The number of vessels has progressively declined since 2002, dropping to five by 2010, and since then, there have been three or four operating per year. The catch of each species has varied between years, with albacore comprising almost 70 per cent of the catch in some years. Over the 2001–2010 period, however, the total catch of albacore was approximately 5,000 tons, making up 59 per cent of the tuna catch, followed by yellowfin (27 per cent) and bigeye (13 per cent). Other commercial billfish species taken in the fishery include blue marlin (*Makaira nigricans*), black marlin (*Makaira indica*), striped marlin (*Kajikia audax*) and swordfish (*Xiphias gladius*).

Reported catches by the Pacific community over this period totalled 900 tons, 11 per cent of the tuna catch. Most of the catch has been taken in the northern part of the EEZ, although there is a fairly scattered pattern. The catches are often near seamounts, which are well known to host higher catch rates of yellowfin, and to a lesser extent, bigeye tuna (Morato et al., 2010). Seamount and similar topographic features are common throughout the Tongan EEZ, which may enhance localized productivity and help support higher densities of fish species. The management of such habitats can be important for fisheries, not just for tuna, but also for deepwater snappers.

All the tuna species are widely distributed. Given the significant proportion of fisheries based on albacore, it is important to note that a South Pacific stock of albacore is distributed between 10°S and 50°S, spawning between latitudes of 10°S and 25°S. More juveniles are found in surface waters at higher latitudes, while adults tend to be found deeper in subequatorial waters. Adults appear to have a seasonal migration pattern, moving south during early summer (December – January) and north in winter (June – August). Both depth and seasonal distribution therefore need to be considered in the spatial management of tuna fisheries in Tonga.

The distribution of tuna and their fisheries is influenced by oceanographic events, in particular the El Niño–Southern Oscillation (ENSO) period. Fish distribution is also expected to shift with climate change, potentially moving to the east and to higher latitudes (Lehodey et al., 2011). This may negatively affect yellowfin but have a positive effect on albacore fish stocks in the Tongan EEZ. In short, environmental change should be a factor considered in longer-term management scenarios.

Deepwater fisheries are a small but important resource for Tonga in terms of export income, employment and local food. However, as deepwater species are often vulnerable to overfishing, careful management is required to ensure such fisheries are sustainable.

Deepwater snapper inhabit reef slopes and shallow seamounts that rise to between 100 metres and 400 metres below the surface. They are an important fisheries resource for many Pacific Island countries, where they support domestic and some small export markets (SPC, 2013a). More than 20 west-central Pacific countries and territories have active deepwater snapper fisheries, have historically participated in deepwater snapper, or have expressed some interest in developing this capacity (Williams and Nicol, 2014). The fish caught in these fisheries are mainly from the families *Serranidae, Lutjanidae*, and *Lethrinidae* (McCoy 2010). However, a range of over 100 species is landed, including those in the families *Gempylidae* and, more recently, *Centrolophidae* (the latter primarily bluenose and blue warehou (SPC, 2013b)).

Deepwater fisheries extending beyond the reef and onto the upper slope and seamounts along the Tonga Ridge and Tafua Ridge are important for small local operators and artisanal fishers. A deepwater snapper fishery was developed in the 1990s, with two main companies targeting snappers for export (200–300 tons per year). However, the export fishery for snappers (in particular *Etelis coruscans*) has become intermittent, and in recent years, there has been a push to develop a new fishery for bluenose (*Hyperoglyphe antarctica*).

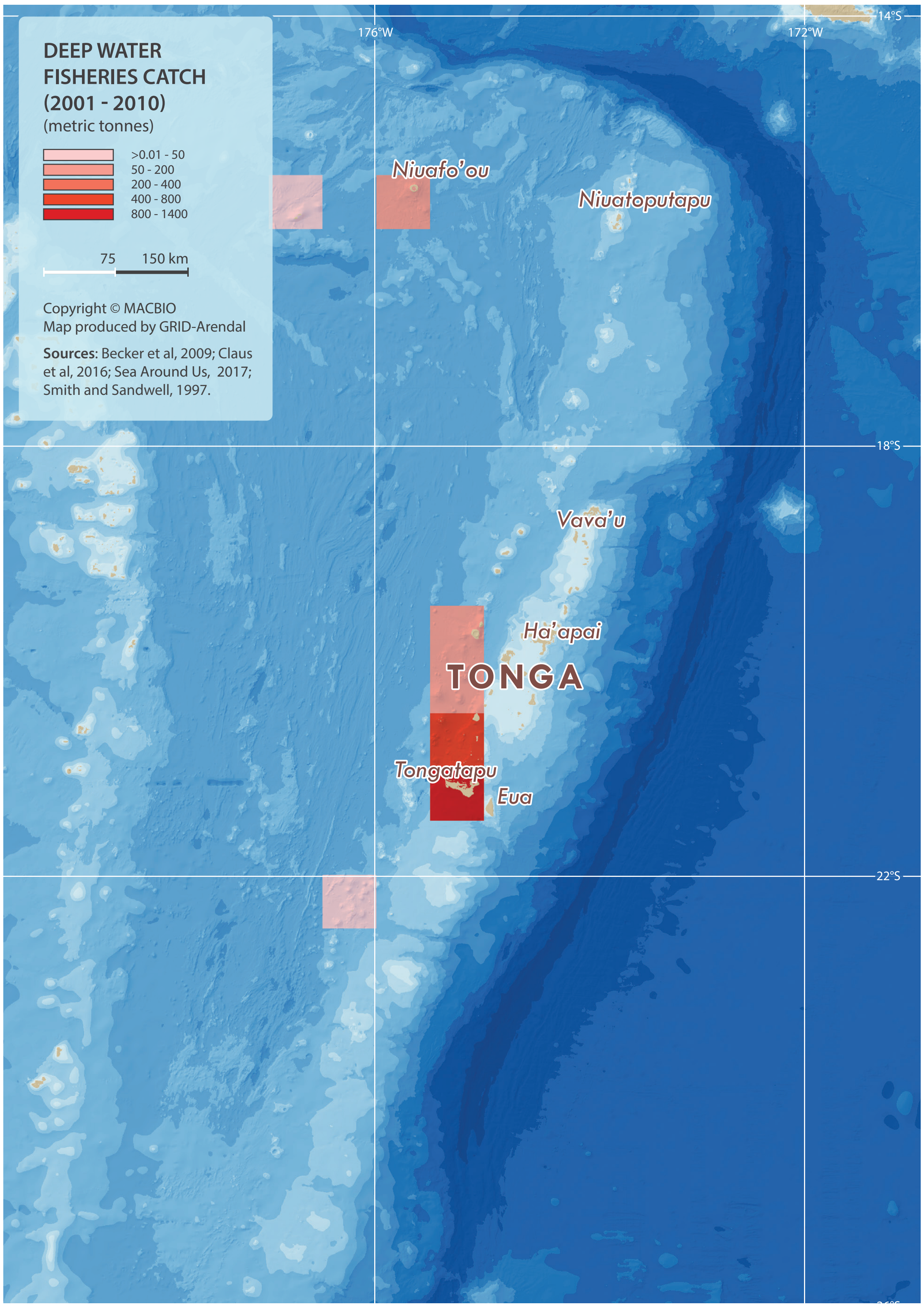
The map shows historical catches over the 2001–2010 period for deepwater fisheries in Tongan waters, based on FAO data and national reports. There is a wide range of fish species caught in these deepwater demersal fisheries, the majority of which are snappers from the families Lutjanidae (snappers, primarily the genera *Etelis* and *Pristipomoides*), Lethrinidae (emperors of the genera *Gymnocranius*, *Lethrinus, Wattsia*) and Serranidae (groupers of the genus *Epinephalus*) (McCoy, 2010; SPC, 2013b). The estimated catches over the 10 years are dominated by snappers (*Pristipomoides filamentosus, P. flavipinnis, Etelis coruscans* and *E. carbunculus*)—totalling about 35 per cent of deepwater species catch—groupers (*Epinephalus* spp.) (40 per cent) and emperors (several species of *Lethrinus*) (5 per cent). Species of emperors, in particular, can occur over a wide depth range, and when individual species are not reported, it can be difficult to assign a generic catch to deepwater rather than shallow coastal areas. Given this caveat, annual catches over the period were generally between 200 and 400 tons. The deep catch is taken largely in coastal waters around the main islands of the Tongatapu group, with smaller catches to the north and south.

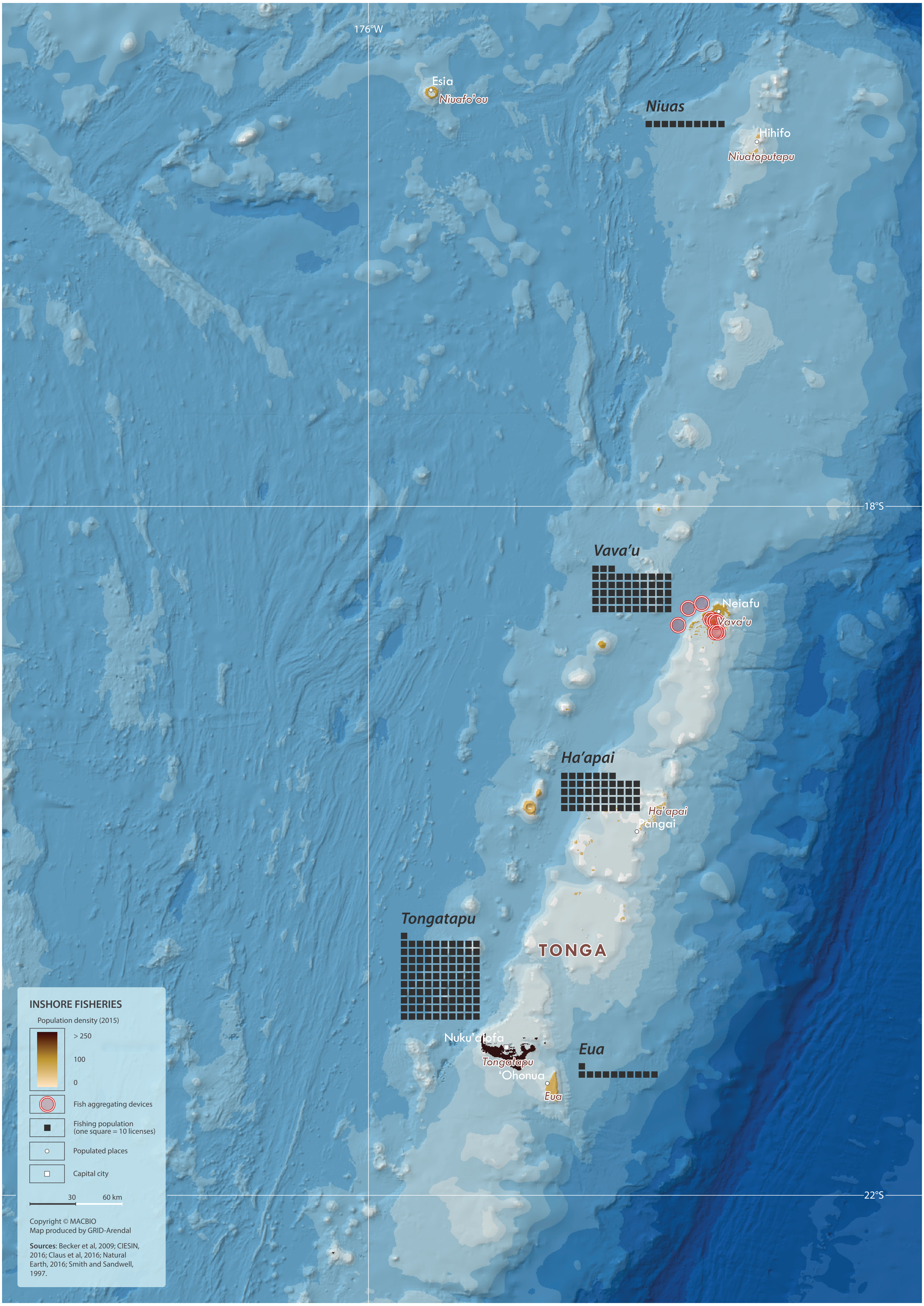
Line fishing is the main method used for these species and has been carried out commercially for several decades. Deepwater snapper fishing was promoted in the 1980s by the Secretariat of the Pacific Community (SPC), and Tonga was actively engaged in this (Dalzell and Preston, 1992), with up to 45 vessels at one time, decreasing to 24 working out of Vava'u and Nuku'alofa (Adams and Chapman, 2004). Numbers of vessels dropped to around 12 in the early 2000s, which maintained both local and export supply. A regional assessment of the fisheries potential following surveys conducted by the SPC was made in 1992, largely based on sea-floor area of around 200 metres depth. This resulted in an estimate of sustainable yield per year for the slope and seamounts in Tongan waters of between 110 and 340 tons (Dalzell and Preston, 1992). However, such fisheries in the region as a whole have struggled due to low catch rates following an initial fishing-down phase, variable export markets and prices, shipping costs and limited habitat area (McCoy, 2010). Catch per unit effort decreased by 70 per cent from the early years of fishing in the late 1980s to levels observed in 2010.

The data set on all known deepwater snapper location records, compiled by Gomez et al. (2015), is dominated by data from Tonga. The modelled distribution of 14 deepwater snapper species using available fisheries and oceanographic data was based largely on depth (Gomez et al., 2015), and indicated extensive suitable habitat and a potential unexploited biomass of 1,100 tons. However, there are currently no reliable estimates of sustainable levels of catch and effort, and there is a poor understanding of stock structure. Deepwater snapper stocks are considered vulnerable to fishing due to their seamount distribution, high longevity, late maturity and slow growth (Williams et al., 2013).

Seamount features are recognized as important habitat for deepwater snappers, and there are numerous seamounts at suitable depths along the main island ridge in Tonga. These are also prospective sites for developing a bluenose fishery, especially in southern areas of the EEZ. However, snapper populations may be fairly resident in areas of slope or on seamounts, which can make them vulnerable to localized overfishing, as well as potential deep-sea mining for sea-floor massive sulfides or cobalt-rich crust—both relevant to potential mineral exploitation in Tongan waters (Clark et al., 2017). Although a management plan has been in place since 2008, the likelihood of restricted distributions of these deepwater species means there is a need to consider regulations specific to seamounts or to localized areas of suitable fish habitat, in order to reduce the risk of serial depletion that occurs when the fishery can move from one place to the next if total catch limits are set for a large area.

Deepwater fisheries over the period considered were an important resource for Tonga, providing both local food and an export fishery. However, the fishery showed signs of substantial overfishing in the 1990s to early 2000s. Little is known about stock structure, stock size and productivity, thereby making the long-term sustainability of historic catch levels uncertain.




176°W
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Niuas
Hihifo
Niuatoputapu
Vava'u
Neiafu
Vava'u
Ha'apai
Ha'apai
Pangai
Tongatapu
TONGA
Nuku'alofa
Tongatapu
'Ohonua
Eua
Eua
INSHORE FISHERIES
Population density (2015)
> 250
100
0
Fish aggregating devices
Fishing population (one square = 10 licenses)
Populated places
Capital city
30
60 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; CIESIN, 2016; Claus et al, 2016; Natural Earth, 2016; Smith and Sandwell, 1997.

SMALL FISH, BIG IMPORTANCE: INSHORE FISHERIES

Catch from Tonga's inshore fisheries is eaten locally and sold on the market. While inshore fisheries are relatively small, they are much more valuable to Tonga than its offshore fisheries. However, to maintain these benefits, sustainable management of dwindling inshore resources is key.

Almost all of Tonga's approximately 700,000 km^2 of marine waters is classed as offshore (99 per cent), as opposed to inshore (1 per cent) (see also chapter "Tonga's commitment to marine conservation"). It would therefore be easy to assume that most of Tonga's fish were caught in the vast offshore area and would produce by far the highest value for the country. However, this is not the case, as outlined below (see also chapter "Fishing in the dark").

Tonga's fisheries can be divided into two broad categories: subsistence fishing and commercial fishing. Subsistence fishing is the use of marine and coastal resources by local populations directly for food or trade, rather than for profit. It typically occurs when these products are consumed by the fisher or their family, given as a gift or bartered locally. In Pacific Island countries, coral reef fisheries are characterized by a strong predominance of subsistence fishing, with an estimated 80 per cent of coastal fisheries' catch consumed directly by the fisher and their communities. While commercial offshore fisheries produce a total of TOP 4 million per year, inshore fisheries yield a much higher amount, with a total of TOP 12 million per year (Salcone, 2015). This underlines how vital inshore fisheries are to the people of Tonga, particularly those in rural and remote areas, who often rely on them for nutrition and income. FAO estimated that fish contributed an average 11.5 per cent of protein to Tongan diets in 2011 (15.6 per cent of all animal protein) (FAO, 2014). Sadly, inshore fisheries are some of the most vulnerable to climate change, natural disasters and direct anthropogenic pressures. Tonga's inshore fisheries are highly dependent on its healthy reef ecosystems (Burke et al., 2011), which are at risk from climate change, storm events, land-based pollution and some fishing practices.

The Kingdom of Tonga is well known in the Pacific region to have one of the most abundant fish communities in its deep reef waters. The extensive series of inshore banks and seamounts support multi-species assemblages of members of the fish family *Lutjanidae* (snappers), *Lethrinidae* (emperors) and *Serranidae* (groupers). However, catches indicate a lot more fish species found at different depths. The Kingdom of Tonga and the SPC (and recently the European Union and New Zealand) have been working on this deepwater and grouper fishery since 1974, acquiring more biological data to inform policies for its sustainable exploitation and for more effective management. The breakdown of catch for key inshore fisheries is given in the table below.

In the early 2000s, a change in Tonga's fisheries legislation allowed for local communities to manage fisheries, through Special Management Areas (SMAs). Since then, the Fisheries Division has been working with coastal communities to establish 11 SMAs (FAO, 2017). SMAs are another spatial tool to increase the management of valuable marine resources.

The map shows the distribution of fishing licences for each of the main island groups. Tongatapu has the most licences, followed by Vava'u and Ha'apai, with a low number of licences in Niuas. However, when population is taken into account, the relative importance of fishing to local economies is often greater in the remote areas, away from large population centres. The map also indicates the placement of nearshore-anchored fish-aggregating devices. These are devices located beyond the reefs that encourage large pelagic fish to aggregate and give the communities greater access to offshore species such as tuna. This effort is intended to improve local food security and livelihoods, reduce fishing pressure on vital reef fisheries and increase community resilience to tropical cyclones and climate change (see also chapters "Hotter and higher" and "Stormy times").

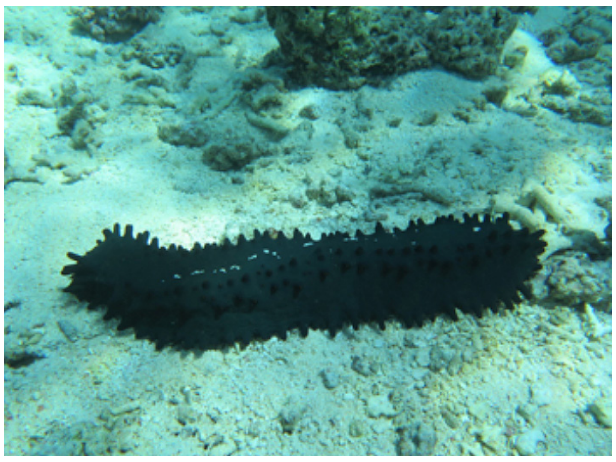
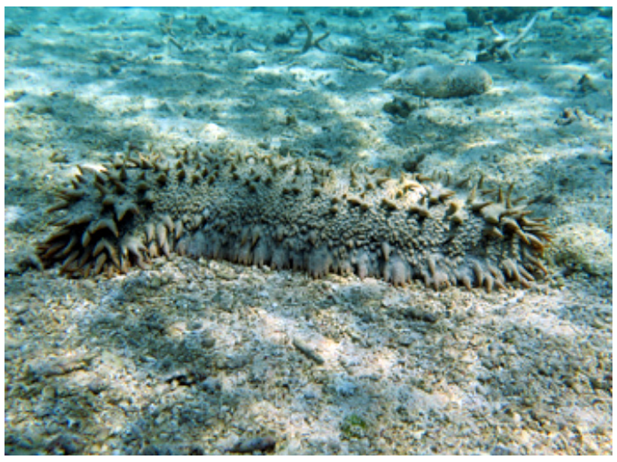
The importance of sustainably managing Tonga's offshore fisheries, but also its valuable inshore fisheries, is becoming increasingly evident. Subsistence food provision from inshore fisheries and coastal resources has been valued at a total national gross value of TOP 7 million per year, while small-scale inshore commercial fisheries produce a total value of up to TOP 5 million per year.

The combined inshore fisheries value of TOP 12 million per year is similar to the licence fees for tuna fisheries, worth TOP 4 million per year (see graphic and previous chapter), which demonstrates that the small inshore fisheries are of big importance for Tonga.

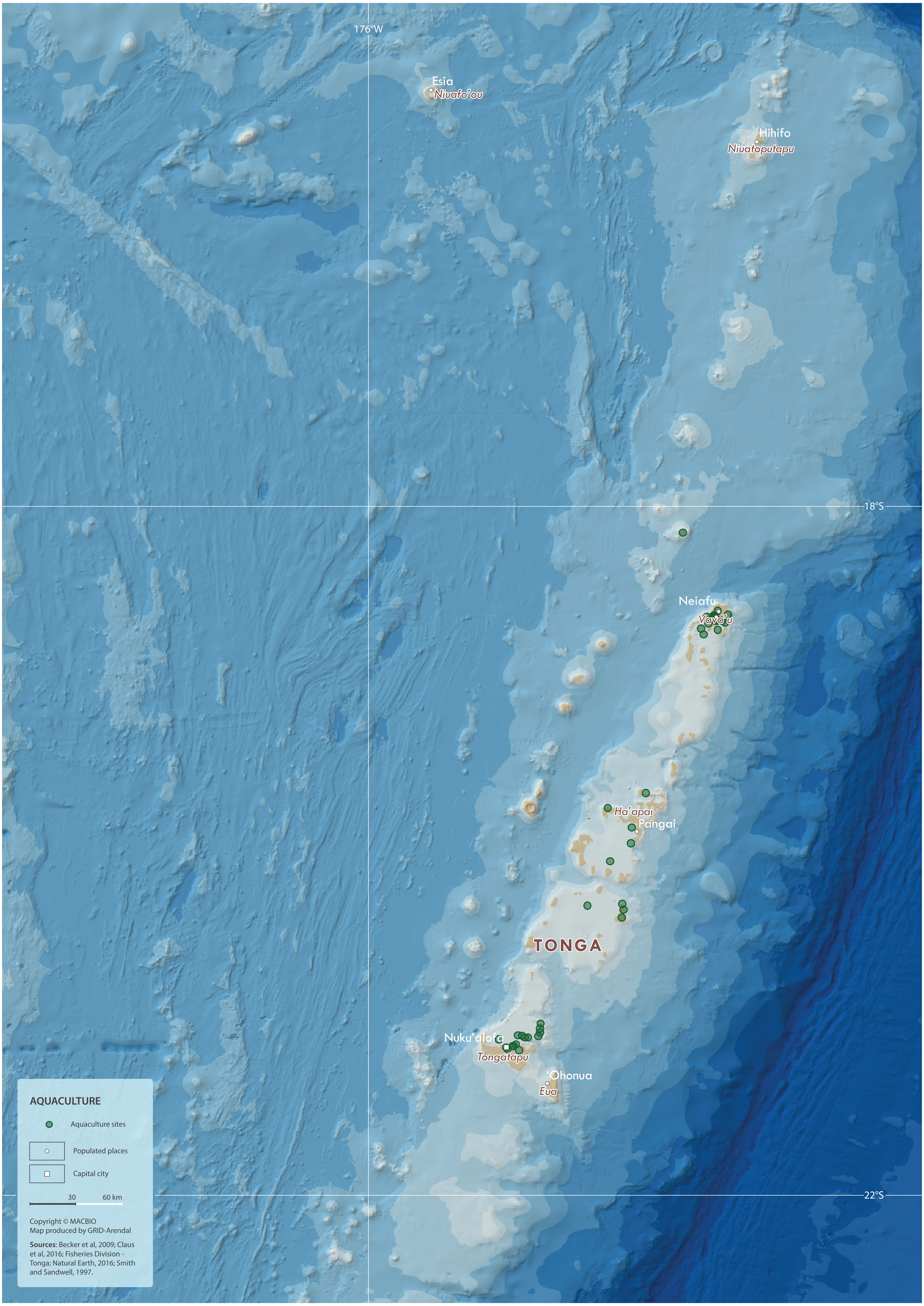
Tonga inshore fisheries statistics 2013.

		Catch Volume (mt)	Net annual value (TOP)
Inshore Subsistence	Rural and urban subsistence	1200–2200	5,460,000
	Total subsistence	1200–2200	5,460,000
Inshore Commercial	Small-scale coastal fisheries	1,000–1,800	4,200,000–7,300,000
	Bêche-de-mer	55	450,000
	Aquarium trade	–	250,0000
	Total commercial	1,055–1,855	4,900,000–8,000,000

Source: Salcone et al. (2015)

Sea cucumber, or bêche-de-mer, is an important inshore fishery in Tonga.


176°W
Esia
Niuafo'ou
Hihifo
Niuatoputapu
18°S
Neiafu
Vava'u
Ha'apai
Pangai
TONGA
Nuku'alofa
Tongatapu
'Ohonua
Eua
22°S
AQUACULTURE
Aquaculture sites
Populated places
Capital city
30
60 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Claus et al, 2016; Fisheries Division - Tonga; Natural Earth, 2016; Smith and Sandwell, 1997.

FISH FROM THE FARM: AQUACULTURE

Aquaculture has faced many challenges in Tonga over the years. Although successful farms exist, Tonga's aquaculture is declining, and the true costs and benefits need to be carefully assessed.

The farming of seafood, known as aquaculture, can be practised in both fresh water or salt water, the latter of which is also known as mariculture (see map).

Aquaculture in Tonga has been practised since the 1970s by the Fisheries Division, with support from the Australian and Japanese governments. Initial aquaculture efforts targeted local oyster culture (MAFFF, 2014). In 1978, with the support of the Japanese government, a Mariculture Centre was established in Sopu to support research and development of aquaculture in Tonga. The Sopu Mariculture Centre has been spawning, rearing and culturing mainly giant clams, trochus, green snail and seaweed (MAFFF, 2014).

Aquaculture activities within Tonga are administered by the Fisheries Division of the Ministry of Agriculture, Food, Forests and Fisheries under the Aquaculture Management Act 2003 and the Tonga National Aquaculture Management and Development Plan (2014–2019). The objectives of aquaculture management in Tonga are: 1) The aquaculture industry will contribute to the economic development and social well-being of the people of Tonga; 2) The aquaculture industry will be environmentally sustainable; 3) The aquaculture industry will be managed in a manner that considers and balances economic and social gains against environmental costs; 4) The aquaculture industry will be managed within a transparent and explicit regulatory framework; 5) There will be broad community consultation about aquaculture developments that have potential to impact on specific communities; 6) Aquaculture product grown for human consumption will be safe and disease-free.

Current aquaculture activities are focused on giant clams, for both wild stock replenishment and for the ornamental market by aquarium traders (FAO, n.d.). The penguin wing oyster (*Pteria penguin*), which was introduced from Japan in the early 1990s, has been the focus for developing a pearl farming industry. In 2008, around 300,000 spats were produced, which were then transferred to longlines for grow-out and later distributed to pearl farmers located in Vava'u. The production of half pearl or 'mabe' pearl is focused on catering for the domestic tourism market. The other area of aquaculture development being pursued is hard corals and live rock farming, which formed part of the technical assistance provided by SPC/Australian Centre for International Agricultural Research (ACIAR) to the Pacific region in 2009. This project aimed to produce cultured live rocks and corals for supply to the aquarium ornamental trade. There are five main companies that specialize in the export of marine ornamental species in Tonga (SPC Aquaculture Portal, n.d.)

In addition to these aquaculture activities, there have been various initiatives to farm mullet *Liza macrolepis* and *Valamugil seheli*, tilapia, seaweed and food oysters. These trials have had limited success due to a range of issues, including lack of technical expertise, high cost of production and environmental conditions. Similarly, there has been little commercialization of different aquaculture species. There is an existing mullet aquaculture site in Fanga'uta Lagoon.

The map shows the location of key aquaculture facilities in Tonga. These include the Sopu Mariculture Centre, the location of pearl aquaculture at Fafa Island SMA and Pangiamotu Island, mabe aquaculture at Uiha and mullet aquaculture at Fanga'uta Lagoon. Despite the limited aquaculture activity, there is continued interest in developing aquaculture in Tonga to provide employment, increase foreign trade, reduce pressure on inshore fisheries and create alternatives, as well as to promote stock enhancement of overharvested fisheries.

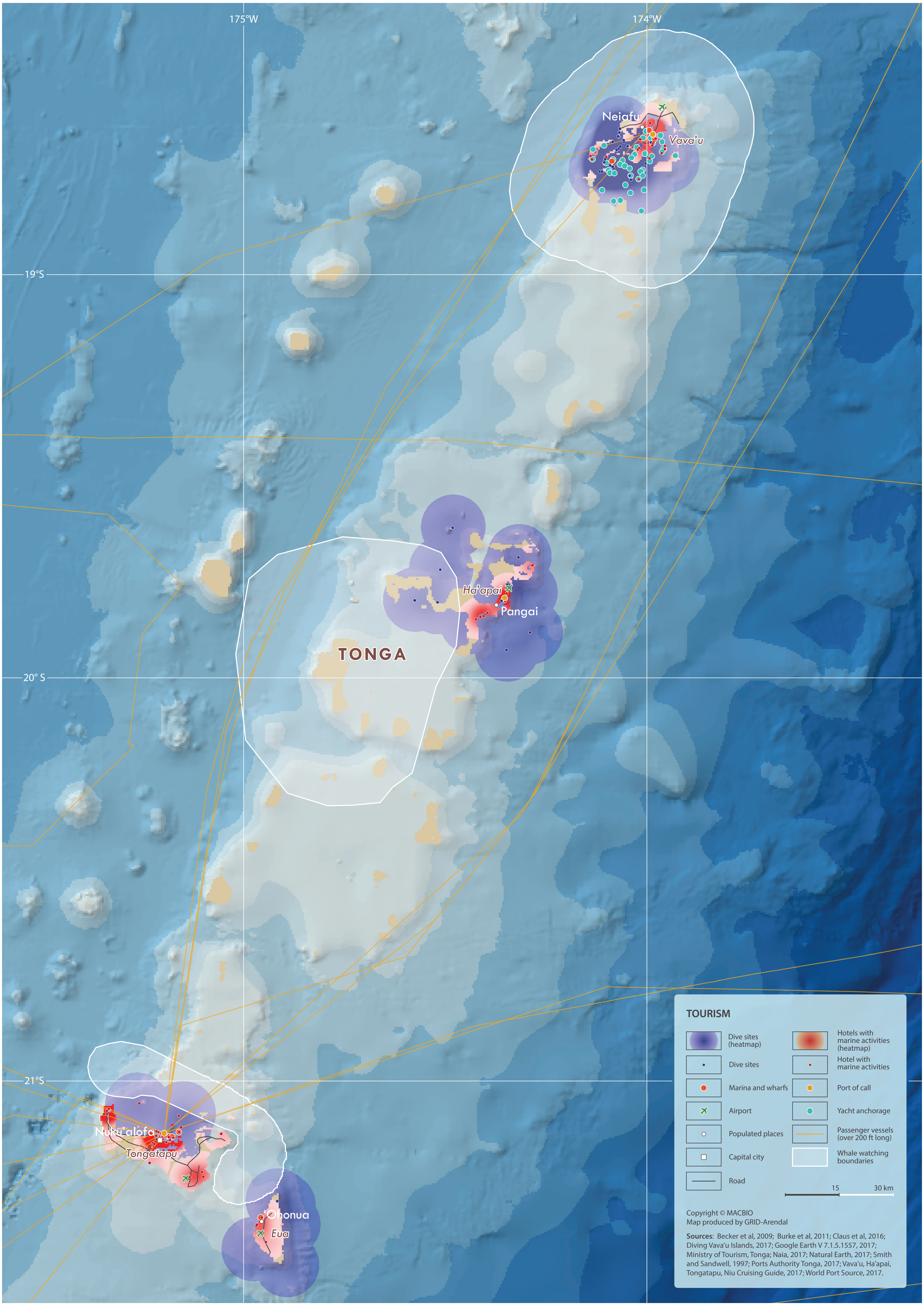
Aquaculture can, however, have negative impacts on the marine ecosystem, including pressure on wild fish used for fish feed, escape of introduced aquaculture species, interbreeding of farmed fish with wild fish, pollution and habitat loss. For example, mangroves are cut to develop shrimp farms, resulting in loss of this key coastal habitat (see also chapter "Home, sweet home"). There is therefore a need for clear priorities when expanding aquaculture to minimize any adverse environmental impacts.

Summary of Tonga Aquaculture sector 2011.

Species	Quantity	Estimated value (USD)
Giant clams – Tridacnidae		
Tridacna derasa (3 years)	3000 pcs	4,000
T.maxima (4 years)	20 pcs	100
T.squamosa (4 years)	14 pcs	100
T.crocea (2 years)	10 pcs	50
Penguin wing oyster – *Pteria penguin*	4 000 pcs – without 'pearl'	
	800 pcs – with 'pearl' (half pearl)	25,000
Live rocks – Sceretania	200 pcs	400

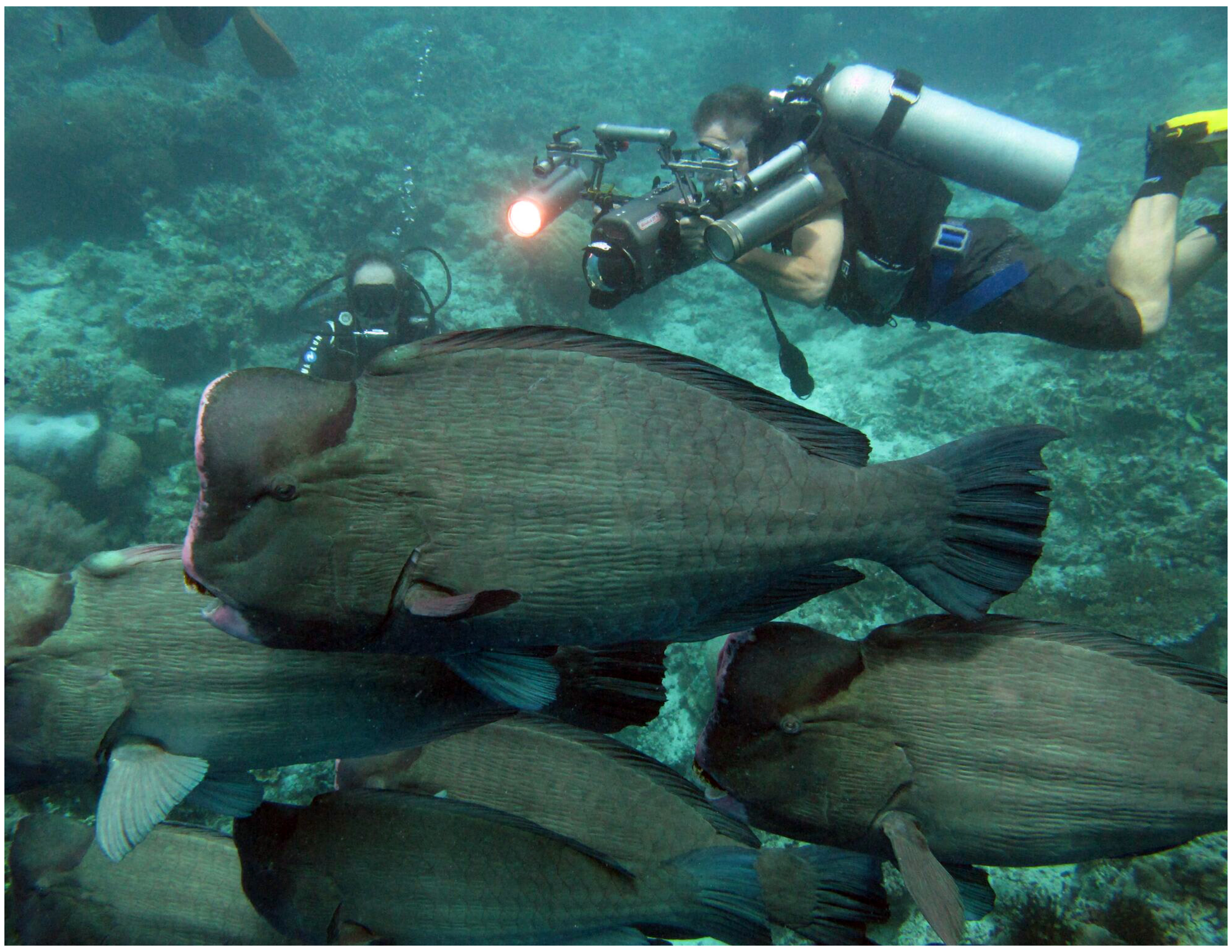
Source: Aquaculture Research and Development Data, Fisheries Division, 2011 (Unpublished).

Trochus aquaculture


175°W
174°W
19°S
20° S
21°S
Neiafu
Vava'u
Ha'apai
Pangai
TONGA
Nuku'alofa
Tongatapu
Ohonua
Eua
TOURISM
Dive sites (heatmap)
Hotels with marine activities (heatmap)
Dive sites
Hotel with marine activities
Marina and wharfs
Port of call
Airport
Yacht anchorage
Populated places
Passenger vessels (over 200 ft long)
Capital city
Whale watching boundaries
Road
15
30 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Burke et al, 2011; Claus et al, 2016; Diving Vava'u Islands, 2017; Google Earth V 7.1.5.1557, 2017; Ministry of Tourism, Tonga; Naia, 2017; Natural Earth, 2017; Smith and Sandwell, 1997; Ports Authority Tonga, 2017; Vava'u, Ha'apai, Tongatapu, Niu Cruising Guide, 2017; World Port Source, 2017.

BEYOND THE BEACH: MARINE TOURISM

"The true South Pacific" is Tonga's tourism slogan. Many tourists take this slogan to heart and come to Tonga to see the true South Pacific, with all its wonders both above and below water.



Humphead parrotfish can grow to a length of 1.3 metres and are one of the many underwater tourist attractions in Tonga.

One of these wonders, whale watching, attracts close to 15 million visitors globally and is worth over US$1 billion per year, a figure that continues to grow. About 17 per cent of global whale watching occurs in the Pacific and most of this happens in Tonga. It is estimated that humpback whales may be worth in excess of US$700,000 annually as a tourism attraction, with a huge potential to boost Tonga's tourism industry.

As such, Tonga is serious about taking a lead on this marine tourism activity. It successfully hosted the Whales in a Changing Ocean Conference in April 2017, for example, which resulted in the adoption of the first Pacific Whale Declaration, already signed by 11 SPREP members. It is interesting to see how whale hunting, prevalent in Tonga only a few decades ago, has shifted to whale watching and conservation, contributing to Tonga's marine tourism that brings in TOP 9 million to the economy every year (Salcone et al., 2015).

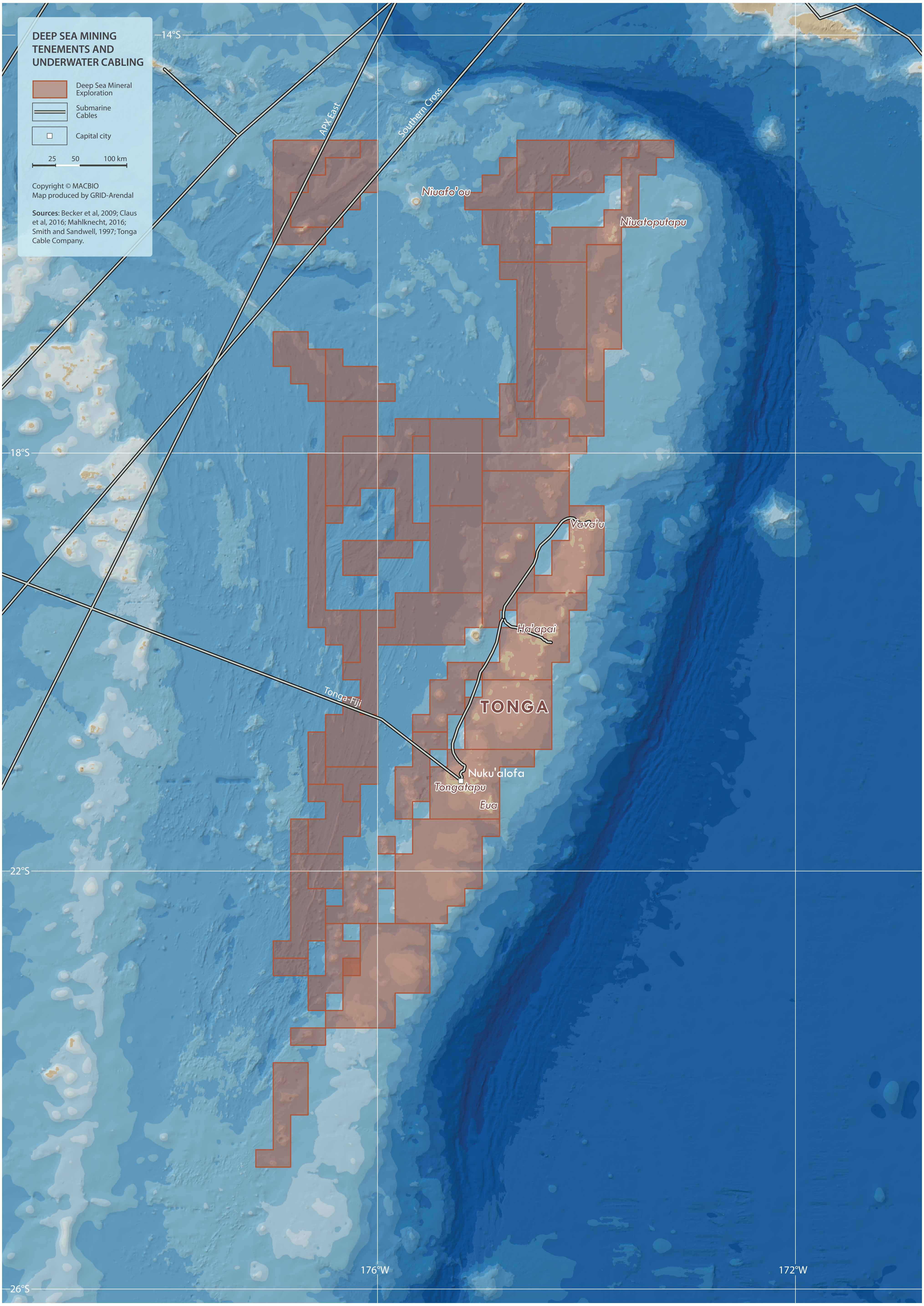
Tourism is important to Tonga, with approximately 30,000 holidaymakers per year (Tonga Tourism Statistics Report, 2012–2013). It has been estimated that the gross value of tourism is worth about TOP 29.2 million per year to the Tongan economy (Salcone et al., 2015). This makes it more valuable than the fishing sector.

The majority of tourists, approximately 18,000, come to Tonga by plane through Fua'amotu International Airport on the main island of Tongatapu. Direct flights are available from Australia, New Zealand and Fiji. The main tourist hub of Vava'u is serviced by the Lupepau'u International Airport, providing access to some 34 islands. Additional airports operated by Tonga Airports Limited are found on the islands of Ha'apai, 'Eua, Niuatoputapu and Niuafo'ou.

Cruise ships, ferries and yachts are moving tourists through Tonga's waters. In 2018, there were 19 scheduled port visits by cruise ships, with the ports of Vava'u and Nuku'alofa being the main ports visited. Approximately 10,000 visitors arrive per year via cruise ships, making this a significant sector of the tourism industry in terms of number of people (Tonga Tourism Statistics Report, 2012–2013). However, cruise ship visitor expenditure is relatively low compared with other visitors—TOP 97 per cruise ship visitor in contrast to TOP 1,383 for airline visitors. Additionally, Tonga is a key destination for cruise yachts, with approximately 2,000 visitors per year arriving by yacht.

Tonga is also popular with dive tourists. For example, 30 per cent of tourists surveyed indicated that scuba diving either strongly influenced or was their primary reason for visiting Tonga (Salcone et al., 2015). Tonga is one of a few places in the world where dive tourists can dive with whales. Every year, between July and October, humpback whales arrive in Tongan waters from their feeding grounds in the Antarctic. The whales give birth and then perform courting rituals. Many companies offer the opportunity to swim and dive with the whales, making them an important asset for marine tourism.

Marine tourism in Tonga takes advantage of its natural beauty and amazing wildlife. The success of the tourism sector is thus reliant on these natural resources being well managed for the future.

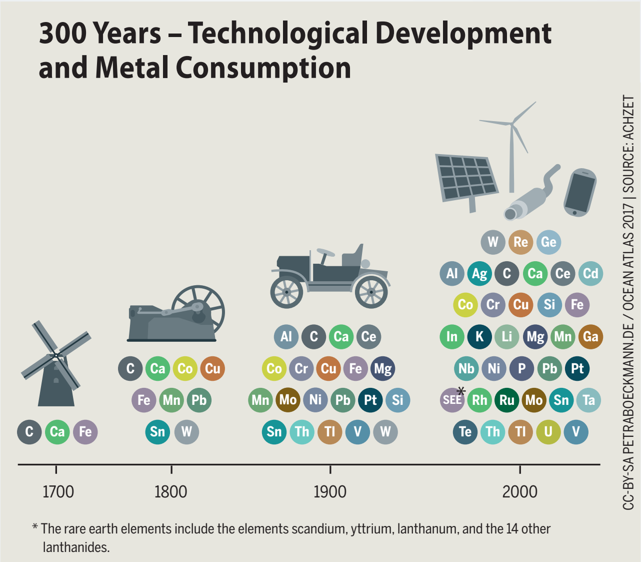

DEEP SEA MINING TENEMENTS AND UNDERWATER CABLING
Deep Sea Mineral Exploration
Submarine Cables
Capital city
25 50 100 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Claus et al, 2016; Mahlknecht, 2016; Smith and Sandwell, 1997; Tonga Cable Company.
14°S
18°S
22°S
26°S
176°W
172°W
APX East
Southern Cross
Tonga-Fiji
Niuafo'ou
Niuatoputapu
Vava'u
Ha'apai
TONGA
Nuku'alofa
Tongatapu
Eua

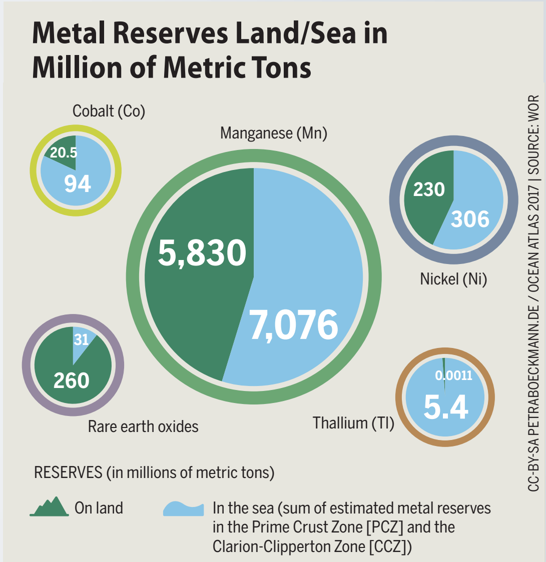
UNDER WATER WILD WEST: DEEP SEA MINING AND UNDER WATER CABLING

Tonga's sea and coasts are rich in deep-sea minerals, petroleum, sand and gravel. These all need to be sustainably managed and a balance found with other, overlapping values and uses.

Gold rush

Is Tonga about to experience a gold rush, like California did in the 1850s, when over 300,000 people rushed to the Wild West with dollars signs in their eyes? While Tonga's wild west may be rich in many ways, gold is much scarcer. Instead, Tonga's gold rush could take place underwater to satisfy the world's hunger for minerals, given that many metal reserves are found in the sea (see graphic).

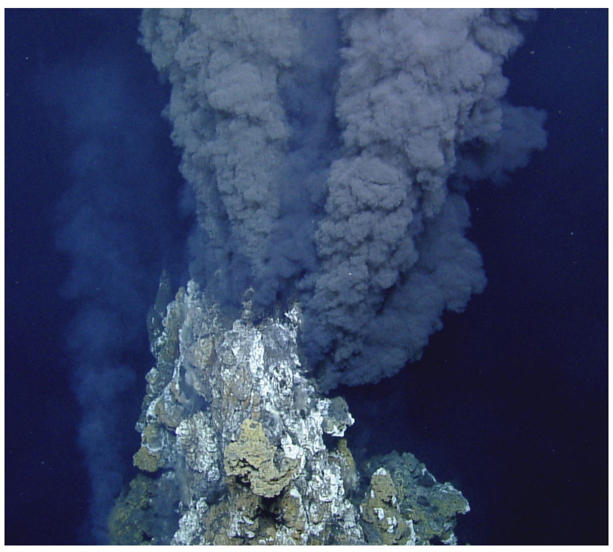




There are three main types of deep seabed mineral deposits found throughout the Pacific Ocean basin, including in the maritime jurisdictions of many Pacific Island countries: sea-floor massive sulfides, polymetallic manganese nodules and cobalt manganese crusts (rich in platinum and rare earth elements). Due to limited opportunities for economic growth in Pacific Island countries, there is considerable interest from the leaders of these nations to develop this as a potential new industry to boost their economic development. Deep-sea mineral mining still entails significant uncertainty and knowledge gaps with regard to resource potential, technology, economic viability and social, cultural and environmental impact (World Bank, 2017).

The Kingdom of Tonga is the first country in the Pacific and in the entire world to have enacted a law (and related regulations) on deep-sea mining in its waters. Tonga's Seabed Minerals Act 2014 positions Tonga at the forefront of good governance for this emerging new industry.

The main seabed mineral resources found in Tonga are sea-floor massive sulfides. This resource is often associated with submarine volcanoes or areas with volcanic activity known as hydrothermal vents (See also chapter "Smoke underwater, fire in the sea"). The known areas of volcanic activity and hydrothermal vents are around the islands and to the west of the islands. These are the areas over which exploration leases have been established.

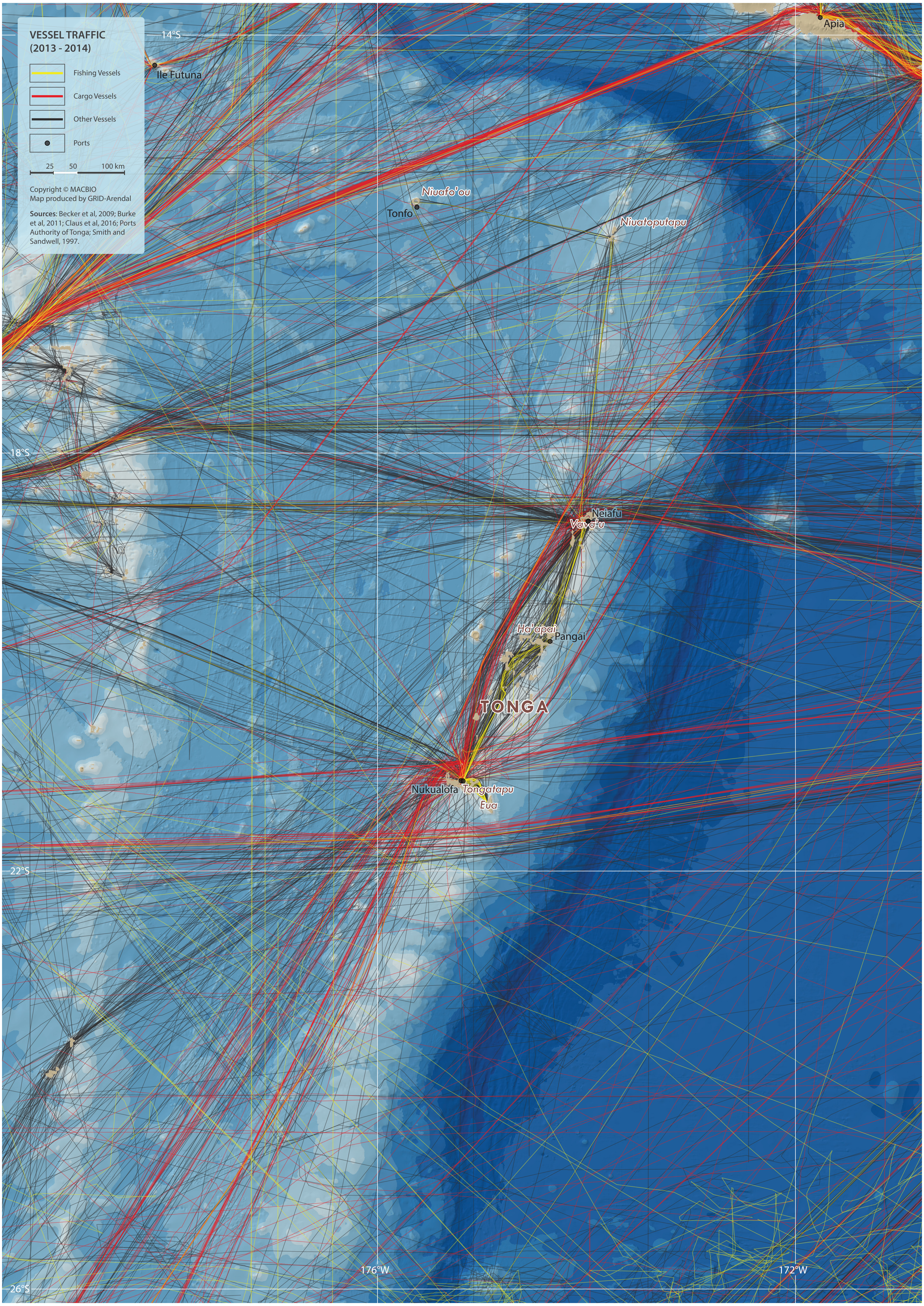


Hydrothermal vent deposits

But Tonga is still waiting for its gold rush, as the mining companies are still undertaking exploration and collecting samples to estimate the magnitude of seabed mineral deposits. In 2008, Nautilus Minerals Tonga conducted the first deepwater commercial sea-floor mineral resources exploration programme in Tongan waters (Nautilus Minerals Incorporated, 2011). Nineteen highly prospective sea-floor massive sulfide sites were identified, with eight of these in the northeast Lau Basin and the other 11 around the Valu Fa Ridge. There are currently three exploration companies with valid permits and licences to undertake exploration and prospecting for seabed minerals in Tonga territorial waters. Between these, they have a total of 34 exploration tenements (see map).

There are other commercial activities that utilize the sea floor. One of the main ones presented on the map is submarine communication cables. The Tonga–Fiji cable is a fibre-optic cable that connects the Tongan capital of Nuku'alofa with Suva and the rest of the world. This cable is an important link for modern communications. Recently, a domestic extension of this cable was approved by the Tongan government, which will see the cable extended between Tongatapu and Vava'u, with a branch to Ha'apai. Additionally, several other submarine communication cables run through the Tongan EEZ, including the Southern Cross and APX-East cables, which link across the Pacific Ocean.

These different and overlapping uses clearly need to be well planned and managed. Since sea-floor massive sulfides, in particular, are found on and close to hydrothermal vents, which are biodiversity hotspots (see also chapter "Smoke underwater, fire in the sea"), deep-sea mining raises questions about its potential environmental impacts. Since deep-sea mining is a relatively new field, the complete consequences of full-scale mining operations on this ecosystem are unknown. Direct risks include disturbances to the benthic layer, increased toxicity of the water column and sediment plumes from tailings with unknown long-term effects, while indirect risks are leakage, spills and corrosion. As mining involves the extraction of a non-renewable resource, it should be managed using the precautionary approach and, technically, cannot be considered sustainable. Given the limited scientific knowledge and high demand for technology in exploring and mining deep-sea areas, marine-based mineral extraction should be treated with caution. Equally, sand and gravel mining, as well as petroleum exploitation, comes with risks that need to be managed. Finally, cable routes have to avoid hazardous conditions and sensitive marine areas, such as deep-sea vents and seamounts.


VESSEL TRAFFIC
(2013 - 2014)
Fishing Vessels
Cargo Vessels
Other Vessels
Ports
25 50 100 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Burke et al, 2011; Claus et al, 2016; Ports Authority of Tonga; Smith and Sandwell, 1997.
14°S
18°S
22°S
26°S
176°W
172°W
Ile Futuna
Apia
Niuafo'ou
Tonfo
Niuatoputapu
Neiafu
Vava'u
Ha'apai
Pangai
TONGA
Nukualofa
Tongatapu
Eua

THREATS

FULL SPEED AHEAD: VESSEL TRAFFIC

Tonga's waters are a highway for thousands of domestic and international vessels that are lifelines for many Tongans, who rely on regular delivery of important goods and food items. Minimizing potential environmental and safety risk is a high priority for all.

Pōpao and Kalia

Although traditional Polynesian navigation and seafaring is rarely used today, there are some organizations around Tonga and throughout Polynesia that still keep the tradition alive. They have built replicas of the old kalia-style vessels. Some of these vessels are used for tourism, offering sailing cruises, while others are manned without the use of modern technology to try to understand what it would have been like without modern navigation and to revive traditions that would otherwise be lost.

The pōpao is the Tongan outrigger canoe, one of the smaller vessels of Polynesian navigation. The canoe's hull is carved out of a tree trunk and sticks (sometimes made out of bamboo) are usually used for the cross beams that connect the outrigger or smaller hull. The canoes were built to hold 1–2 people and were used primarily for fishing.

Voyaging canoes improved over time; however, the largest of them all was the Tongan kalia. In the late eighteenth century, the kalia, a double-hull voyaging canoe up to 35 metres in length, was built. The hulls were of unequal length with a movable, single mast. They were known to carry more than 100 men and today, they are thought to have been the fastest Polynesian voyaging vessel around.

Ships coming in and out of Tongan ports, from fishing vessels to cargo vessels, cruise ships and ferries, serve many different purposes. Fishing vessels operate in a range of fisheries, including artisanal and subsistence inshore fisheries and commercial offshore fisheries for tuna and billfish (see also chapters "Fishing in the dark" and "Small fish, big importance").

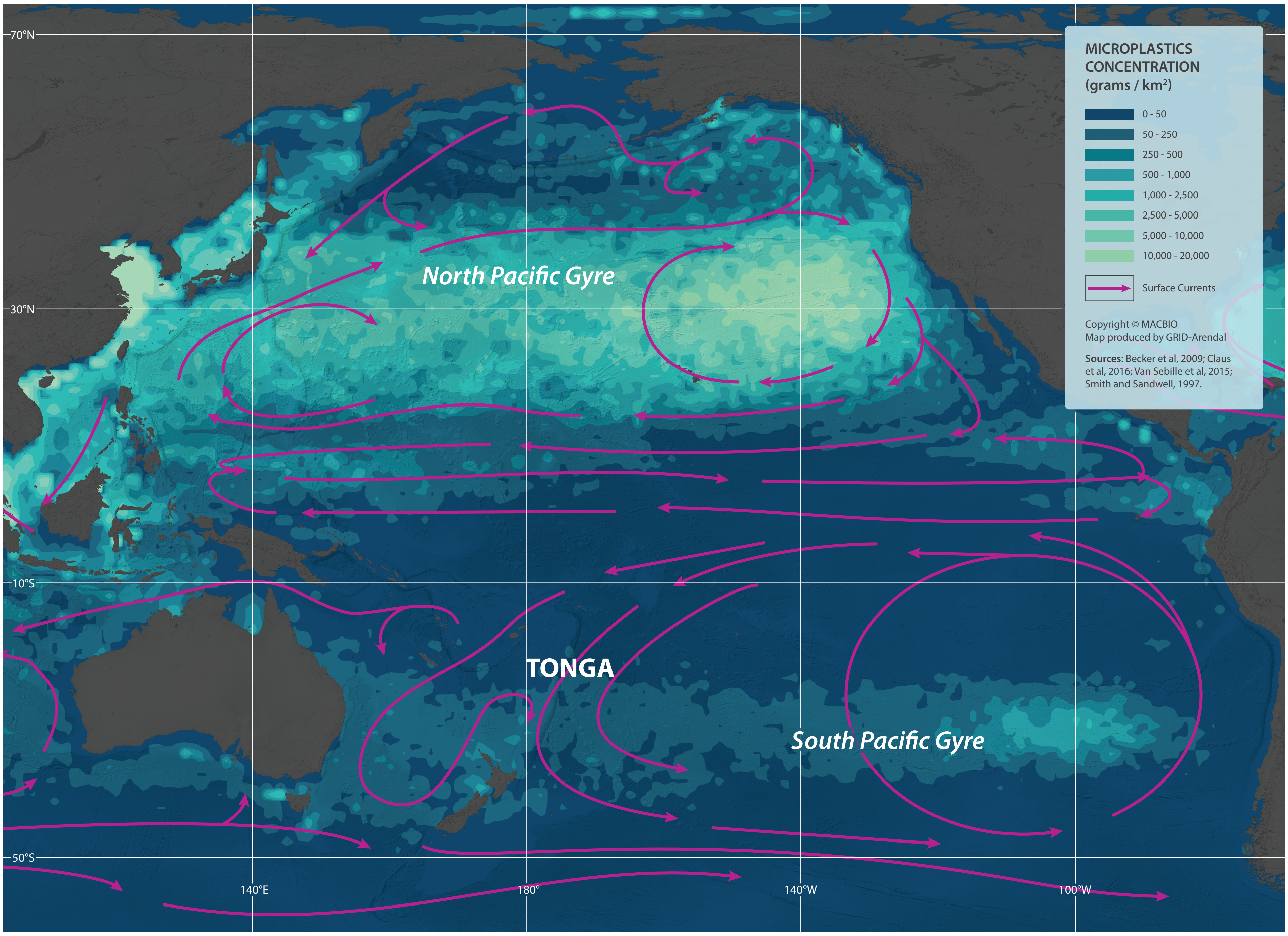
The main cargo vessels operate out of the port of Nuku'alofa, with additional ports at Neiafu (Vava'u) and a small port at Pangai. Shipping of cargo is important to the Tongan economy, both for imports and exports. In 2017, more than 200 ships arrived at the port of Nuku'alofa, with a throughput of over 400,000 tons (Ports Authority Tonga, 2017). Freight arrivals into Tonga have been increasing over the last few years, driven largely by major construction projects. The main commercial shipping routes include routes to other Pacific Island countries, Australia, New Zealand and destinations in Asia.

In addition, cruise ships have been visiting Tonga for quite a while now, with approximately 10,000 passengers arriving per year (Tonga Tourism Statistics Report, 2012–2013). Infrastructure improvements, such as the construction of a new wharf that can accommodate larger cruise ships, are under way to help develop the cruise industry. There are also many yachts cruising Tonga's waters, with Tonga being a key location for boats cruising the Pacific (see also chapter "Beyond the beach").

From the map of different types of vessels criss-crossing Tonga's waters, it is clear that MSP is key not only for navigational safety, but also to minimize conflicts with Tonga's many other marine values that are threatened, be it by fishing or oil spills. Sustainable forms of sea transport are being explored to avoid the negative impacts of oil transporters, and shipping emissions in general, and to decrease Tonga's fossil fuel dependence. As a seafaring nation, Tongans can look to their ancestors, who were advanced sailors following the stars in their traditional canoes, for inspiration

PLASTIC OCEAN: MICROPLASTICS CONCENTRATION

Like the rest of the world's oceans, Tonga's waters are overflowing with plastic. Only 5 per cent of plastics are recycled effectively and forecasts expect that by 2050 there will be more plastic than fish in the world's ocean.



The world produces 300 million tons of plastic each year. About 2 per cent of it—around 8 million metric tons—ends up in the ocean. It is a staggering amount, yet only 1 per cent of this plastic is actually found on the surface of the ocean. Half of this 1 per cent becomes caught in large gyres (see map); the other half is more widely dispersed. The other 99 per cent (7.92 million metric tons) of plastics in the ocean worldwide are unaccounted for each year.

Science has only just begun to unravel the riddle of where this unaccounted-for plastic ends up. At the turn of the millennium, scientists uncovered a previously unknown phenomenon: microplastic. Eighty per cent of plastic waste enters the ocean via rivers and the other 20 per cent is tossed overboard from ships (see graphic). A portion of the plastic waste is carried great distances by ocean currents and gathers in large trash vortices such as the Great Pacific Garbage Patch in the North Pacific Gyre. On this journey, which can take up to 10 years, large pieces of plastic are progressively eroded, broken down by sunlight and eaten by bacteria, fragmenting into many smaller pieces. The result is microplastic—plastic particles that are smaller than 5 millimetres.

Thus, the Great Pacific Garbage Patch is not the massive islands of trash that one might first imagine. Large bits of plastic are relatively rare, and one could actually swim through a gyre without noticing the microplastic that composes it. The remaining 99 per cent of the waste that begins its journey on the coasts never reaches garbage patches. It also breaks down into microplastic and disperses through the ocean, before finally sinking into the depths. In fact, the plastic concentration on the ocean floor is 1,000 times greater than on the surface. In light of this, Tonga's comparably low concentration of microplastic at the ocean surface (see the map) is not necessarily good news.

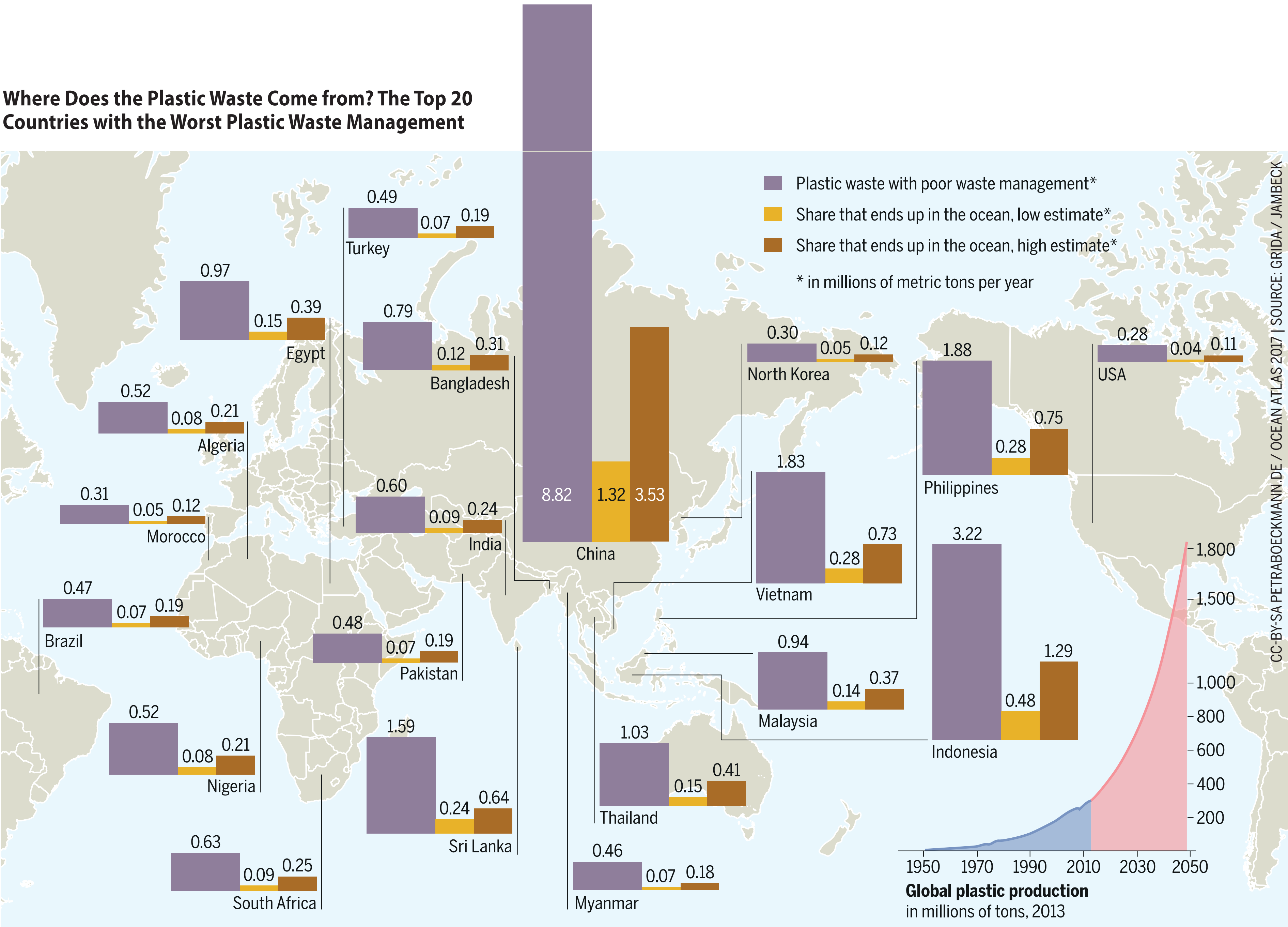
Litter in the deep

As we know, the second deepest part of the world's oceans is the bottom of the Tonga Trench. You wouldn't expect to find signs of civilization at this depth, would you? Yet just as plastics and other types of pollution are affecting the shallow waters of the marine environment, so they are the deepest marine trenches. In March 2017, scientists discovered a container of Spam at 4,947 metres on the slopes of a canyon leading to the Sirena Deep in the Mariana Trench. This is symbolic of how pollution can penetrate even the deepest marine environments, such as the Tonga Trench. (The Guardian, 2017)

The microplastic is trapped on the ocean floor, embedded in the sediment. It is gradually forming a new geological layer, the "plastic horizon", which researchers of the future will attribute to our era. The sad truth is that we use the deep sea as a gigantic dustbin and benefit from the fact that the majority of the waste seemingly disappears forever, rather than washing up at our feet again.

While the portion of microplastic that remains afloat may seem small, it is the cause of a large problem with far-reaching effects. It is no wonder that fish mistake microplastic for plankton and eat it, since there is six times as much plastic as plankton in some parts of the ocean. Very small pieces of plastic can penetrate the fish's intestinal walls and become trapped in the surrounding tissue. The microplastic then enters the food chain and eventually winds up on our plates and in our own stomachs. The consequences of consuming microplastic have yet to be studied—after all, microplastic itself has only been a research topic since 2007. One finding is already cause for concern: the surface of microplastic acts like a sponge that soaks up toxins, including environmental poisons such as PCB and disease-causing germs, helping them spread and threatening entire fish populations.

Where Does the Plastic Waste Come from? The Top 20 Countries with the Worst Plastic Waste Management



How Does All That Plastic Get Into the Ocean?

1. *A poor waste management/recycling system (or none at all) is the leading cause.*
2. *Plastic garbage from cities and industrial centers flows directly into rivers and seas with untreated wastewater.*
3. *Microplastic used as additives in cosmetic products is not filtered out by water treatment plants.*
4. *Fishing nets and lines lost or intentionally abandoned at sea.*
5. *Lost loads and ship materials.*
6. *Garbage illegally dumped at sea.*
7. *Catastrophic waste: wreckage and garbage swept out to sea by hurricanes, floods, and tsunamis.*

Once plastic gets into the ocean, there is currently no way to retrieve it. Most becomes microplastic, which is so small that filtering it out of the water would filter out the aquatic life as well and would still leave larger pieces of plastic that are dangerous to larger animals. Many technical solutions aimed at ocean cleanup are under development and must consider the ecological consequences as well as the benefits. For instance, plans to scoop rubbish out of large areas of the sea could unintentionally catch fish and other organisms. The benefits must therefore be compared with the resulting damages.

The solution to the problem actually lies on dry land: on coasts and river deltas, at markets and in households. The good news is, it is within our grasp. As a significant portion of the plastic waste in the ocean comes from the packaging and products we use, we can have a direct influence by changing our consumption patterns. Governments can also ban the use of microplastics in cosmetics. But the most effective step that we can take is to build a globally functioning recycling economy, or circular economy, so that fewer new plastics are created and fewer are disposed of in an uncontrolled manner. Political engagement is a powerful lever for setting the right incentives for change, and developing a circular economy is just a matter of political will.

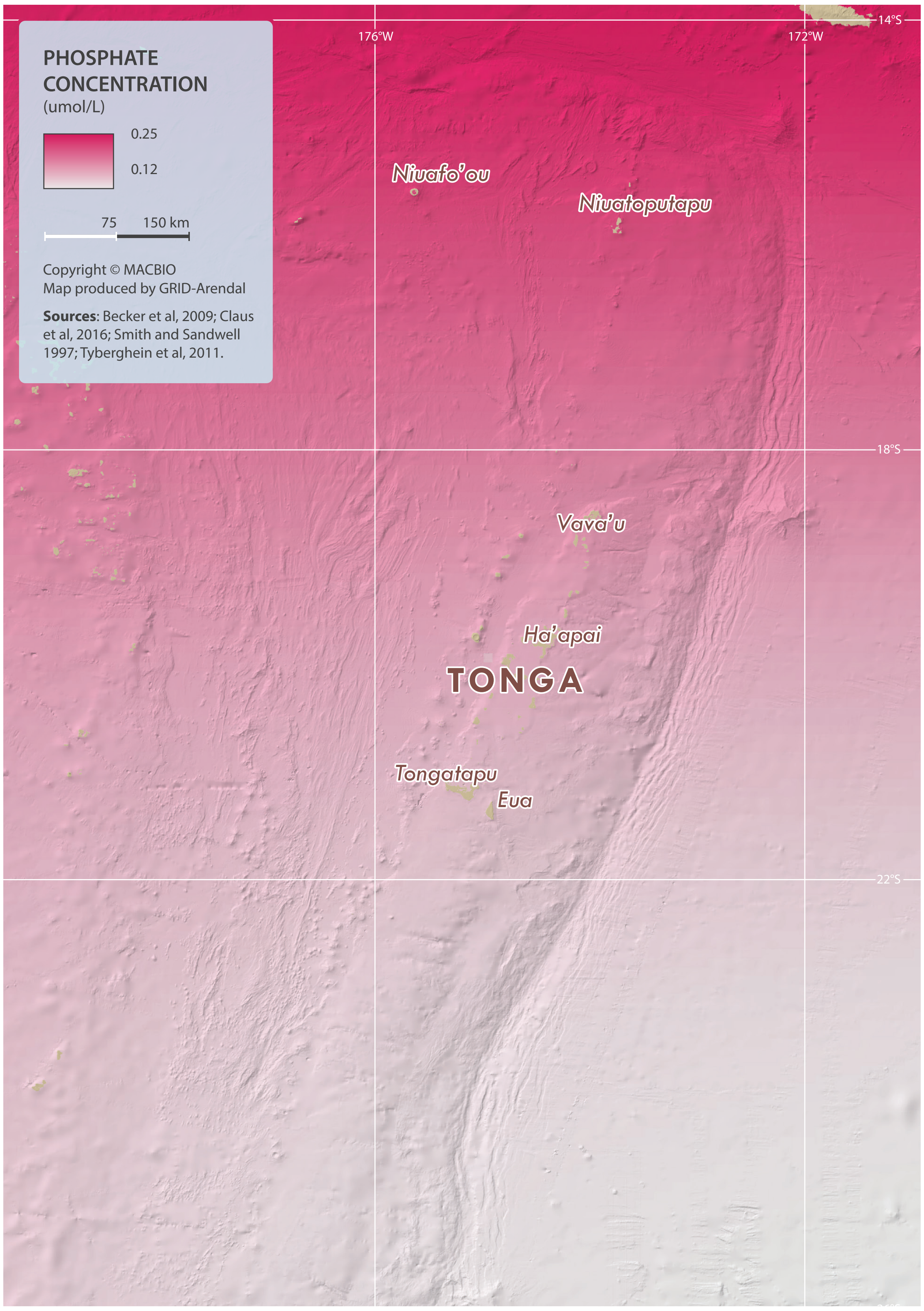
As a first step, many Tongans are involved in coastal cleanup activities, helping keep Tonga's waters from turning into a plastic ocean.

THE DOSE MAKES THE POISON: PHOSPHATE AND NITRATE CONCENTRATION

While nutrients including phosphate and nitrate provide much-needed nutrients for the marine food chain, too much from agricultural run-off and other sources negatively affect Tonga's coastal ecosystems.

On a global scale, Tonga's waters have a moderately low phosphate concentration, ranging from 0.13 to 0.24 umol/L. Higher concentrations of phosphate are observed in the northern waters and gradually decrease to the south. Moreover, nitrate concentrations in seawater are generally low, with the highest concentrations found in high latitudes and some areas of coastal upwelling. Within Tonga's waters, the nitrate concentration ranges from 1.1 to 1.5 mmol m-3, with the highest concentrations in the south-west, but the South-West Tropical Pacific (SWTP) is generally considered a nitrogen-limited area.

Phosphate and nitrate concentrations are higher in the waters close to the main islands due to land and coastal inputs, which can include inorganic fertilizers, wastewater treatment from municipal sources, and soaps and detergents. This is where the dose makes the poison: while phosphate and nitrate are important nutrients, too much of them can be bad for marine and coastal ecosystems. In Tonga's waters, there is certainly no shortage of sun, and thus photosynthetically available radiation, but there is a general limit of phosphate and nitrate. Once these nutrients are added from the land-based activities such as farming and wastewater treatment, primary productivity increases dramatically. The impact of too many nutrients (eutrophication) is especially significant in coastal waters, where increased nutrients can result in algal blooms. These blooms can affect coastal habitats such as coral reefs by smothering, in the case of macro-algae, or limiting light availability, which can lead to rapid declines in reef biodiversity (Fabricius, 2005).



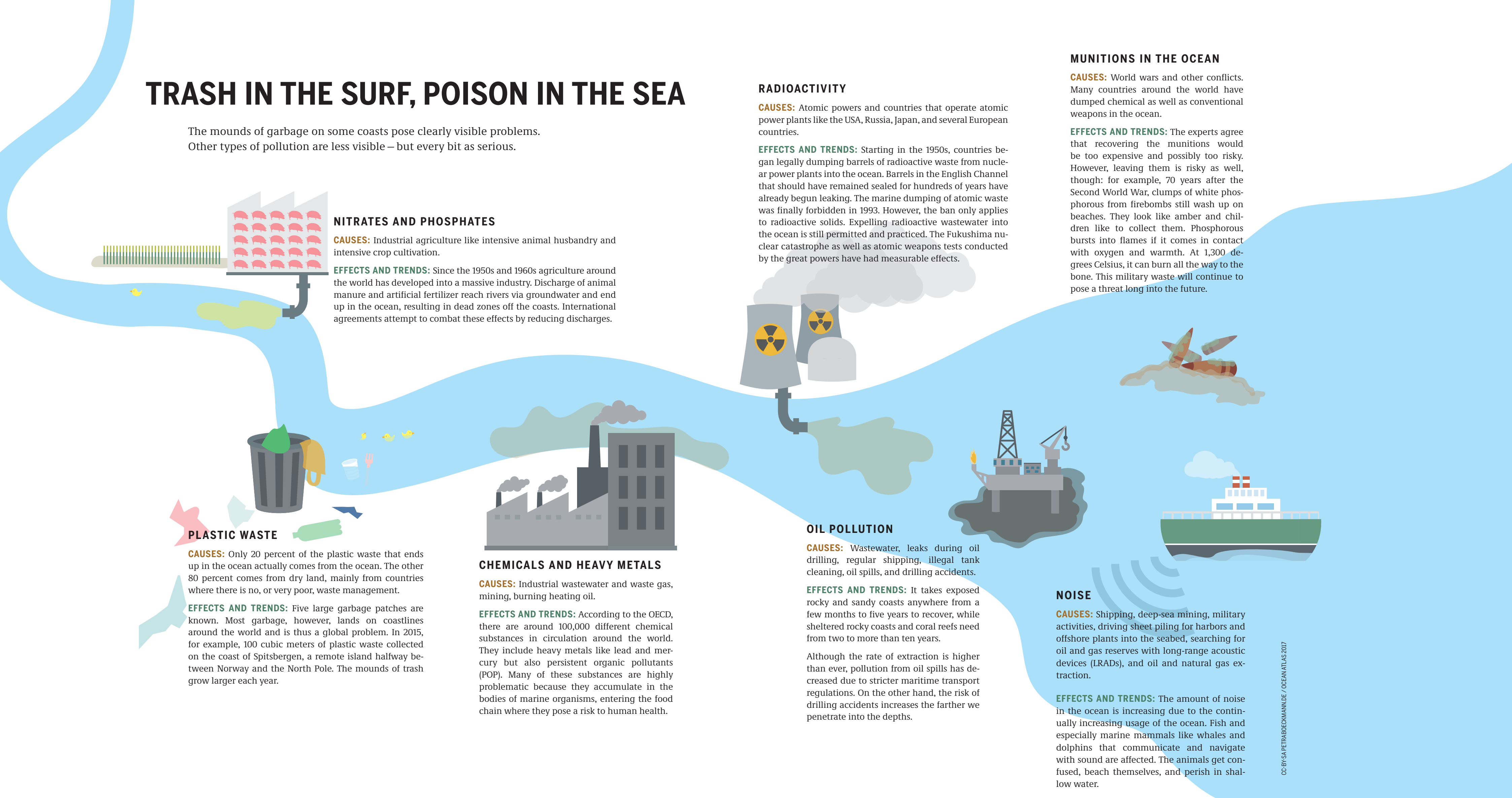
Seafood

"All things are poison and nothing is without poison; only the dose makes a thing not a poison", stated the Swiss physician Paracelsus 500 years ago. And indeed, the dose makes the poison. We need to eat food, but too much food is evidently bad for us.

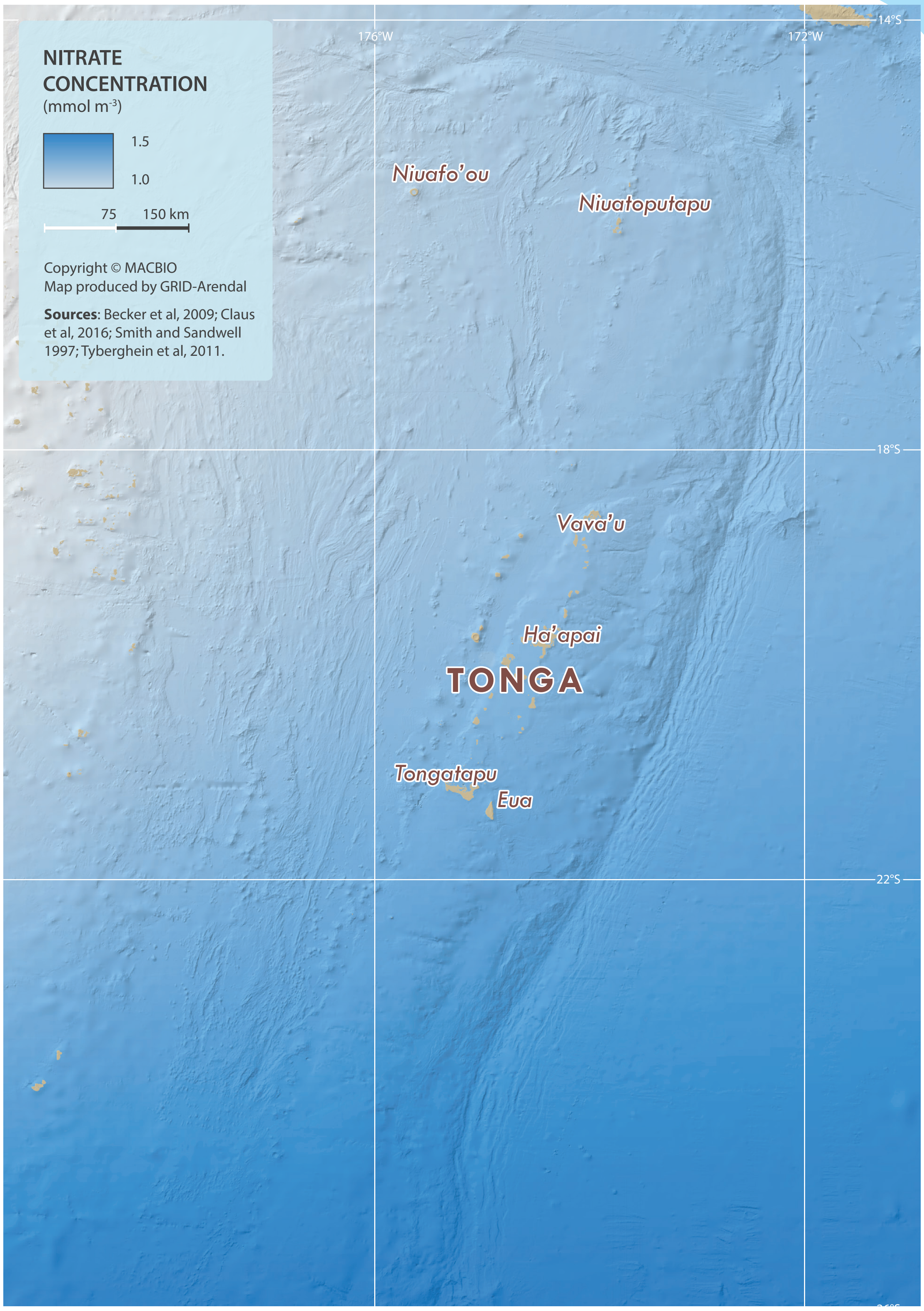
Marine organisms need food and nutrients as well. Phosphate (see map) is one of the important nutrients that supports biological activity and is important for the growth of tiny plants known as phytoplankton, which form the basis of many marine food chains (see also chapter "Soak up the sun").

Another food source is nitrogen (see map), which is present in the marine environment in various forms, with nitrate being the principal form used by organisms. Phytoplankton productivity at the surface of the ocean is often limited by the amount of available fixed inorganic nitrogen (Falkowski et al., 2009). However, where there is too much of these nutrients, algal blooms can occur, which can have negative impacts on the environment.

As the chapters "Plastic oceans", as well as the graphic, show, excess nutrients are only one type



of pollution and threat to Tonga's marine values. To keep Tonga's coastal habitats healthy (see also chapter "Home, sweet home"), it is important to manage both point-source pollution, which comes from a single identifiable source such as a factory, as well as non-point pollution, for example from agricultural run-off. The MARPOL Convention (see also chapter "One world, one ocean") is one international instrument to regulate pollution. MSP can help spatially identify sources and areas of pollution to guide sustainable ecosystem management, ensuring the dose does not make the poison.



CLIMATE CHANGE THREATS

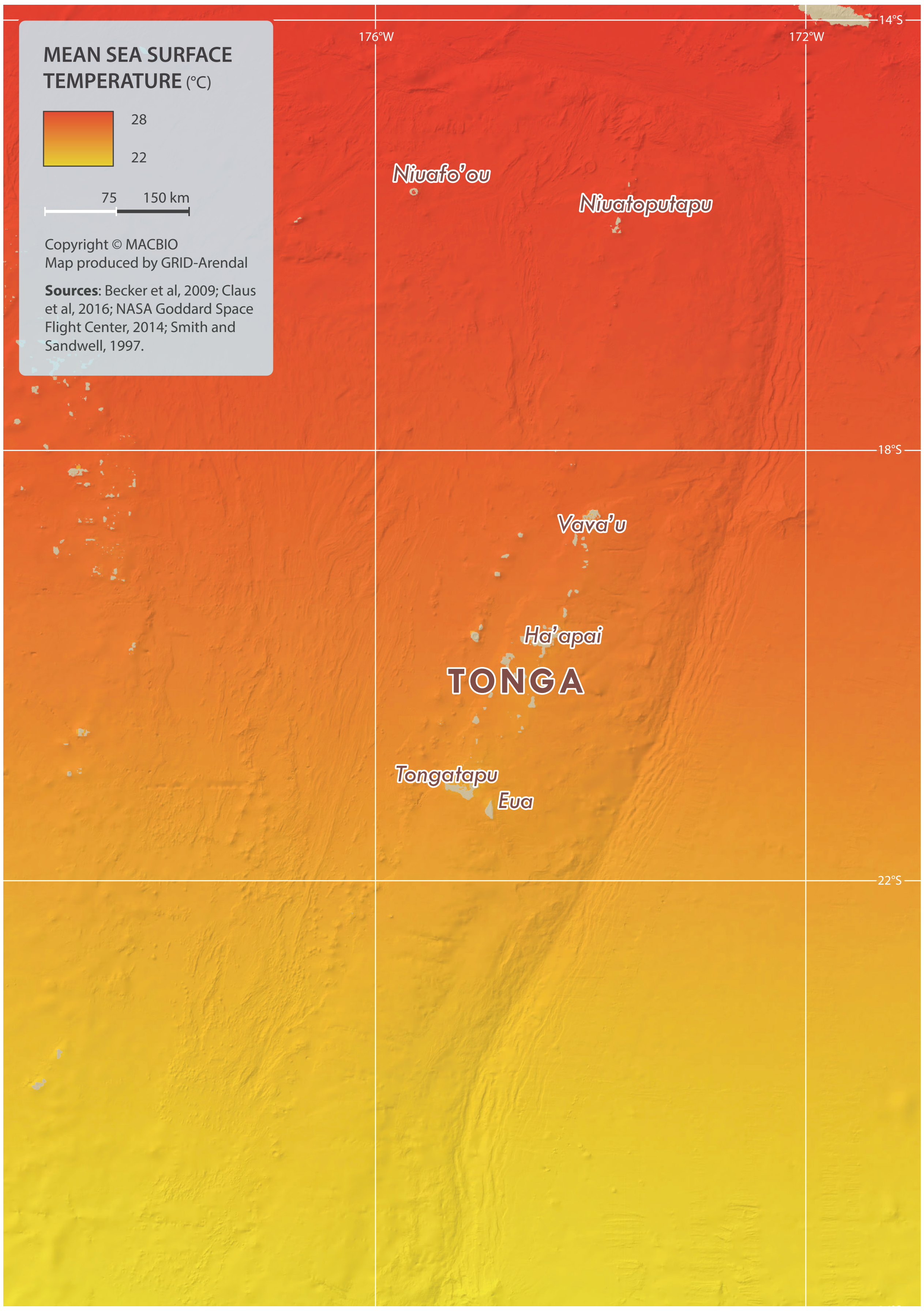
HOTTER AND HIGHER: MEAN SEA SURFACE TEMPERATURE AND PROJECTED SEA LEVEL RISE

Sea surface temperature (SST) is a limiting factor for much marine life. Climate change is leading to higher sea temperatures, as well as sea levels, thus compromising Tonga's marine biodiversity.

The following chapters explain how observed and predicted climate change will affect Tonga's marine values, starting with SST, which is the water temperature close to the ocean's surface. The very hot temperatures in 2012 were not only uncomfortable for humans, but for the ocean's inhabitants too. Warm water holds less dissolved oxygen than cooler water and once the level of dissolved oxygen drops below a critical threshold, fish and invertebrates suffocate. This is especially bad in shallow-water habitats, which can rapidly heat up and lose dissolved oxygen, resulting in thousands of dead fish.

Corals also find hot water uncomfortable. Shallow-water corals grow optimally between 23°C and 29°C, hence they are confined to tropical regions of the globe. When the water temperature falls outside this range, they can become stressed and expel their symbiotic algae (see also chapter "Home, sweet home") in a process known as bleaching. Coral bleaching is an increasing threat to coral reefs in tropical regions and can have a negative impact on ecosystems, fisheries and tourism. An increase in SST of only 1°C for four weeks can trigger a bleaching event. When increased temperatures last for longer periods (eight weeks or more), corals begin to die. This shows how SST is an important factor in the distribution of ocean life, with many species confined to specific temperature ranges.

Moreover, air masses in the Earth's atmosphere are highly modified by SST. Warm SST is known to be a cause of tropical cyclones over the Earth's oceans, with a threshold temperature of 26.5°C being a trigger mechanism (see also chapter "Stormy times"). At the same time, tropical cyclones can also cause a cool wake, due to turbulent mixing of the upper 30 metres of the ocean. SST changes diurnally, like the air above it, but to a lesser degree due to its higher specific heat. There is less SST variation on breezy days than on calm days. In addition, ocean currents can affect SST on multi-decadal timescales. Coastal SST can cause offshore winds to generate upwelling, which can significantly cool or warm nearby land masses, and additionally, shallower waters over a continental shelf are often warmer. Onshore winds can cause a considerable warm-up even in areas where upwelling is fairly constant.



The annual mean SST in Tonga's waters ranges from 23°C in the south to 28°C in the north, as the map shows. Across the year, there is relatively little variation in the SST, with ±4°C in the south and ±1.5°C in the north. Tonga is strongly influenced by the North Tonga and South Tonga Jets, both of which bring warm water westward from the South Equatorial Current, which itself brings warm water from the eastern tropical Pacific Ocean.

Sea level rise has the potential to negatively impact the low-lying coastal areas of Tonga, through flooding and wave inundation, with consequent shoreline erosion and groundwater salinization. These impacts could lead to a loss of infrastructure and productive land, thereby posing a challenge to livelihoods in the region. Improved data

Blame it on the weatherman?

When coastal waters in Tonga heat up during summer, is it just a few hot sunny days or global warming that warms the water way above its average temperature?

To understand this, we need to look at two different things. On the one hand, climate variability, which refers to shorter term (daily, seasonal, annual, inter-annual, several years) variations in climate, including the fluctuations associated with El Niño (dry) or La Niña (wet) events (see also chapter "Go with the flow"). On the other hand, climate change, which refers to long-term (decades or longer) trends in climate averages such as the global warming that has been observed over the past century, and long-term changes in variability (e.g. in the frequency, severity and duration of extreme events) (see also chapter "Stormy times"). There may always be particularly rainy weather, or a particularly hot week. Only by observing trends in the long term can we show how the climate is changing.

and information on sea level rise are necessary in order to plan effectively for these changes.

Sea level rise, as a consequence of global warming, threatens many low-lying regions of the world. The Fifth International Panel on Climate Change assessment projects a global rise in mean sea level for 2081–2100 relative to 1986–2005 of between 0.2 and 0.98 metres, depending on different emissions scenarios. Furthermore, the western tropical Pacific Island region is considered one of the most vulnerable regions under future sea level rise (Nicholls and Cazenave, 2010). Sea level rise is not uniform across the western Pacific and is affected by ENSO events. These have a strong modulating effect on inter-annual sea level variability, with lower than average sea level during El Niño and higher than average during La Niña events (of ±20–30 cm). In addition, there is also an observed low-frequency (multi-decadal) variability, which in some areas adds to the current global mean sea level rise due to ocean warming and ice melting (Becker et al., 2012).

Tonga is a mix of high volcanic islands and low-lying coral atolls. Vulnerability to sea level rise is influenced by coastal geography and prevailing ocean currents. Islands exposed to higher wave energy in addition to sea level rise can experience higher rates of erosion than their more sheltered counterparts. However, the coral atolls of Tonga may be able to adjust their size, shape and position in response to sea level rise, as has been suggested for other reef islands such as Funafuti Atoll in Tuvalu (Kench et al., 2015). Vertical reef accretion that occurs in response to sea level rise may be able to prevent the significant increases in shoreline wave energy and wave-driven flooding that are predicted in the absence of reef growth (Beetham et al., 2017).

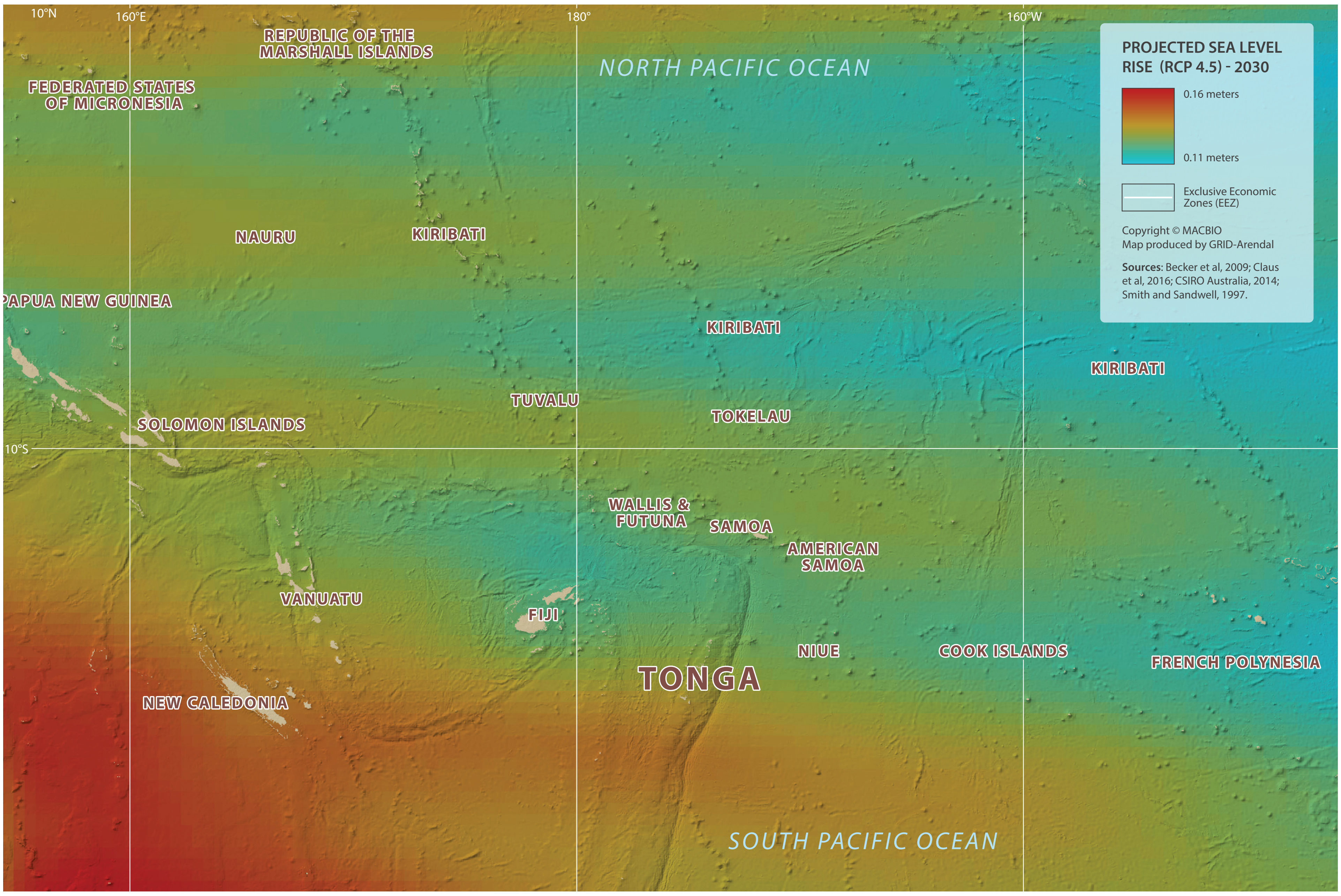
Satellite data indicate the sea level has risen near Tonga by about 6 millimetres per year since 1993, compared with the global average of 2.8–3.6 millimetres per year (Australian Bureau of Meteorology and CSIRO, 2011). The impacts of rising sea level can be compounded by other factors, such as natural disasters. Tonga was identified as the second most-at-risk country for natural disaster, as measured by the World Risk Index (Garschagen et al., 2016). Sea level rise coupled with storm surge during a cyclone can lead to significant inundation of lowlands, damaging coastal infrastructure and property and affecting livelihoods. There is therefore a planning need for coastal infrastructure to take this risk into consideration.

The map indicates that by 2030, Tonga will experience a sea level rise of between 0.14 and 0.16 metres. The southernmost parts of the EEZ will see the largest increase, with predicted sea level rise of 0.15 metres around the main island of Tongatapu.

This is likely to be accompanied by increases in episodes of flooding and wave inundation in some coastal areas, especially in the southernmost islands. Pacific Island nations are therefore focused on developing adaptation strategies to address the predicted continued rise in sea level.

In the past, atolls and islands, which often rise a mere metre above the waves, were only flooded by the ocean every couple of decades. That trend has since changed, with an increased frequency in these flooding events. When these events become too frequent, it makes it difficult for islands to recover. The land becomes too salty, the freshwater reserves in the lagoons become undrinkable and the islands themselves can no longer support human habitation.

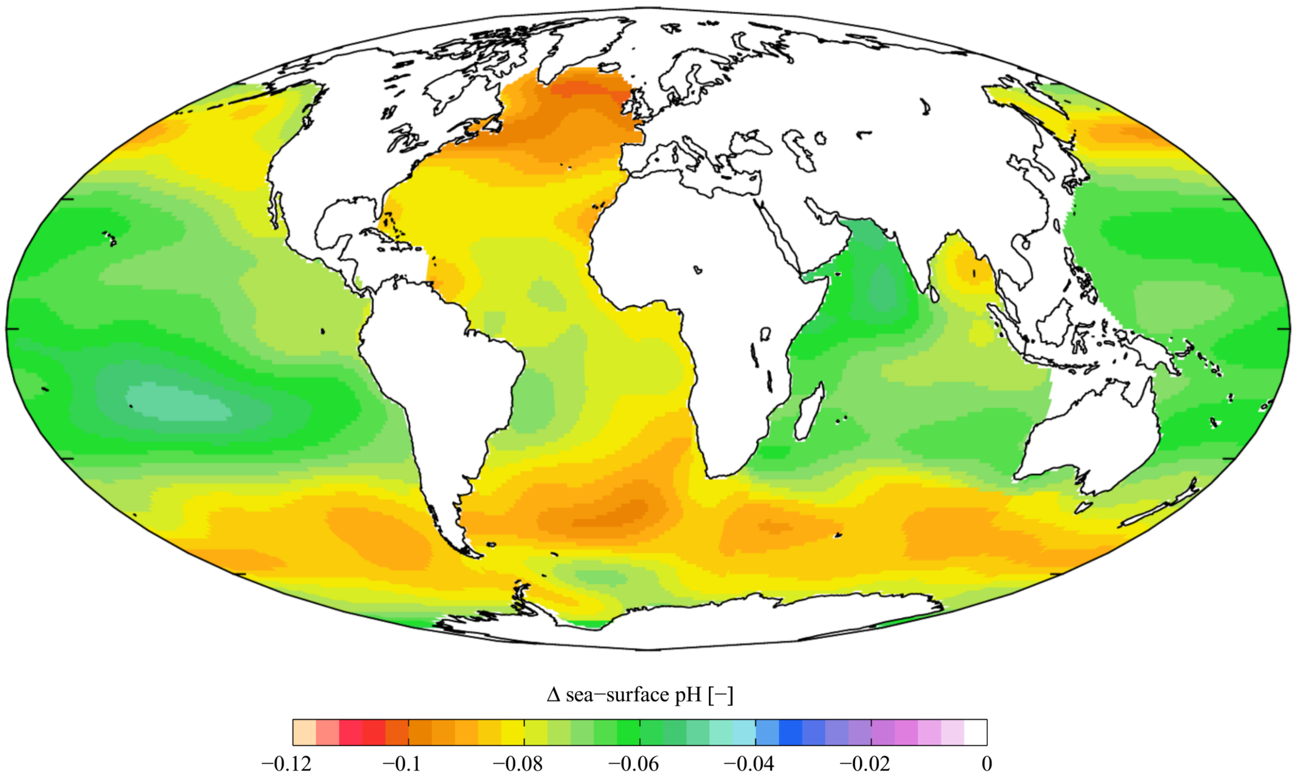
It is becoming clear that in a warming world, Tonga's sea will become hotter and higher, with drastic consequences for coastal habitats and their inhabitants.



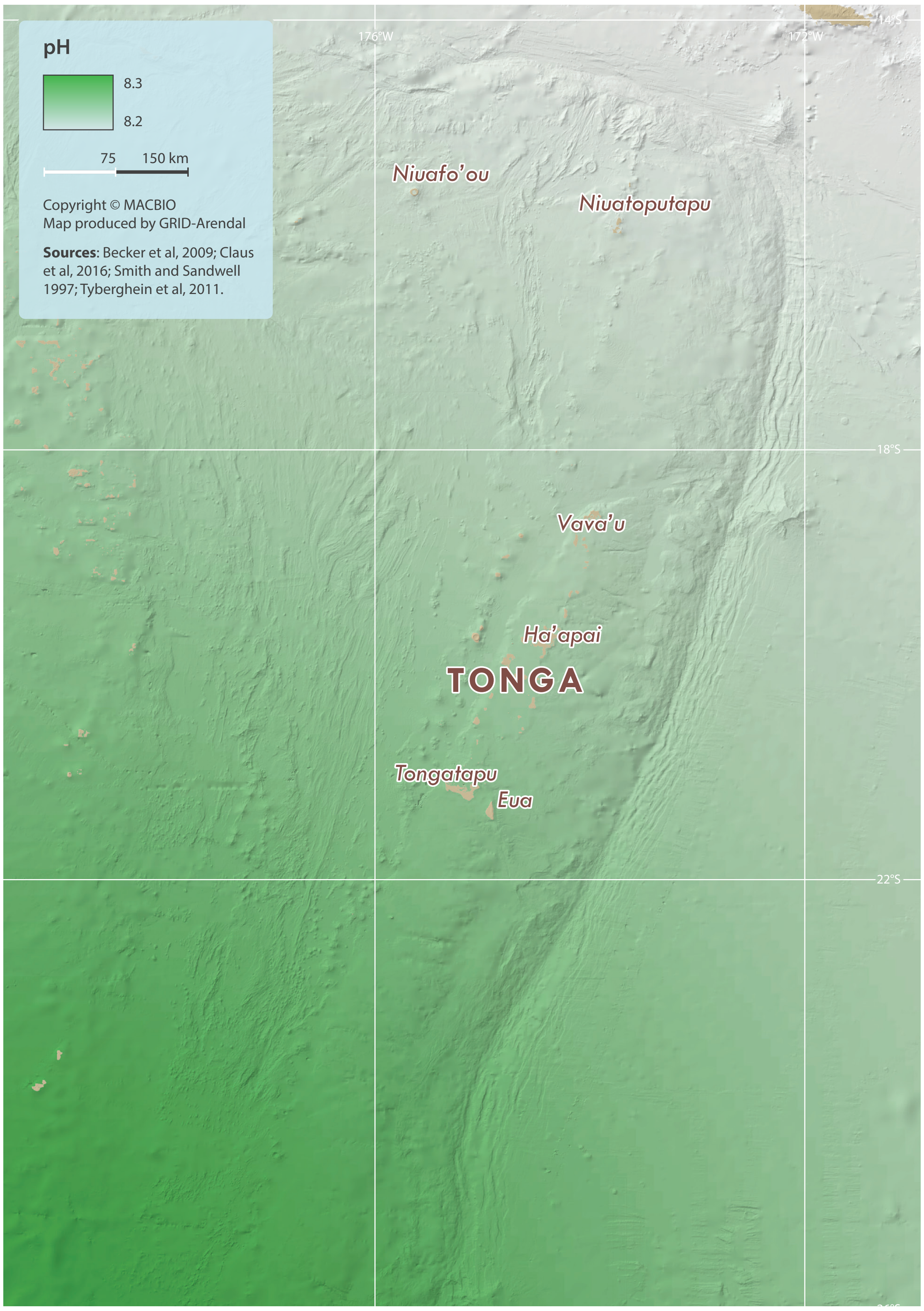
TURNING SOUR: OCEAN ACIDITY

Climate change is not only causing sea temperatures and levels to rise but also its acidity, which causes serious problems for many marine organisms.

Seawater acidity can be measured using the pH, a numeric scale to specify the acidity or basicity of a solution; a pH of 7 is neutral—neither acidic nor basic. A decrease in pH by one means a solution is twice as acidic, whereas an increase by one means a solution twice as basic (see graphic). The pH of the global oceans ranges from around 7.5 to 8.4. Tonga's waters are at the higher end of this range, with pH between 8.25 and 8.29. Increasing CO_2 in the surface water leads to increased acidification (lower pH). Already, CO_2 emissions have resulted in a 26 per cent increase in the acid content in the ocean (see small map).



In this context, it is important to look at calcite, which is another vital element found in seawater (see map on the right), as calcium carbonate is a building block of the skeletons of most marine organisms, including corals. Globally, calcite concentrations are highest in the high latitudes and in coastal areas. The calcite concentrations in Tonga's oceanic waters are low, with the coastal areas around the islands having a higher concentration (see calcite map).



How does acidification affect calcite levels? Firstly, CO_2 in the water transforms into carbonic acid and the carbonate saturation decreases. This is problematic for all animals that use marine carbonate to make their shells, such as mussels, snails, corals and sea urchins, among many others (see also chapter "Travellers or homebodies"). The less carbonate there is in the water, the more difficult it is for them to make suitable shells. The effects can already be seen among foraminifera: tiny calcifying creatures that make up an important part of the plankton. The shell-thickness of animals in the Southern Ocean has noticeably decreased compared with specimens from the pre-industrial period. The effect on oysters is slightly different: it has been observed that the thickness of their shells does not decrease, but only because they invest so much energy into shell production that it stunts their overall growth. This makes them easier prey for predators, such as murex snails.

Ocean acidification

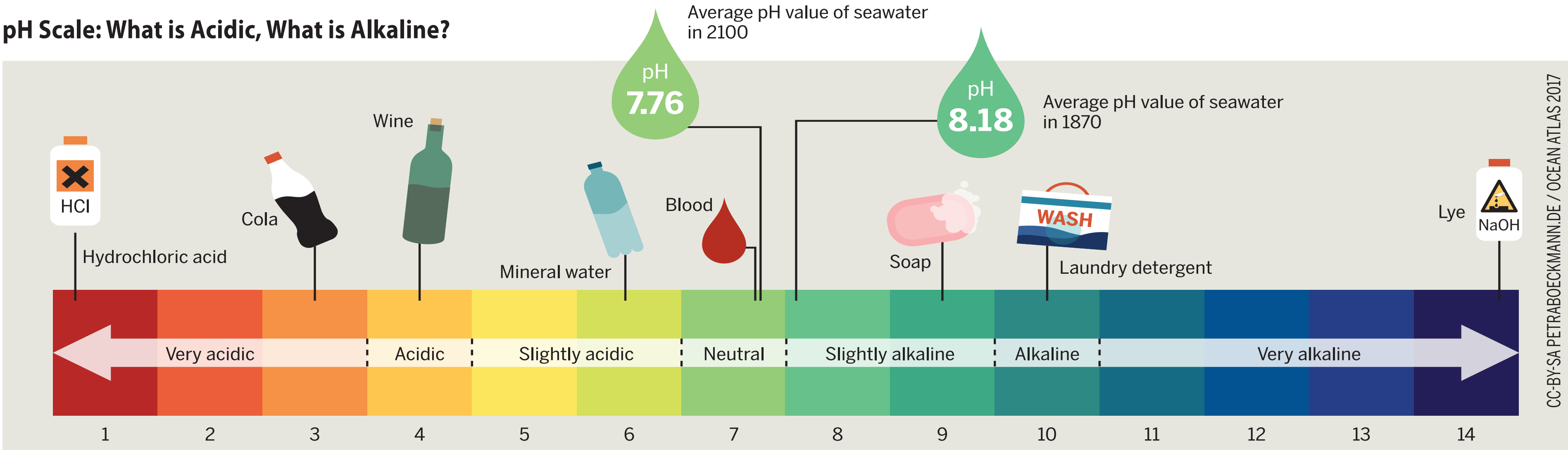
Tonga is suffering the effects of global warming, with greenhouse gas emissions not only heating the nation's sea, but also ending up in it. In fact, worldwide the oceans have absorbed about one third of the carbon dioxide (CO_2) produced by human activities since 1800 and about half of the CO_2 produced by burning fossil fuels (Sabine et al., 2004).

As CO_2 in the ocean increases, ocean pH decreases, resulting in the water becoming more acidic. This is called ocean acidification, the "evil twin" of sea temperature and sea level rise, described in the previous maps.

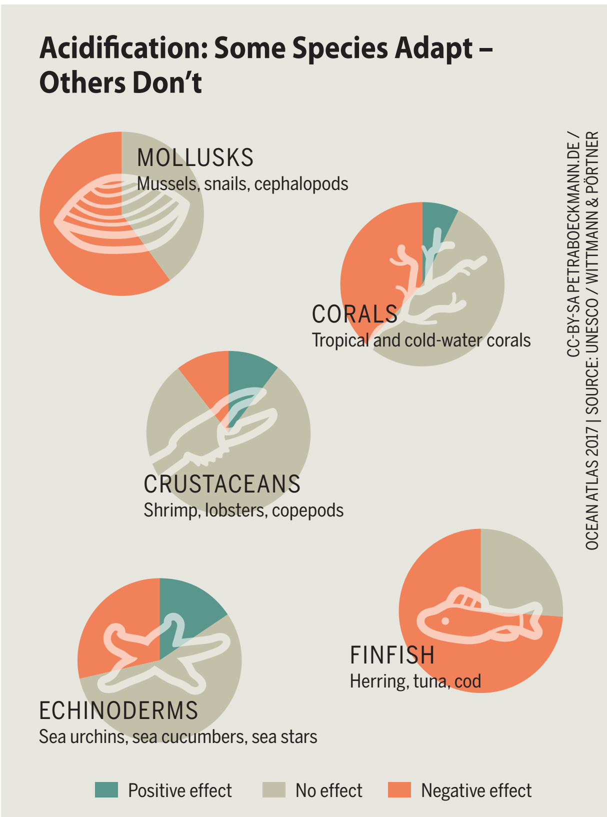
The situation is particularly critical for calcifying species in zones in which carbonate saturation drops too far. In that case, the water actually begins to draw carbonate out of their shells and corrodes them. This is already happening in some regions in Antarctica and in the North Atlantic. The cold-water corals that live there cannot maintain their skeletons and will eventually collapse.

Tonga's shallow-water corals are also affected. For example, it has been predicted that ocean acidity will decrease from a current pH of around 8.3 to a pH of 7.9 by 2100. This level of decrease has been shown to result in a 50 per cent reduction in coral productivity, and increased acidity makes coral bleaching more likely. Moreover, other non-calcium carbonate-skeleton-producing species, such as fish, are threatened, as their eggs can be corroded in more acidic water.

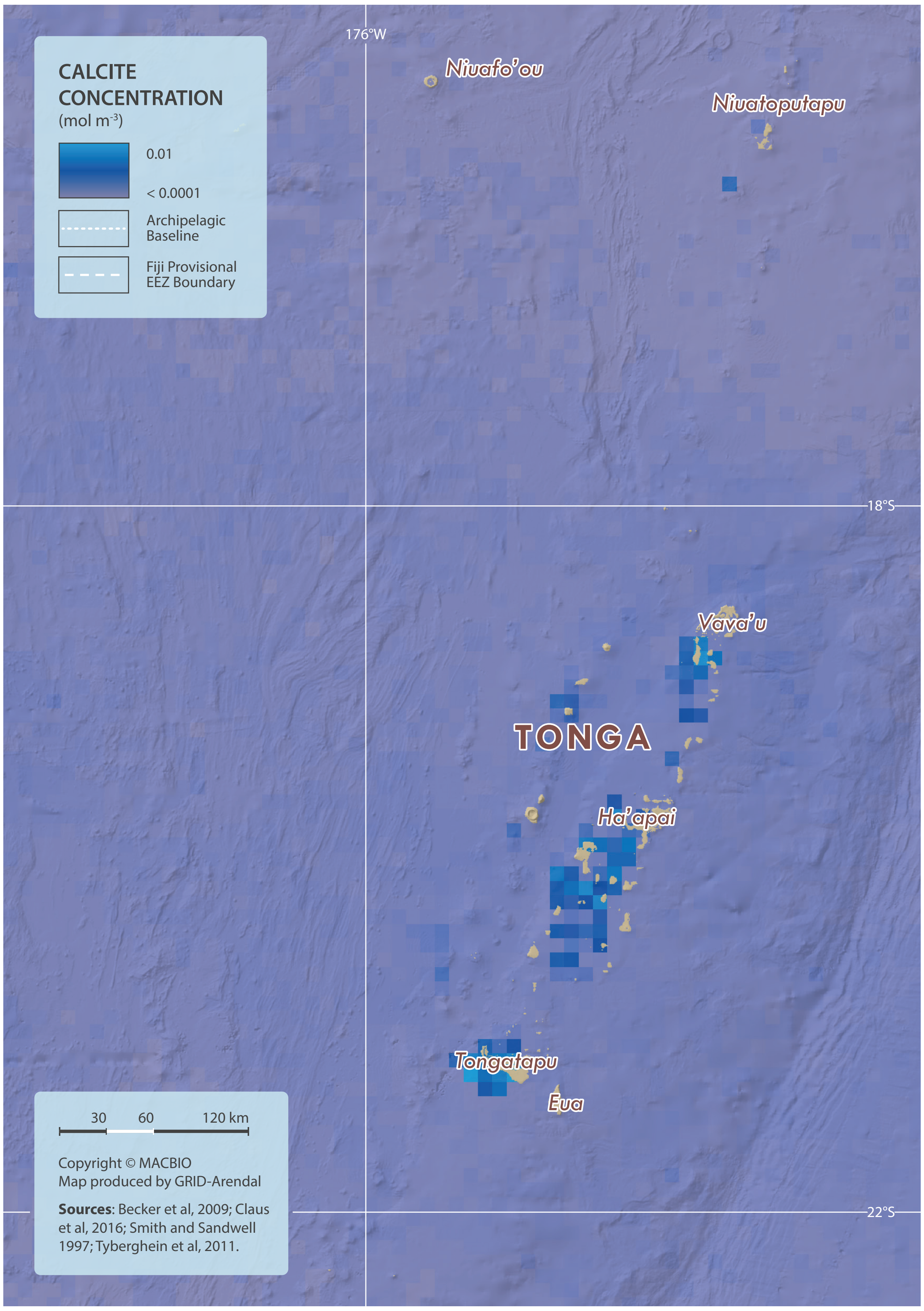
pH Scale: What is Acidic, What is Alkaline?

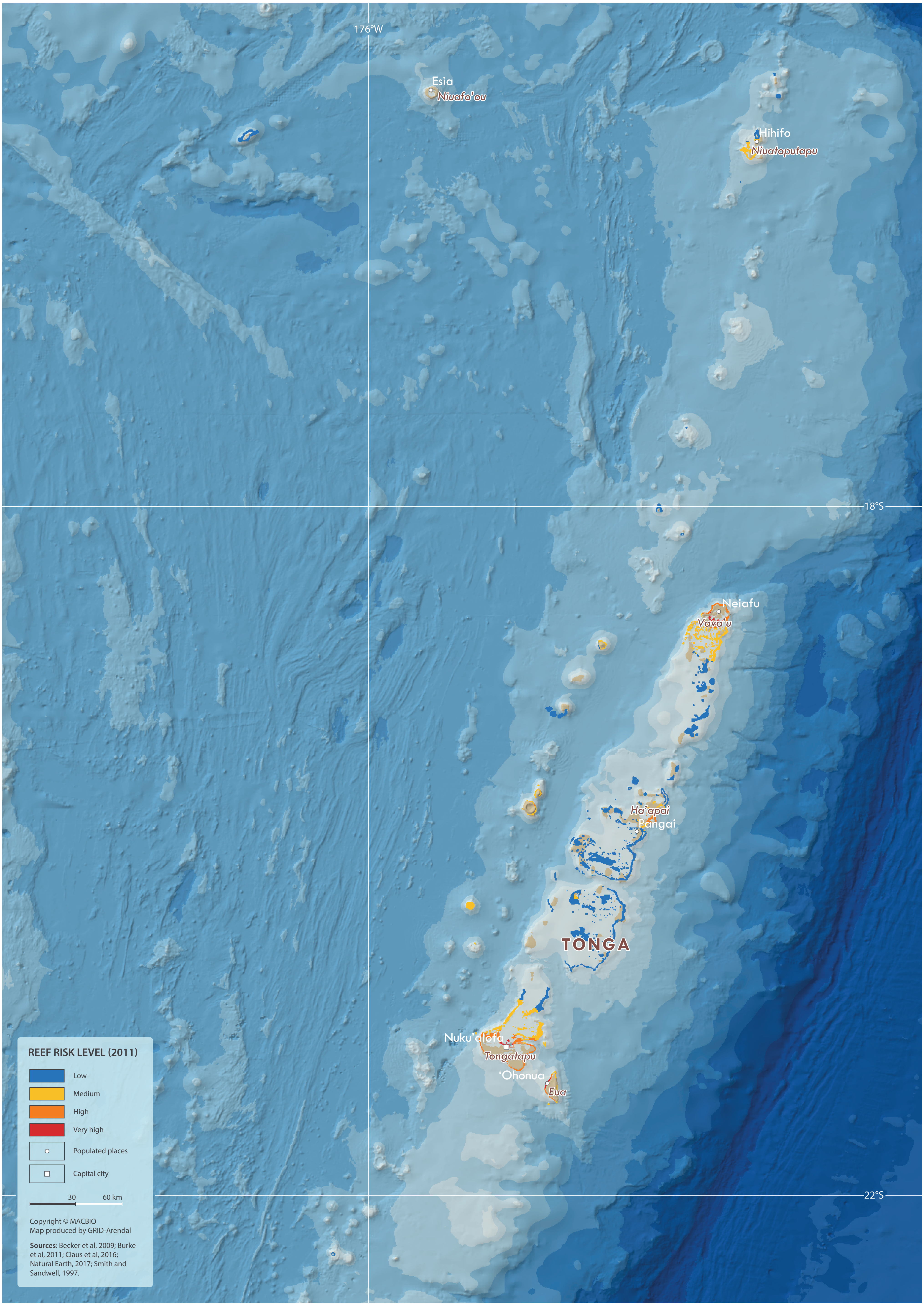


The difference may seem small, but the decline in the pH value from the year 1870 (pH 8.25) to 2100 (pH of 7.9) would mean a 170 per cent increase in acidity. Much smaller changes already pose problems for many sea creatures.



Many animals, including fish and snails, are negatively affected by acidification. Only a few actually benefit from it.




176°W
Esia
Niuafo'ou
Hihifo
Niuatoputapu
18°S
Neiafu
Vava'u
Ha'apai
Pangai
TONGA
Nuku'alofa
Tongatapu
'Ohonua
Eua
22°S
REEF RISK LEVEL (2011)
Low
Medium
High
Very high
Populated places
Capital city
30
60 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Burke et al, 2011; Claus et al, 2016; Natural Earth, 2017; Smith and Sandwell, 1997.

REEFS AT RISK: REEF RISK LEVEL

Tonga's reefs are at risk and the direct and indirect impacts of climate change are exacerbating a system already under threat, jeopardizing marine values worth billions of dollars.

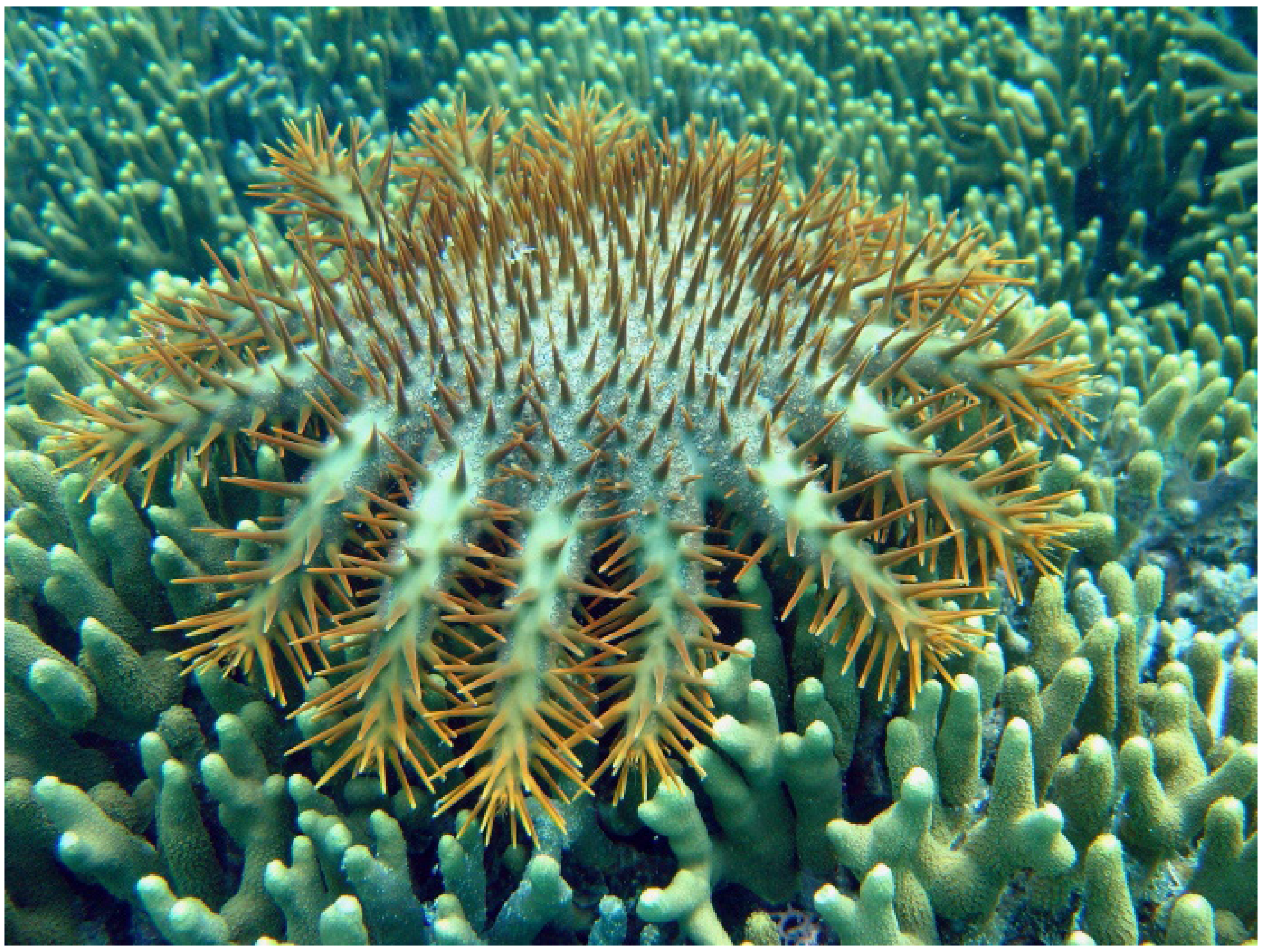
As seen in the previous maps, coral bleaching is the silent reef killer, caused by rising sea levels and ocean acidification. A large coral bleaching event was recorded in Tonga in 2000 (Lovell and Palaki, 2003), with significant coral bleaching around Tongatapu and the Ha'apai group. This same bleaching event also affected coral reefs in Fiji. During this event, certain species of coral exhibited between 80 and 100 per cent bleaching. Outbreaks of the crown-of-thorns starfish (Acanthaster planci) were also recorded in the 1970s and 1980s, with moderate numbers in 1992. These starfish can destructively graze corals. Predicted rise in SST and sea level, coupled with increased nutrients from land-based activities, will add further stress to the corals of Tonga.

The cumulative impact of climate change and local human activities on Tonga's reefs will increase over time. The risk of these threats is shown on the map of Tonga's reefs, classified by estimated present threat from local human activities, according to the Reefs at Risk integrated local threat index (Burke et al., 2011). Threats considered in the index include coastal development, including coastal engineering, landfilling, run-off from coastal construction, sewage discharge (see also chapter "The dose makes the poison") and impacts from unsustainable tourism (see also chapter "Beyond the beach"); watershed-based pollution, focusing on erosion and nutrient fertilizer run-off from agriculture entering coastal waters via rivers; marine-based pollution and damage, including solid waste, nutrients, toxins from oil and gas installations and shipping, and physical damage from anchors and ship groundings (see also chapter "Full speed ahead"); and overfishing and destructive fishing, including unsustainable harvesting of fish or invertebrates, and damaging fishing practices such as the use of explosives or poisons (see also chapters "Fishing in the dark" and "Small fish, big importance").

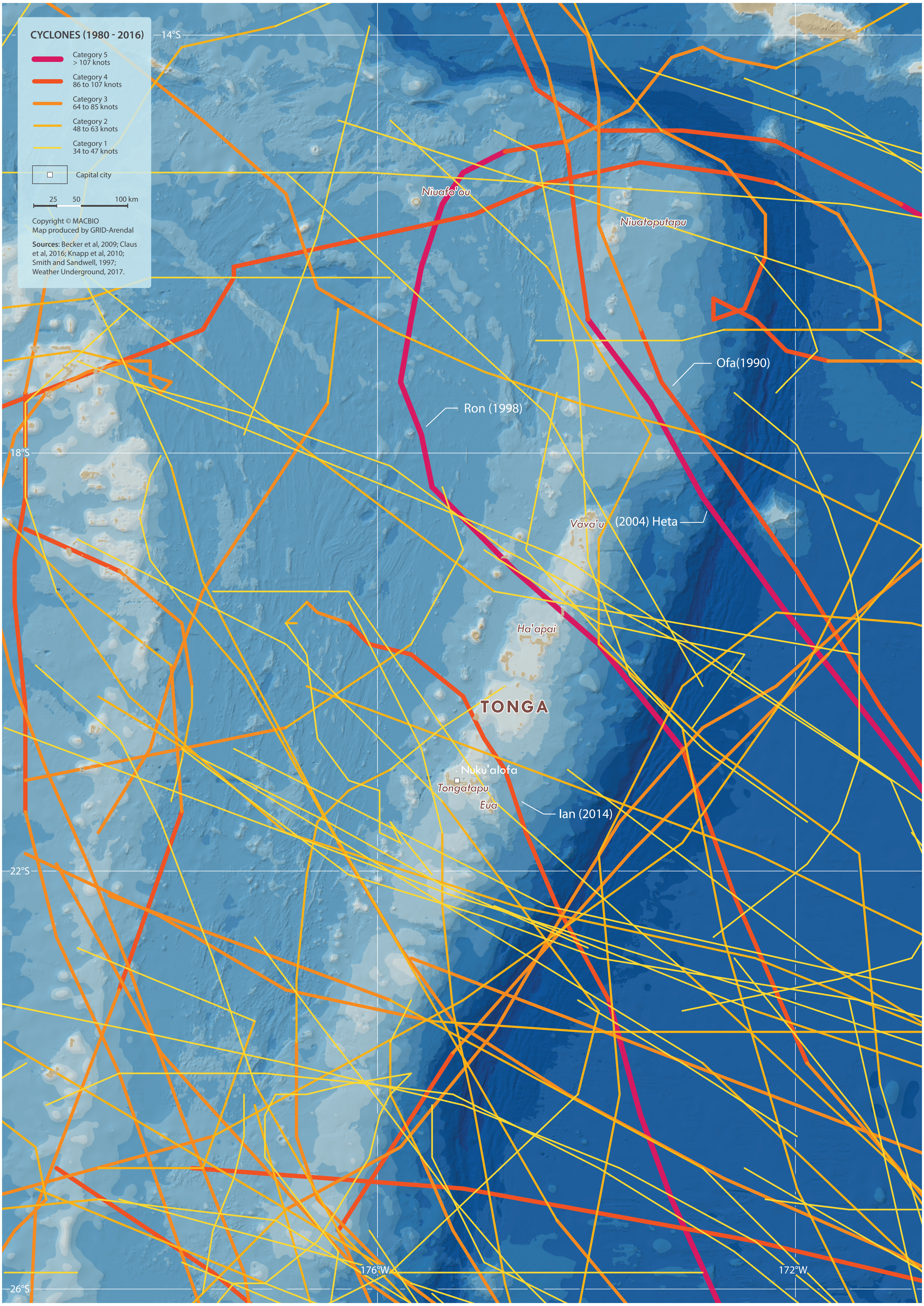
Acropora coral field in Tonga was exposed to multiple impacts, including a crown-of-thorns outbreak and cyclone damage.

This multitude of man-made threats leaves Tonga's reefs at risk. Analysis of the threat index indicates that 65.7 per cent of the reef area is classified as facing low risk, 25.4 per cent medium risk, 7.7 per cent high risk and 1.2 per cent very high risk. The areas of high and very high risk (orange and red) are concentrated around urban centres such as Tongatapu, the Ha'apai group and the Vava'u group. Wilkinson (2008) identified the major human disturbances as overfishing, pollution, sedimentation, eutrophication and coastal development. The reefs are important to the economies of local communities, especially through tourism. They are also important for subsistence and coastal protection. According to the Reefs at Risk Assessment (Burke et al., 2011), there is a very high social and economic dependence on coral reefs in Tonga.

Luckily, there are many initiatives aiming to facilitate the necessary changes. However, an integrated approach to coral reef conservation needs to include acknowledgements of land–sea connections and requires an understanding of how and where terrestrial conservation actions influence reefs. Klein et al. (2012) examined the impact and cost effectiveness of protecting forests as a reef conservation measure. They found that relative coral reef condition could be improved by 8–58 per cent if all remnant forest was protected rather than deforested. It seems that rainforests on land support Tonga's "underwater rainforests". The Pacific Ridge to Reef project is working to build these connections into management decisions and planning in Pacific Island countries.



Crown-of-thorns starfish damage Tonga's reefs. Outbreaks often occur when their natural predators are overfished.



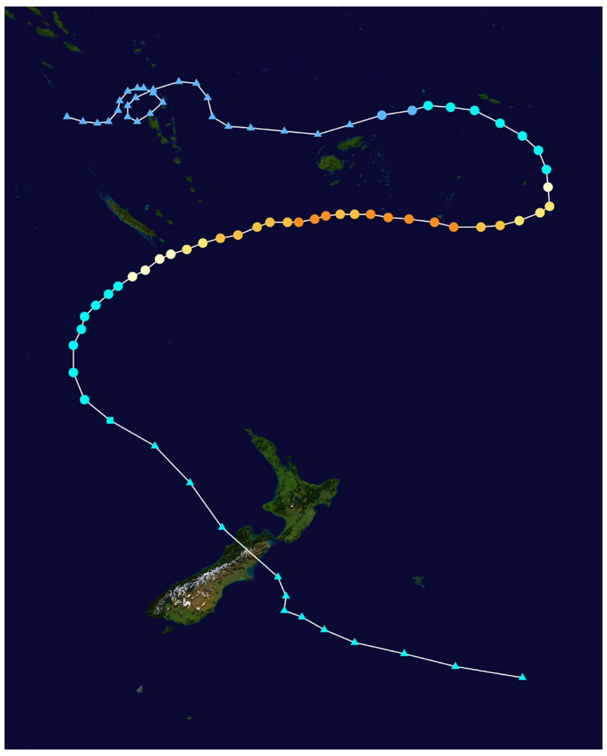
CYCLONES (1980 - 2016)
Category 5
> 107 knots
Category 4
86 to 107 knots
Category 3
64 to 85 knots
Category 2
48 to 63 knots
Category 1
34 to 47 knots
Capital city
25
50
100 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Claus et al, 2016; Knapp et al, 2010; Smith and Sandwell, 1997; Weather Underground, 2017.
14°S
18°S
22°S
26°S
176°W
172°W
Niuafo'ou
Niuatoputapu
Ofa(1990)
Ron (1998)
Vava'u
(2004) Heta
Ha'apai
TONGA
Nuku'alofa
Tongatapu
Eua
Ian (2014)

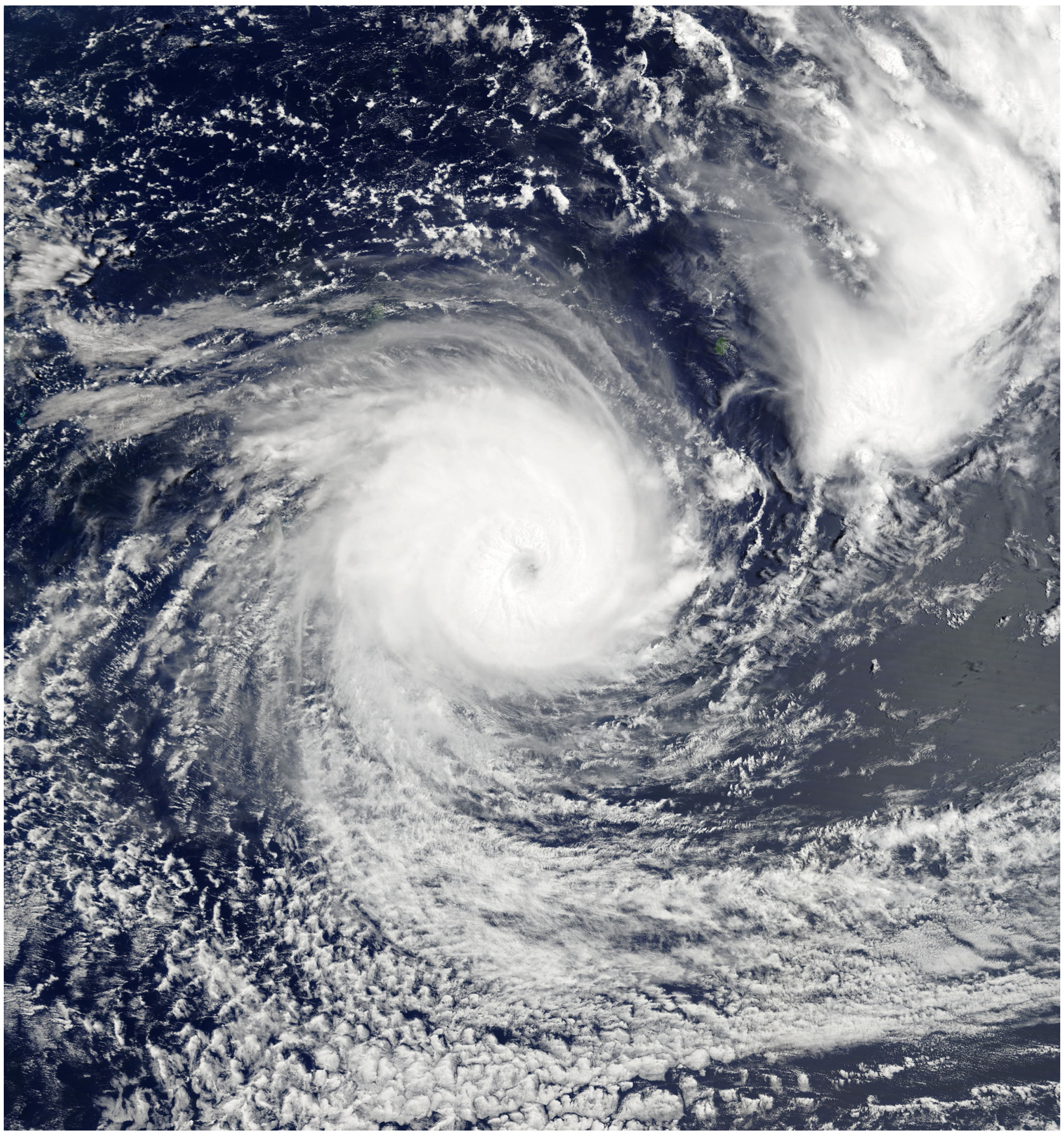
STORMY TIMES: CYCLONES

Tropical cyclones pose direct threats to Tonga, its people and its marine life. Marine and coastal habitats including mangroves, seagrasses and coral reefs play an important role in offering effective protection and therefore need to be sustainably managed and conserved.

While it has a lower number of cyclones than some of its neighbouring countries to the west, Tonga is still heavily affected by tropical cyclones. One of the most recent of these, Tropical Cyclone Gita, was the most intense cyclone to hit Tonga since records began. It caused extensive damage on the islands of Tongatapu and ʻEua, including in the capital Nuku'alofa, where many homes were either damaged or destroyed.

Cyclones are monitored by the Regional Specialized Meteorological Centre of the Fiji Meteorological Service, located in Nadi. In Tonga, the Tongan Meteorological and Coastal Radio Service provide warnings about tropical cyclones. Tropical cyclones are categorized according to the Australian





and South Pacific Category System from category 1 (90 km/h gusts) to category 5 (280 km/h gusts). The cyclone season is considered to run from the beginning of November to the end of April, but destructive cyclones can occur outside this period. The formation of cyclones in the region is strongly influenced by the ENSO (see also chapters “Go with the flow” and “Hotter and higher”). During El Niño years, cyclones are more likely to form between 6°S and 18°S and 170°E and 170°W. During La Niña years, slightly fewer tropical cyclones form and the origin moves to the south of Tonga (Chand and Walsh 2009). Therefore, although there is not a great deal of difference between El Niño and La Niña years, the northern Tongan islands have a lower incidence of cyclone strike during La Niña conditions than the southern Tongan islands (Chand and Walsh, 2009). On average, Tonga receives 1.6–1.9 cyclones per season. El Niño brings a heightened risk of cyclones.

In the past decade, there has been increasing attention on the relationship between climate change and the frequency and intensity of cyclones in the region. Diamond et al. (2013) found a statistically significant increase in the number and intensity of cyclones in the period 1991–2010 compared with the period 1970–1990. Rising SSTs are fuelling cyclones (see also chapters “Hotter and higher”) that are resulting in increasing damage, including to Tonga's valuable coastal habitats.

At the same time, conserving coastal habitats, such as coral reefs and mangroves, offers a very effective form of protection against storms. In this way, Tonga can strengthen its defences against cyclones like Gita.

Very vulnerable Tonga

Not only is the Kingdom of Tonga situated within the Ring of Fire in the Pacific Ocean, but most of its atoll islands, including Tongatapu, are flat, with an average elevation of 2–5 metres. Thus, the country is very vulnerable to storm surges that accompany tropical cyclones, tsunami inundation and flooding from heavy rainfall. A joint Commonwealth Secretariat and World Bank study conducted in 1999, which examined the vulnerability of 111 countries to the effects of natural disasters, ranked Tonga as being “very vulnerable”. In the 25 years prior to 1999, Tonga was the second-most affected country (in terms of percentage of population) by natural disasters of all the countries in the study. Since the 1960s, four cyclones (in statistical terms, approximately one per decade) have very severely affected Tonga, causing extensive damage to crops and food supply, buildings (residential and commercial), tourist resorts and infrastructure (electricity supply and roads), and disrupting essential services. Tropical Cyclones Isaac (1982) and Waka (2001) resulted in seven fatalities. Estimates of damage caused range from approximately US$20 million (1982) to US$48 million (2001), representing in excess of 20 per cent of GDP in those two years. The recent Tropical Cyclone Gita in 2018 (above) was reported to be the strongest of all tropical cyclones ever to hit Tonga, with winds reaching 233 kilometres per hour, causing severe damage to crops, houses, infrastructure and much more worth several million US dollars.

MANAGING

The marine and coastal ecosystems of Tonga's waters provide benefits for people in and beyond Tonga. To better understand and improve the effective management of these values on the ground, Pacific Island countries, including Tonga, are increasingly building institutional and personal capacities for planning and management.

However, there is no need to reinvent the wheel, as Pacific Islanders possess centuries of traditional management knowledge. Coupled with scientific approaches and lessons learned, this knowledge can strengthen effective management of the region's rich natural capital.

The maps in this chapter showcase marine management in Tonga that starts at the local level, based on the management of traditional fishing grounds. In addition, Tonga has made strong national commitments to effectively manage its marine resources, which are embedded in regional and international efforts and commitments, such as the Aichi Biodiversity Targets, the United Nations Oceans Conference in support of the 2030 Agenda for Sustainable Development and the Pacific Oceanscape Framework. These management efforts can be effectively supported by marine planning efforts.

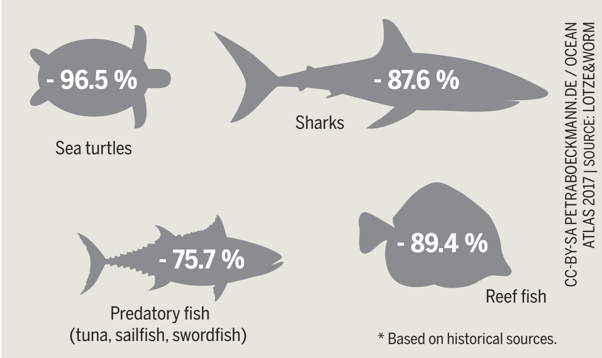
To maximize benefits from these marine values for Tonga, national and regional stakeholders are working together to document effective approaches to sustainable marine resource management and conservation. This chapter encourages stakeholders to share tried and tested concepts and instruments more widely throughout the Oceania region.

Further Reading: **http://macbio-pacific.info/effective-management**

SPACE TO RECOVER: MARINE MANAGEMENT

Marine managed and protected areas are key to maintaining Tonga's valuable marine resources. To effectively implement these areas, it is important to combine traditional marine management with national and international efforts.

Declining Populations* (Percentage Change)



Taking into account every type and category of protected area globally, only 3.5 per cent of the ocean is currently protected. Environmental organizations and scientists recommend that between 20 and 50 per cent of the ocean should be protected. The goal is not to preserve things as they are—even protected areas harbour only a tiny fraction of the biodiversity that once existed—but to allow life to recover.

This is crucial, given the decline of global marine populations (see graphic). For this reason, the world wants to protect at least 10 per cent of coastal and marine areas by 2020, as formulated in an international CBD target (see also chapter "Tonga's commitment to marine conservation"). Indeed, marine managed areas are steadily increasing.

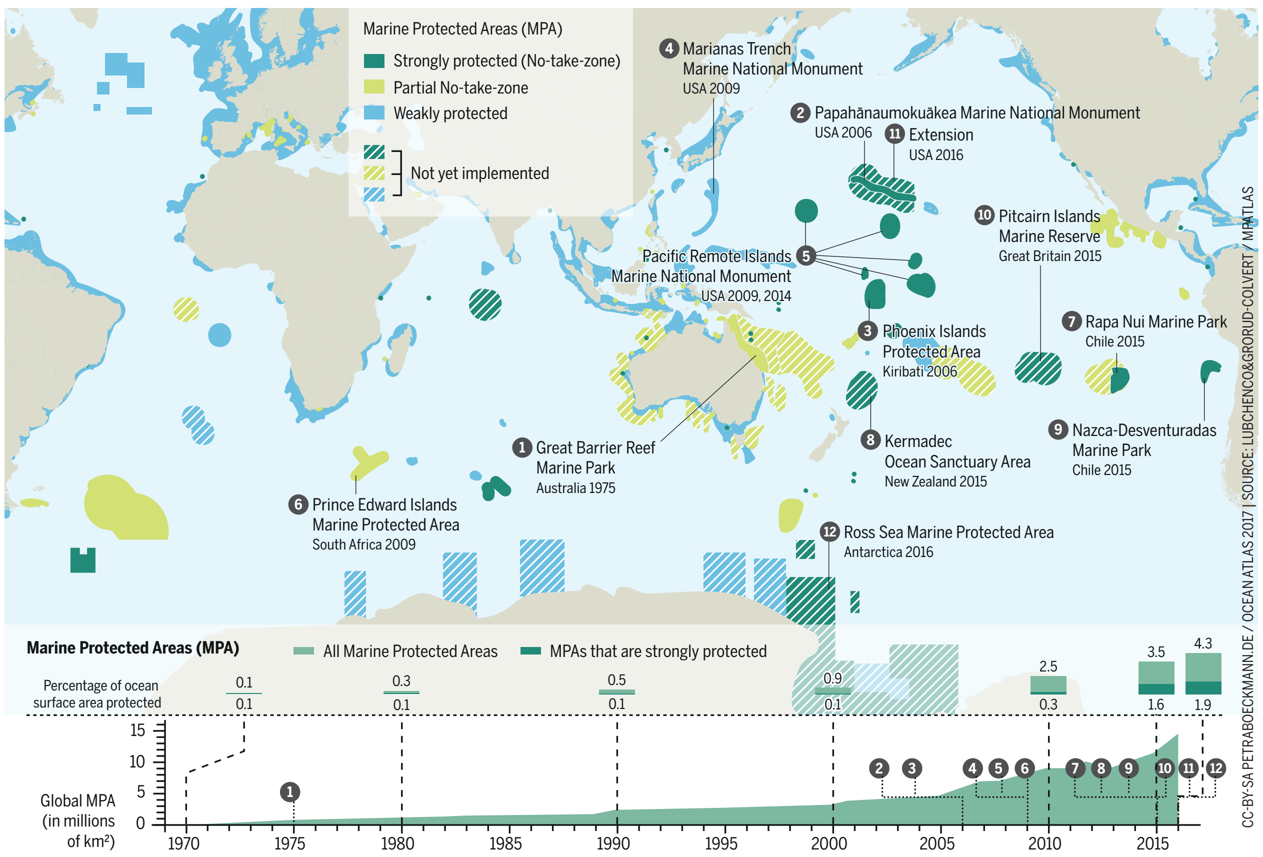
Marine managed areas are areas of the ocean that are managed for specific purposes, which can include protection of biodiversity or sustainable use of the resources. These areas are summarized in the World Database on Protected Areas (WDPA), which is a global compilation of both terrestrial and MPAs produced by IUCN and UNEP-WCMC (Protected Planet, 2018). For protected areas to be included in this database, they must align with one of six IUCN protected area management categories, which provide international standards for defining protected areas and encourage conservation planning according to their management aims. Only one of these categories is "no take", and they are often placed at the core of a protected area. However, holistic, sustainable marine management on a large scale is key to conserving the marine values.

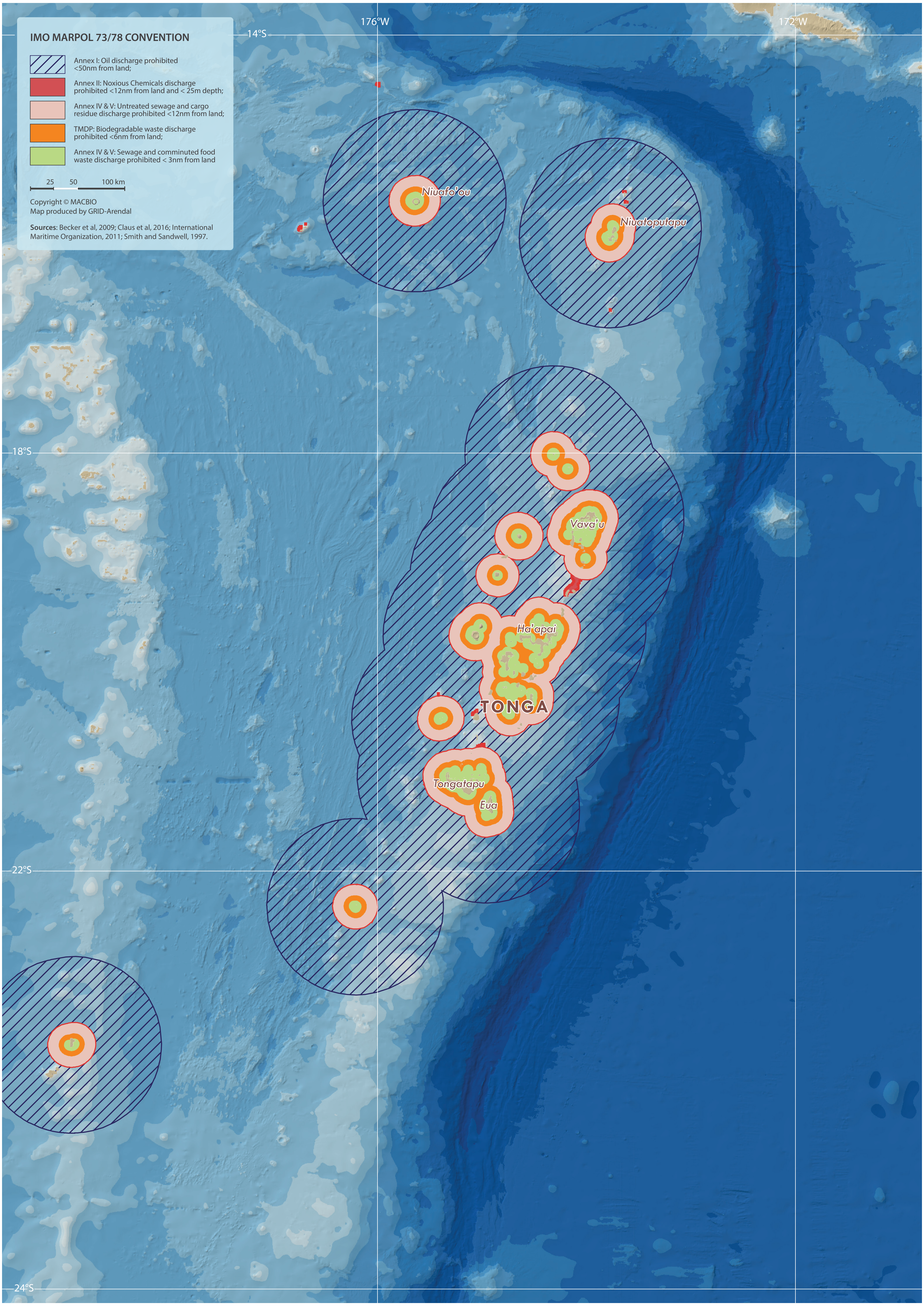
Recognizing the role that MPAs play in allowing marine life to recover, Tonga has committed to protecting and sustainably managing 30 per cent of its sea (see also chapter "Tonga's commitment to marine conservation") by 2020, using Tonga-specific categories of protection. While this is an ambitious goal, Tonga has a rich tradition of marine management upon which to build. Traditional fisheries management is common in Tonga, where community leaders (particularly chiefs) implement management initiatives for the betterment of their marine resources. Known examples include closed seasons, closed areas and size limit restrictions.

There are more than several small MPAs in Tonga, covering 1.5 per cent of the marine area (UNEP-WCMC, 2018). These consist of a range of marine managed areas, including reserves/marine reserves, multiple-use conservation areas and national parks, with a number of different management instruments. The boundaries of some of these are available and presented on the map. The largest of these is the Fanga'uta and Fanga Kakau Lagoons Marine Reserve, with an area of 28 km² covering the lagoons on the island of Tongatapu. However, many of these management areas do not have defined boundaries. For example, the Ha'apai multiple-use conservation area has a reported area of 10,000 km² according to the WDPA (UNEP-WCMC 2018), however, there is limited publicly available information on this area.

In July 2015, Tonga's Cabinet decided to initiate MSP throughout its EEZ to the outer extent of the zone. The government Marine Spatial Planning Technical Working Group, known as the Ocean 7, is working with MACBIO to define the workplan, timelines and deliverables to ensure progress in Tonga's MSP by 2020.

Marine Protected Areas – Space to Recover





IMO MARPOL 73/78 CONVENTION
Annex I: Oil discharge prohibited <50nm from land;
Annex II: Noxious Chemicals discharge prohibited <12nm from land and < 25m depth;
Annex IV & V: Untreated sewage and cargo residue discharge prohibited <12nm from land;
TMDP: Biodegradable waste discharge prohibited <6nm from land;
Annex IV & V: Sewage and comminuted food waste discharge prohibited < 3nm from land
25
50
100 km
Copyright © MACBIO
Map produced by GRID-Arendal
Sources: Becker et al, 2009; Claus et al, 2016; International Maritime Organization, 2011; Smith and Sandwell, 1997.
176°W
172°W
14°S
18°S
22°S
24°S
Niuafo'ou
Niuatoputapu
Vava'u
Ha'apai
TONGA
Tongatapu
Eua

ONE WORLD, ONE OCEAN: INTERNATIONAL MARITIME ORGANIZATION (IMO) MARPOL CONVENTION

Tonga's marine values do not stop at national borders. This makes international cooperation increasingly important for effective management of values and their uses, such as mining, fisheries and shipping.

Tonga has sovereign rights over a vast marine area of 700,000 km². This area is rich in marine values and managed through various local, national and international instruments (see also chapter "Space to recover"). However, nearly half the Earth is covered by areas of the ocean that lie beyond national jurisdictions. Marine Areas Beyond National Jurisdiction (ABNJ), commonly called the high seas, are those areas of ocean for which no one nation has sole managerial responsibility. In the Pacific and around Tonga (see map "A sea of islands"), there are many high sea pockets that are connected to very important ecosystems and fisheries. Yet, marine species and ecosystems do not abide by the country borders shown on the map, as everything is connected in the ocean (see also chapter "Go with the flow" and "Travellers or homebodies"). Similarly, threats to marine values go beyond national boundaries. Hence, holistic, sustainable and effective marine management calls for appropriate international instruments.

Tonga is therefore part of the international governance structures for the ocean, which follow a multisectoral approach and involve a plethora of organizations (see graphic) dedicated to different uses, be it seabed mining (see also chapter "Underwater Wild West"), fisheries (see also chapter "Fishing in the dark") or shipping (see also chapter "Full speed ahead").

Addressing the latter, the Convention for the Prevention of Pollution from Ships (MARPOL 73/78; see map) is an important international instrument that applies to Tonga's waters. Developed by the IMO in an effort to preserve the marine environment, it attempts to completely eliminate pollution by oil and other harmful substances, to minimize accidental spillages of such substances and to prevent air pollution from ships. The MARPOL 73/78 Convention contains six technical annexes, most of which include Special Areas with strict controls on operational discharges:

- Annex I Regulations for the Prevention of Pollution by Oil (entered into force 2 October 1983)
  Covers prevention of pollution by oil from operational measures as well as from accidental discharges..

- Annex II Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk (entered into force 2 October 1983)
  Details the discharge criteria and measures for the control of pollution by noxious liquid substances carried in bulk. No discharge of residues containing noxious substances is permitted within 12 miles of the nearest land.

- Annex III Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form (entered into force 1 July 1992)
  Contains general requirements for the issuing of detailed standards on packing, marking, labelling, documentation, stowage, quantity limitations, exceptions and notifications.

- Annex IV Prevention of Pollution by Sewage from Ships (entered into force 27 September 2003)
  Contains requirements to control pollution of the sea by sewage; the discharge of sewage into the sea is prohibited, except when the ship has in operation an approved sewage treatment plant or when the ship is discharging comminuted and disinfected sewage using an approved system at a distance of more than three nautical miles from the nearest land; sewage which is not comminuted or disinfected has to be discharged at a distance of more than 12 nautical miles from the nearest land.

- Annex V Prevention of Pollution by Garbage from Ships (entered into force 31 December 1988)
  Deals with different types of garbage and specifies the distances from land and the manner in which they may be disposed of; the most important feature of the annex is the complete ban imposed on the disposal into the sea of all forms of plastics.

- Annex VI Prevention of Air Pollution from Ships (entered into force 19 May 2005)
  Sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances; designated emission control areas set more stringent standards for SOx, NOx and particulate matter.

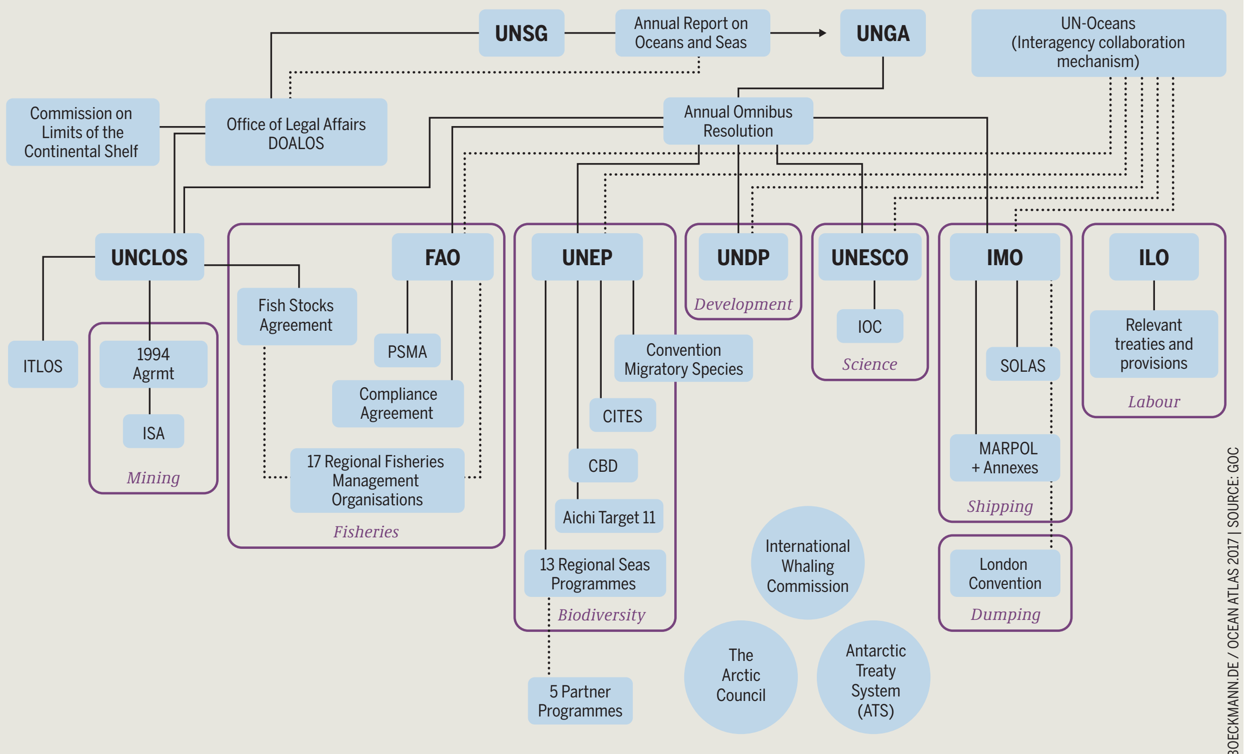
In addition, in 2015 a joint workshop run by the IMO, the Pacific Regional Environment Programme (SPREP) and Pacific Island representatives in Nadi, Fiji identified areas off Tonga for consideration as Particularly Sensitive Sea Areas (PSSA). PSSAs are areas that need special protection through IMO action because of their ecological, socioeconomic or scientific significance, and which may be at risk from maritime activities. As an example, a PSSA can be protected by routing measures, meaning that ships avoid these areas.

Beyond addressing pollution and invasive species, the Pacific Oceanscape Framework provides orientation at the regional level for sustainable marine management.

Under invasion

In addition to pollution, international shipping routes pose another threat to Tonga's marine values in the form of invasive species. Since the arrival of humans on the Pacific Islands, they have deliberately brought with them species that are useful for their survival, yet unwanted species have also been accidentally introduced. One of the major vectors for introduced species is the ballast water of ships. Some of the unwanted species get out of control and can cause enormous ecological, economic or health problems. These "invasive" species are also known as "pest" species. In response, the Pacific has developed the Pacific Invasives Partnership (PIP) as a coordinating body for international agencies that provide services to Pacific countries and territories.

International Governance Structures for the Ocean – Multi-sectoral Approach and a Plethora of Organizations



CBD Convention on Biological Diversity; **CITES** The Convention on International Trade in Endangered Species of Wild Fauna and Flora; **DOALOS** Division for Ocean Affairs and the Law of the Sea; **FAO** Food and Agriculture Organization [of the United Nations]; **ILO** International Labour Organization; **IMO** International Maritime Organization; **IOC** Intergovernmental Oceanographic Commission; **ISA** International Seabed Authority; **ITLOS** International Tribunal for the Law of the Sea; **MARPOL** International Convention for the Prevention of Pollution from Ships; **PSMA** Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing; **RFMOs** Regional Fisheries Management Organisations; **SOLAS** International Convention for the Safety of Life at Sea; **UNDP** United Nations Development Programme; **UNEP** United Nations Environment Programme; **UNESCO** United Nations Educational, Scientific and Cultural Organization; **UNGA** United Nations General Assembly; **UNSG** United Nations Secretary-General

TONGA'S COMMITMENT TO MARINE CONSERVATION

Tonga is committed to sustainably managing and conserving its marine values.

The Tongan government recognized the importance of spatial management with the launch of their National Spatial Planning and Management Act.

In 2015, for the first time in Tongan history, three ministries submitted a joint paper to the Cabinet to initiate MSP for the nation (Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECC), Ministry of Lands and Natural Resources (MLNR) and Ministry of Agriculture, Food, Forests and Fisheries (MAFFF)). This was passed on 22 July 2015. In this paper, the Cabinet decided that cross-sectoral planning and coordination would be required.

Thus, the Ocean 7 was established—Tonga's Marine Spatial Planning Technical Working Group. The working group is co-chaired by the three ministries that prepared the original cabinet paper and also includes the following four ministries (thus comprising the Ocean 7), as well as the Tonga Ports Authority:

- Ministry of Finance and National Planning (Departments of Finance and the National Planning Authority)
- Ministry of Internal Affairs
- Ministry of Commerce, Consumer, Trade, Innovation and Labour (Department of Tourism)
- Ministry of Infrastructure and Tourism (Marine Division)

With MACBIO's assistance, the Ocean 7 has already developed the following building blocks for its marine spatial plan:

- A vision and set of objectives
- An analysis of the legal basis for a marine spatial plan
- A national marine ecosystem service valuation
- A typology of different ocean management areas
- A report on the SUMAs of Tonga and a report classifying the entire marine environment into bioregions
- Placement guidelines for the ocean management areas and a draft national consultation strategy

Next steps include finalizing the placement guidelines, preparing the consultation materials and initiating the consultations on a marine spatial plan for the country.

This is testament to the fact that Tonga is committed to sustainably managing and conserving its marine values. In this spirit, Tonga submitted seven Voluntary Commitments (VCs) to the United Nations Ocean Conference in June 2017. One of these VCs was the call to develop parts of Tonga's waters as "Whale Sanctuaries". The other VCs included adoption of Tonga's Marine Spatial Plan, increasing the number of SMAs and efforts to eliminate illegal, unreported and unregulated (IUU) fishing.

THE OCEAN CONFERENCE
UNITED NATIONS, NEW YORK, 5-9 JUNE 2017

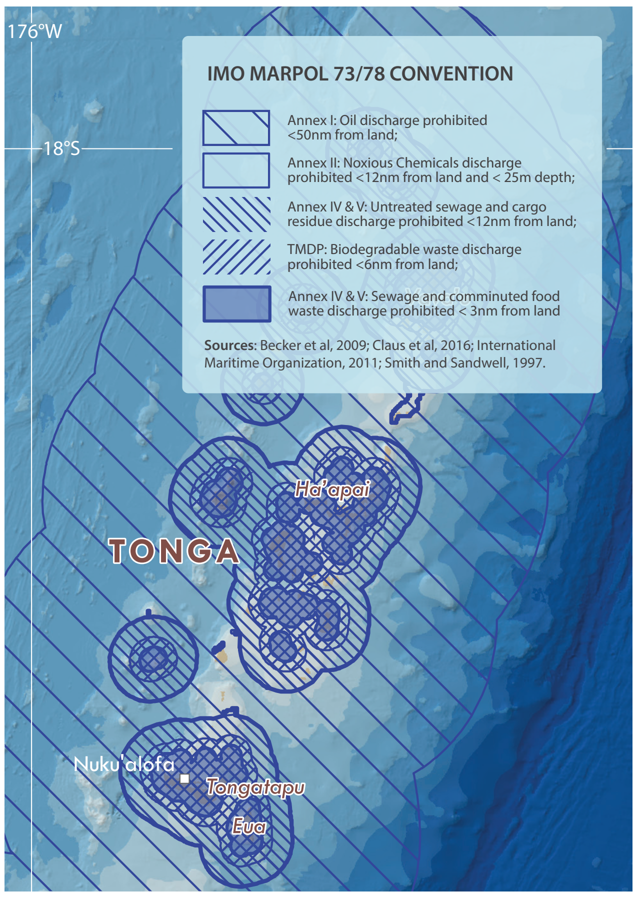
"The Ocean Conference has changed our relationship with the ocean. Henceforth none can say they were not aware of the harm humanity has done to the ocean's health. We are now working around the world to restore a relationship of balance and respect towards the ocean," said the President of the United Nations General Assembly Peter Thomson, from Fiji, at the closing of the United Nations Ocean Conference.

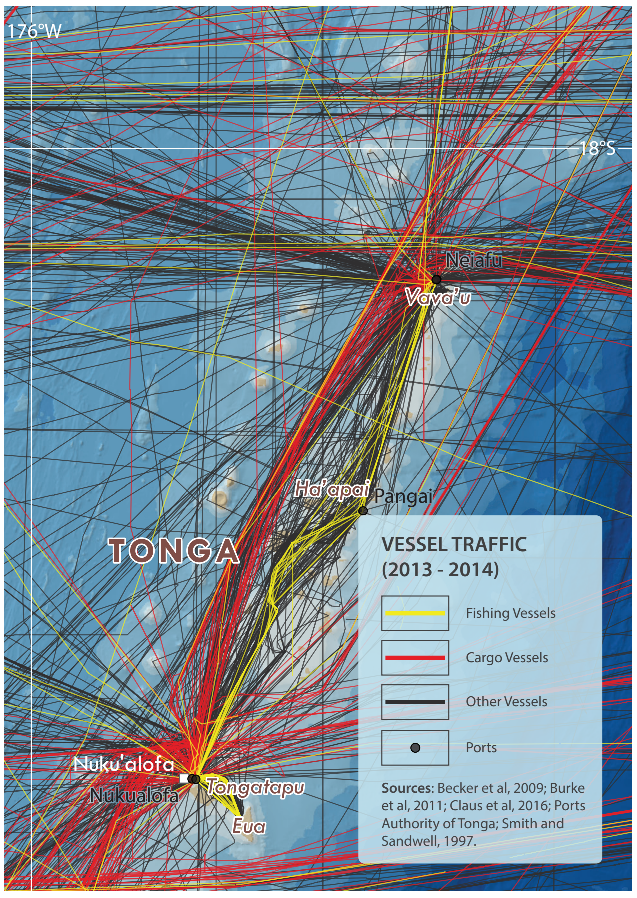
The 193 Member States of the United Nations unanimously agreed to a set of measures that aim to reverse the decline of the ocean's health. The "Call for Action" outcome document, together with more than 1,300 commitments to action, marks a breakthrough in the global approach to the management and conservation of the ocean. Recognizing that the well-being of present and future generations is inextricably linked to the health and productivity of the ocean, countries collectively agreed in the Call to Action "to act decisively and urgently, convinced that our collective action will make a meaningful difference to our people, to our planet and to our prosperity".

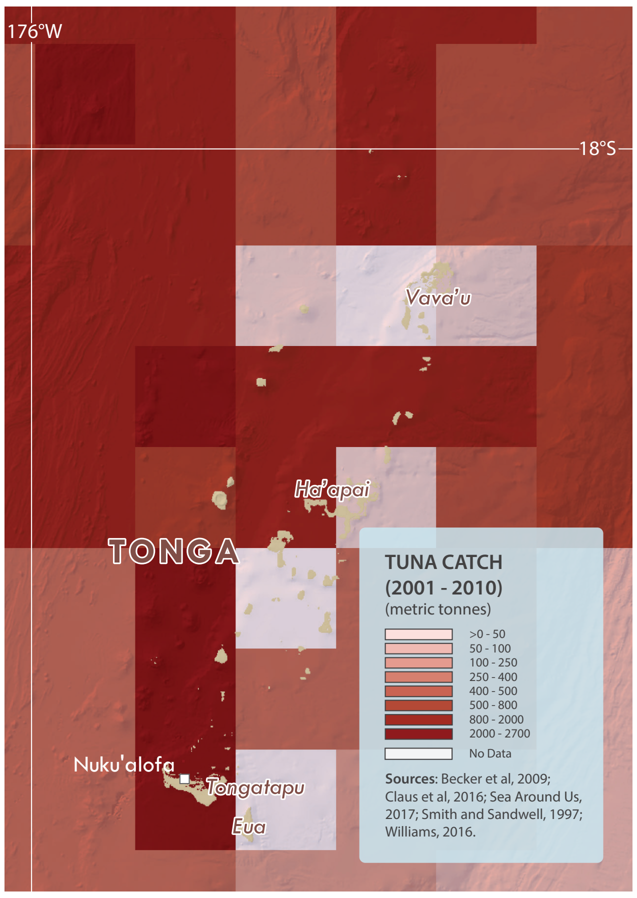
The second highest number of commitments come from the South Pacific, highlighting not only the importance of the ocean to Pacific Island countries, but also their commitment to "Conserve and sustainably use the oceans, seas and marine resources for sustainable development" (SDG 14).

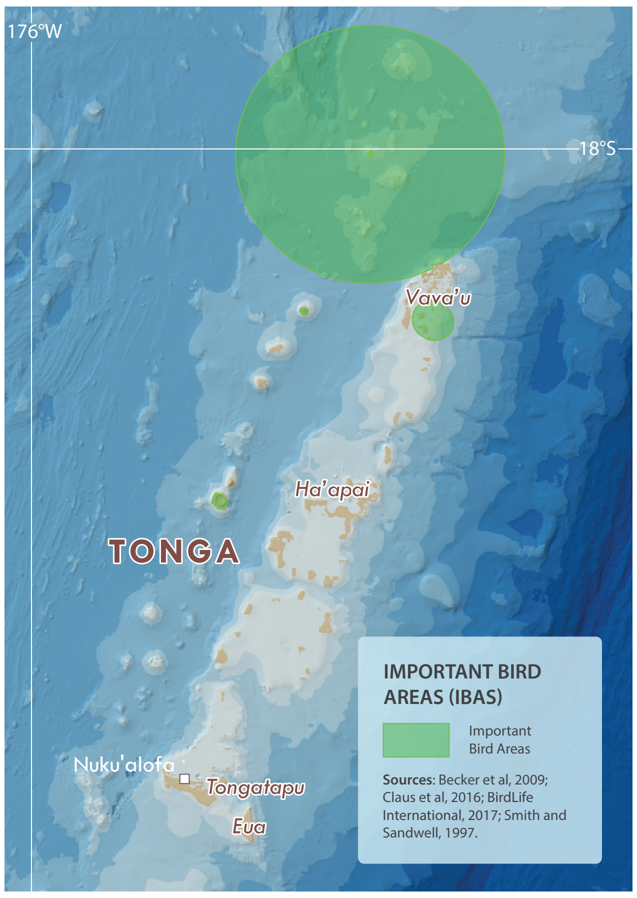
Tonga is calling for action to conserve valuable life below the surface, within its own waters and beyond.

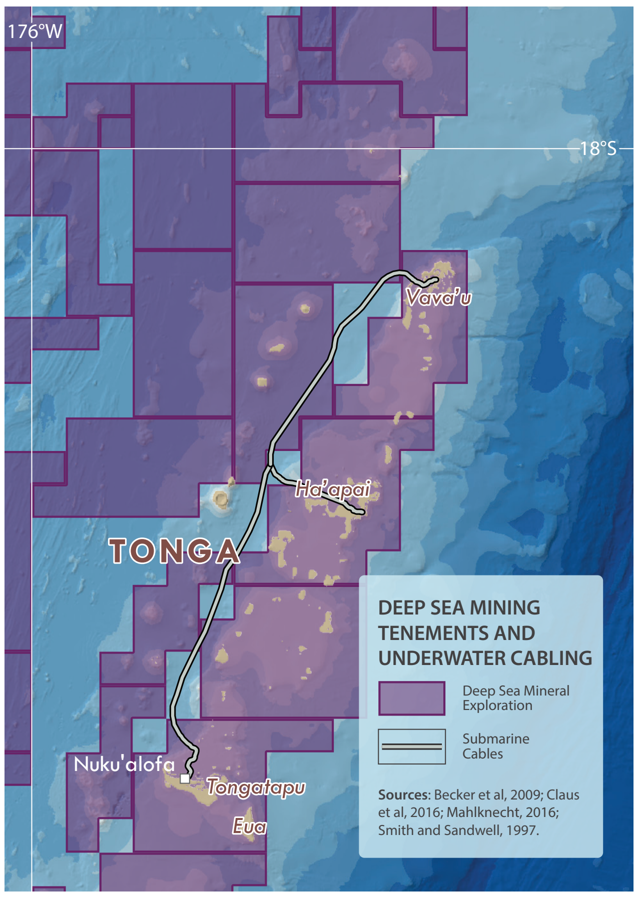
A MARINE LAYER CAKE

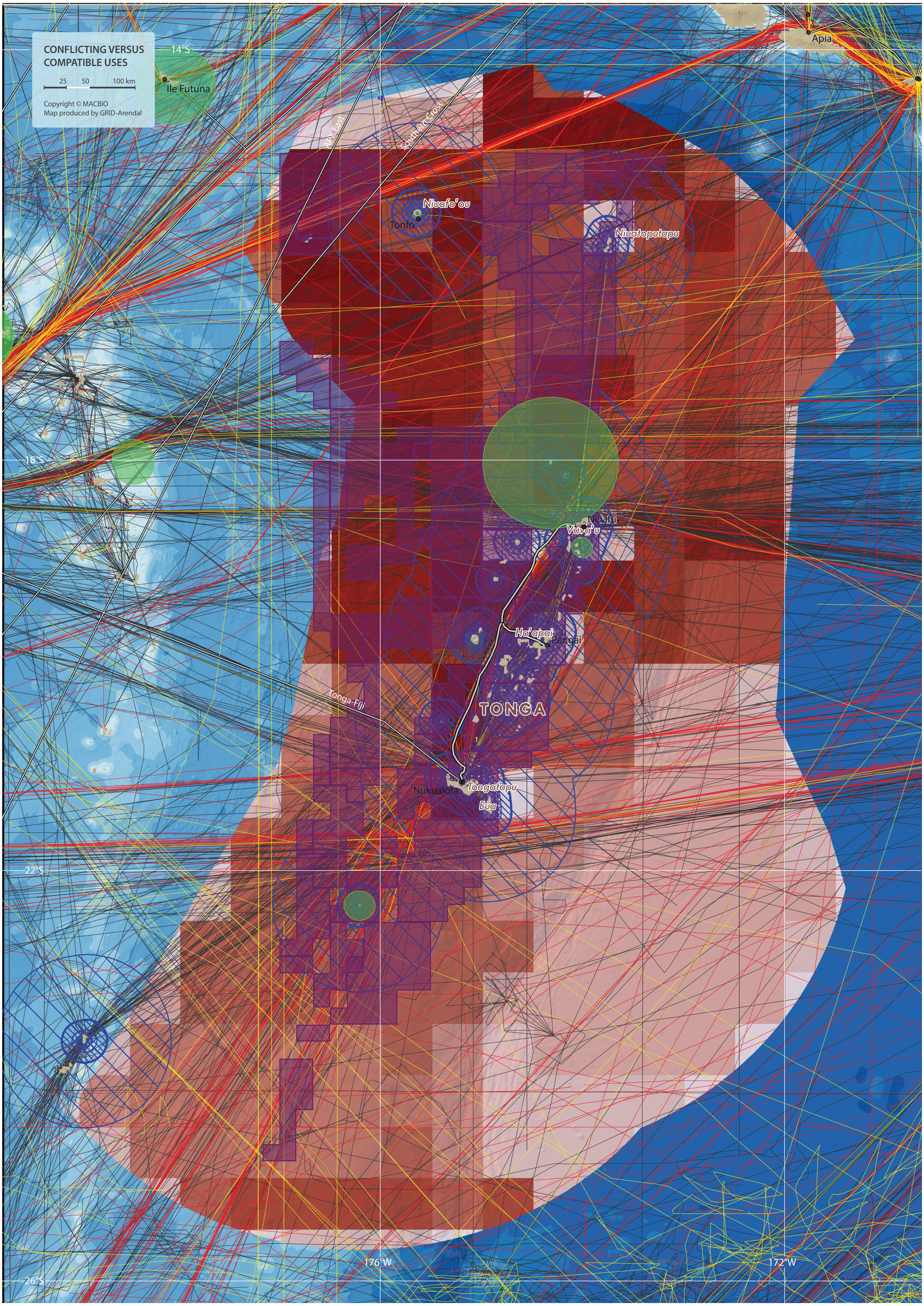











CONFLICTING VERSUS
COMPATIBLE USES
25
50
100 km
Copyright © MACBIO
Map produced by GRID-Arendal
14°S
18°S
22°S
26°S
176°W
172°W
Ile Futuna
Apia
Southern Cross
Niuafo'ou
Tonfe
Niuatoputapu
Neiafu
Vava'u
Ha'apai
Pangai
TONGA
Tonga-Fiji
Nukualofa
Tongatapu
Eua

CONFLICTING VERSUS COMPATIBLE USES

In an increasingly crowded seascape, MSP helps avoid conflict and maximize benefit between overlapping uses.

Marine Spatial planning

Marine Spatial Planning (MSP) is an inter-sectoral and participatory planning process and tool that seeks to balance ecological, economic and social objectives, aiming for sustainable marine resource use and prosperous blue economies.

The six map close-ups on vessel traffic (see also chapter "Full speed ahead"), mining (see also chapter "Underwater Wild West"), fisheries (see also chapter "Fishing in the dark") and management (see also chapter "Space to recover") show snapshots of the many marine uses detailed in the previous chapters. On its own, each looks manageable. However, zooming out and looking at the big picture of all uses, it is clear that many overlap. Some of these may be complementary, such as conservation and tourism, while other uses impact each other and may lead to conflicts, such as pollution from shipping in an important fishery, or deep-sea mining on a biologically diverse seamount.

How can Tonga address these conflicts?

Marine Spatial Planning (see text box) holds the key to sharing marine uses fairly, and one of the key tools used to implement MSP is a zoning plan. This is a tool that divides the ocean into zones, where each zone includes different activities that are or are not permitted.

The main purpose of a zoning plan (Ehler and Douvere, 2009) is to:

- separate conflicting human activities or to combine compatible human activities
- protect the natural values of the marine management area while allowing reasonable human uses of the area
- allocate areas for reasonable human uses while minimizing the effects of these human uses on each other and nature
- provide protection for biologically and ecologically important habitats, ecosystems, and ecological processes
- preserve some areas of the marine managed area in their natural state, undisturbed by humans except for scientific or educational purposes

There is no need to reinvent the wheel, as zoning of Tonga's waters is not a new concept and there are already a large number of different types of zones—although they may not be called zones. These include shipping lanes, IMO regulations regarding pollution at sea (see also chapter "One world, one ocean"), fisheries closures and marine protected or managed areas, including locally managed marina areas (LMMAs) (see also chapter "Space to recover"). Each of these different zones stipulate different areas within which particular activities are permitted or not permitted.

In the past, however, these zones have been largely designated within single sectors, with little

consideration of other human uses in the same area. Instead, a zoning plan that is derived through comprehensive MSP process takes into account how human uses impact each other and the environment. MSP can occur at a site level (such as a bay), across an entire marine managed area, within an EEZ or between neighbouring countries (transboundary). It should aim to achieve clear ecological, economic and social goals and objectives.

Each marine zone should have an assigned objective that permits a range of activities to occur, provided that each activity complies with the relevant zone objective. All zones should contribute to the overall goals and objectives of the Marine Spatial Plan. For example, if the objective of a zone is to protect the sea floor habitat, then activities such as trawling, mining or dredging should not be permitted, while other zones where the objective is to allow for a broad range of industrial uses may allow industrial tuna, shipping or even mining to occur.

Preparing a zoning plan is not an easy task, and is best achieved through considerable consultation, including across government departments at all levels, users, other stakeholders and the community. Zoning plans must accommodate and balance the cultural, economic, social and biological needs of the community.

MPAs are primarily established to meet biodiversity objectives, but can also have sociocultural and economic objectives that are consistent with national, regional and local needs. To meet these different objectives, MPAs can contain one or more zones to provide for different levels of protection.

The IUCN Protected Area Categories classify protected areas according to their management objectives. The categories are recognized by international bodies, such as the United Nations, and by many national governments as the global standard for defining and recording protected areas, and as such, are increasingly being incorporated into government legislation.

However, the process of aligning standardized categories to individual MPAs is not an easy one and not without a degree of controversy. For example, protected areas that are culturally appropriate for Tonga may not always fit neatly into any one of the seven IUCN categories. If they are to be applied effectively, therefore, any categories used by a nation must be interpreted and adapted to meet the country's biophysical, sociocultural and economic needs.

This is a very promising way to share and manage Tonga's rich and complex marine environment in a fair and sustainable manner, while maximizing benefits.

CONCLUSION

Tonga's vast ocean supports a myriad of marine values. To successfully conserve and manage these values, the island nation is committed to holistic planning and effective management of its ocean.

Through valuing, planning and managing the values and benefits of its coastal and marine systems, Tonga can achieve this. Nevertheless, the experience with MSP shows that only a truly participatory and inclusive process can generate nationwide ownership across sectors. Stakeholders across Tonga are working together to secure a healthy, productive, resilient and biodiverse ocean for all.

We thank everyone who participated in meetings regarding this atlas and who, through their involvement, contributed input, guidance, data and/or information to this atlas and identified its utility to policy and decision-making (see list of data providers listed in the References).

In particular, we would like to thank the Tonga Department of Environment of the Ministry of Local Government, Housing and Environment, the Fisheries Department of the Ministry of Fisheries and Forests, the Tonga Bureau of Statistics and other relevant ministries for providing data and support to the project.

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While the atlas provides the best data currently publicly available, the information about Tonga's waters is constantly increasing. In this way, the atlas is an open invitation to use, modify, combine and update the maps and underlying data.

The e-copy and interactive version of the Tonga Marine Atlas are available here: **http://macbio-pacific.info/marine-atlas**

Timeline of the Tonga Marine Spatial Planning process

2015–2017
Collation of over 140 spatial data sets, including on environmental and biological uses and risk variables, which were then assessed and prepared for use in MSP.

2015
- Cabinet decides to initiate cross-sectoral, national MSP for Tonga.
- The Ocean 7 (Tonga's MSP Technical Working Group) has its first meeting and determines its terms of reference, the vision and objectives for Tonga's MSP and a workplan extending to 2020.

2016
- Analysis of 91 instruments to assess the legal basis for MSP in Tonga completed.
- National marine ecosystem service valuation report completed.

2017
- Typology of ocean management areas for Tonga defined.
- Tonga's United Nations Ocean Conference Voluntary Commitments detail an MSP, including a network of 30 per cent MPAs by 2020 (#OceanAction 21256 and 21468).
- Report defining 38 biophysically SUMAs of Tonga launched by the Deputy Prime Minister.

2018
- Report on the 25 marine bioregions that describe all of Tonga's marine environment published.
- Draft communication materials prepared for national consultations.
- Placement guidelines for ocean management areas drafted.
- Formal national consultations for Tonga's MSP take place.

2019
- Prepare draft map (Ocean Plan) of candidate ocean zones.
- Initiate second round of national consultations in draft map.

2020
- Finalise Ocean Plan and enact within law.
- Conduct national consultations to inform everyone of the new Ocean Plan.

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A Marine Layer Cake

MAPS

For map data, please check references for chapters: "Fishing In The Dark – Offshore Fisheries", "Full Speed Ahead – Vessel Traffic", "One World, One Ocean – IMO MARPOL Convention", "Underwater Wild West – Deep Sea Mining And Underwater Cabling."

Fish Aggregating Devices data courtesy to Tonga government.

Conflicting Versus Compatible Uses

MAP

For map data, please check references for chapters: "Fishing In The Dark – Tuna Catch", "Full Speed Ahead – Vessel Traffic", "One World, One Ocean – IMO MARPOL Convention", "Underwater Wild West – Deep Sea Mining And Underwater Cabling."

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APPENDIX 1. DATA PROVIDERS

Organisation Name	Organisation Website
AquaMaps	http://www.aquamaps.org/search.php
Commonwealth Scientific and Industrial Research Organisation	http://www.csiro.au/
Convention on Biological Diversity	https://www.cbd.int/
Earth & Space Research (ESR)	http://www.esr.org/
Ecologically or Biologically Significant marine Areas	https://www.cbd.int/ebsa/
exactEarth	http://www.exactearth.com/
Government of The Kingdom of Tonga	http://www.gov.to/
Government of Vanuatu	http://governmentofvanuatu.gov.vu/
GRID-Arendal	http://www.grida.no/
Institute for Marine Remote Sensing	http://imars.marine.usf.edu/
Interridge	http://www.interridge.org/
Khaled bin Sultan Living Oceans Foundation	https://www.livingoceansfoundation.org/
Marine Ecology Consulting	http://marineecologyfiji.com/
National Aeronautics and Space Administration	http://www.nasa.gov/
National Oceanic and Atmospheric Administration	http://www.noaa.gov/
Oregon State University	http://oregonstate.edu/
Pacific community	http://gsd.spc.int/
Ports Authority Tonga	http://portsauthoritytonga.com/
Reef Life Survey	http://reeflifesurvey.com/
Republic of Kiribati	http://www.pso.gov.ki/
Sea Around Us is a research initiative at The University of British Columbia	http://www.seaaroundus.org/
Secretariat of the Pacific Regional Environment Program	http://www.sprep.org/
Solomon Islands Government	http://www.parliament.gov.sb/
The University of Queensland	http://www.uq.edu.au/
The Fijian Government	http://www.fiji.gov.fj/
The General Bathymetric Chart of the Oceans (GEBCO)	http://www.gebco.net/
The Nature Conservancy	http://www.nature.org/
Tonga Cable Limited	http://tongacable.to/
Tourism Tonga	https://plus.google.com/110982421797787387797
U.S. Geological Survey	https://www.usgs.gov/
University of South Florida	http://www.usf.edu/
Vava'u Environmental Protection Association	http://www.vavauenvironment.org/
Vlaams Instituut voor de Zee	http://www.vliz.be/
Western & Central Pacific Fisheries Commission	https://www.wcpfc.int/
Wildlife Conservation Society	https://www.wcs.org/
World Wildlife Fund	http://www.worldwildlife.org/
Zoological Society of London	https://www.zsl.org/

APPENDIX 2. PHOTO PROVIDERS

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27	GRID-Arendal/Glenn Edney
27	GRID-Arendal/Lawrence Hislop
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49	Ministry of Tourism
51	Ocean Exploration Trust
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Marine and Coastal Biodiversity Management
in Pacific Island Countries