STATUS AND TRENDS OF CORAL REEFS OF THE PACIFIC

EDITED BY
CHARLOTTE MORITZ · JASON VII · WARREN LEE LONG
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Dedication

This book is dedicated to the coral reef people who live by them, depend on them, use them, monitor them, study them, and protect them. We recognize the people of all islands from all nations in the wide Pacific Island region who strive to sustain healthy coral reefs for future generations.

Front cover

School of Manini (*Acanthurus triostegus*) feeding on a coral reef in Moorea, French Polynesia (©Lauric Thiault).

Back cover

Reefscape of Kimbe Bay, Papua-New Guinea (©Tane Sinclair Taylor).

Photograph credits

Charles Birkeland (page 59); **Lauric Thiault (**pages 26, 42 and 90); **Gilles Siu** (page 70).

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GCRMN

GLOBAL CORAL REEF MONITORING NETWORK

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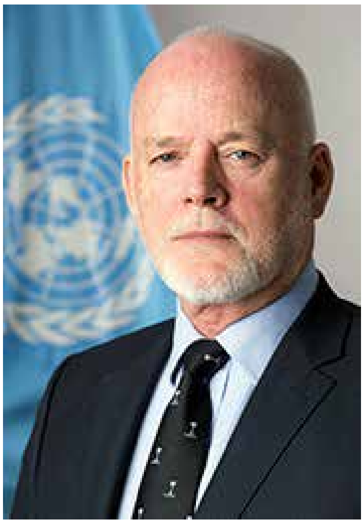
FOREWORD



Earth is an ocean planet. For the eight million people of the Pacific Islands, surrounded by ocean's magnitude, this fact is self-evident. For them, coral reefs are an integral part of life on this blue planet. For them, coral reefs are not just a vital source of food, they are a treasured element of cultural identity.

Globally, coral reefs are in trouble. Already much has been lost, and if overfishing, pollution, and global warming continue unabated, many scientists predict we will lose remaining reefs in a matter of decades. The Pacific is home to a quarter of the world's coral reefs, thus what happens in the Pacific has critical bearing on the fate of the reefs worldwide. The findings of this comprehensive study of coral reef status and trends in the Pacific Islands are therefore very timely and important for us all to consider with care.

It is interesting to read that at a regional level, coral cover on Pacific reefs has declined only marginally over 20 years, and that El Niño events and subsequent coral bleaching have not had region-wide, lasting impacts; for this contrasts markedly with patterns in other reef regions. To be sure, there are warning signals: reefs are changing in terms of species composition, some fish species important to maintaining reef resilience have declined, and projections for future coral bleaching are dire.

But, importantly, this study offers hope. It shows that, where human impacts on reefs are moderated, reefs can still thrive. At a time when much reporting and scientific publishing discusses terminal coral reef decline, this report gives us pause for consideration. It points to a window of opportunity for functioning reefs in the future, if we are prepared to take decisive action.

A good example of such action this year is Fiji's nomination of the Great Sea Reef as a Ramsar site, thereby setting out to ensure the reef's management and protection for future generations. Contributing roughly one million Fijian dollars per annum to the national economy for every hectare of coral reef, this great natural asset, this bunker of biodiversity, is indeed a national treasure.

Half way through 2018, in what has been declared the International Year of the Reef, I commend this report to readers, and trust it will inspire urgently required efforts to tackle the multiple threats to coral reefs. For further information on how to join in such efforts, please visit oceanconference.un.org

His Excellency Mr Peter Thomson
United Nations Secretary-General's Special Envoy for the Ocean, United Nations General Assembly

MESSAGE

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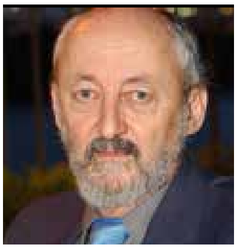

The Pacific Ocean is not only the largest ocean in the world, but also contains the largest proportion of coral reefs, especially remote reefs. These predominantly sit atop seamounts surrounded by deep oceanic waters and many are remote from most human disturbances, with the obvious exception of global climate change. The previous reports from Global Coral Reef Monitoring Network (GCRMN) and the World Resources Institute have considered the coral reefs of the Pacific, especially those from the Central Pacific island and atoll reefs, as the least degraded on the planet. One could say that these reefs should probably remain the best reefs of the world in the next few decades.

We are particularly pleased to endorse the timing for the current report 'Status and Trends of Coral Reefs of the Pacific'. This is especially timely in that 2018 is the third International Year of the Reef (IYOR 2018) launched by the International Coral Reef Initiative (ICRI), coordinated by France and Madagascar, to be followed by Australia, Monaco and Indonesia, who will lead the IYOR initiative from 2018-2020. The first International Year of the Reef was launched by the USA and was principally led by the Department of State and the National Oceanographic and Atmospheric Administration (NOAA) in 1998 (IYOR 1998). This was preceded in 1997 by the Pacific Year of the Reef largely organised by the Secretariat for the Pacific Environmental Programme (SPREP), which featured a multitude of island-based community events focused on celebrating the strong links that Pacific Island people share with their coral reefs. These people have developed strong cultural and resource links and practices that relied on healthy reef re-sources for their very existence.

One of ICRI's primary objectives is to communicate with governments, relevant agencies and the public to raise awareness about coral reef issues, and, in particular to bring attention to the key threats facing today's coral reefs and the actions that can be taken to reduce these threats. The second International Year of the Reef was held in 2008 (IYOR 2008) to build progress since the initiation of ICRI. IYOR 2008 was announced by the Secretariat of Japan and Palau in 2006 and hosted by the USA and Mexico. The Global Coral Reef Monitoring Network (GCRMN) released the 'Status of Coral Reefs of the World: 2008', featuring expert opinions from 372 coral reef scientists and managers from 96 countries, territories, and economies. This global report estimated that the world had effectively lost 19% of the original reef area since 1950, and 15% was at a critical state, with loss possible within the next 10 to 20 years. However, the report listed 46% of the world's reefs as healthy and not immediately threatened except for 'currently unpredictable' global climate change threats; most of the 46% are in the Pacific. Thus, this report 10 years later can help to further assess the negative effects of climate change and the positive results of coral reef conservation management efforts.

ICRI was initiated at the Small Islands Developing States conference in Barbados in 1994, and held its first major meeting in Dumaguete, Philippines, in mid-1995. The 35 countries present recognised that data on reef status and trends were essential for effective coral reef management and conservation, therefore one of the four ICRI platforms was Research and Monitoring. They also recognised that current reef monitoring mechanisms were inadequate to meet this challenge, thus they recommended the development of the Global Coral Reef Monitoring Network (GCRMN). This was established under the sponsorship of IOC/UNESCO, UN environment, IUCN and the World Bank with a financial catalyst provided through the government of the USA. The GCRMN has two distinct goals: gathering information on the status and trends in coral reefs around the world; and raising awareness amongst those who participate and observe the monitoring to stimulate rapid action to reduce damaging impacts. The main mechanisms to contact governments are through national, regional and global status reports, and through national and international forum communication.

The first Global Coral Reef Monitoring Network report 'Status of Coral Reefs of the World: 1998' was published based on summary reports on reef regional status presented at a special session organized during the 8th International Coral Reef Symposium in Panama in 1996 by established experts. This report included two Pacific chapters compiled by just three authors: Jim Maragos, Charles Birkeland and Gregor Hodgson. Many people at that time suggested that it was too premature for the GCRMN to attempt a global report on coral reef status, but the report was based on what little information we had on the reefs of the world and indicated very clearly that there were large gaps in our information base, especially in the Pacific. This was the main message in that report: there was insufficient information and data on the status of Pacific coral reefs to base management and conservation policies. That report was one of the catalysts for this much, much larger and more comprehensive report, which results from the input of about 100 reef scientists and managers.

There has been a steady progression of reports on coral reef status since 1998. Even as the first report was being presented at an ICRI General Meeting in Townsville in 1998, alarming reports were coming in of mass bleaching event around the World. Before the massive El Niño - La Niña climate shifts of 1997-1998, the focus at that time was on two themes - managing coral reefs recognising the natural and human stresses. Climate change had not appeared as a major threat but was considered as a threat into the future. The climate shift events of 1998 changed all that. Al Gore, the Vice President of the USA, wrote the foreword to 'Status of Coral Reefs of the World: 2000': «Scientists now believe that coral reefs may be the first natural ecosystem to clearly show the potential impacts of global climate change». The key finding of that report was that 16% of the world's coral reefs had largely been destroyed; not all have recovered since then. Four chapters were devoted to the Pacific under the coordination of Robin South, Bernard Salvat, Charles Birkeland and David Gulko. The following GCRMN reports in 2002, 2004 and 2008 adopted almost the same format. The two last reports mentioned an effective loss of about 20% of the surface area of coral reefs in the World, which mainly resulted from damaging human activities unrelated to climate change. This percentage has been misinterpreted by some in media outlets and frequently quoted in the scientific literature and media, even currently, about the losses of reefs due to climate change. The 2004 and 2008 reports indicated that many of the reefs degraded during the global bleaching of 1997-98 were gradually recovering. The GCRMN 2008 report edited by Clive Wilkinson, as all reports since 1998, was the last one reporting on the world scale.

GCRMN reports since 2008 have adopted a more regional format with reports on damage from the Indian Ocean tsunami of late 2004, massive coral bleaching damage throughout the wider Caribbean in 2005, a precursor to this Pacific report in 2011, and a Caribbean report in 2014 edited by Jeremy Jackson and colleagues.

The Pacific region has been probably the most active in continuing the reporting of coral reef status and trends, especially through the French coral reef group IFRECOR and the CRIOBE station in French Polynesia, lead initially by Bernard Salvat and more recently by Serge Planes. They issued special Pacific reports in 2000, 2004, 2008 with the focus on French territorial areas. In 2011, there was a Pacific wide status report 'Status of Coral Reefs of the Pacific and Outlook: 2011' through the same network and edited by Andrew Chin and seven others. This report continued the appraisal that many Pacific reefs remained in good to excellent health, especially those surrounding remote islands and the atolls. These remote Pacific reefs (and also other remote reefs in the Atlantic and Indian Oceans) warrant special attention for conservation as most are removed from the stresses that arise from continental land masses: organic and heavy metal pollution; sediment inundation; over- and unregulated fishing; and development pressures on or near the reefs. Most of these remote reefs have grown on top of seamounts, surrounded by deep oceanic waters, such that any land-based pollution is rapidly dispersed, and fishing pressures are often light or virtually non-existent. The deep water and upwellings of cooler water along with oceanic currents suggest that these remote reefs will have the greatest potential to resist and recover from warm water bleaching damage, with the probable exception of increasing ocean acidification (which will affect all reefs). Thus, these reefs are a global treasure trove that we should cherish. It is not considered that these reefs will be able to repopulate other reefs as the movement of coral and other reef larvae and juveniles will be restricted. But this does not exclude the possibility that Pacific reefs may be a form of 'insurance reservoir' to physically repopulate reefs elsewhere once the major threats of global climate change have abated.

This report of 220 pages written by nearly 90 authors clearly presents the summation of an enormous amount of data and information on 19 of the 23 nations and states of the Pacific and outlines both the problems and stresses on these thousands of reefs, and the potential that these reefs will prove to be the reservoir of coral reefs for the world in the immediate future with the largest threat being global climate change. Although the following chapters illustrate that coral reefs in the wider Pacific are facing many threats and have shown significant losses of coral reef structure, this report clearly demonstrates that Pacific reefs without much doubt contain the best coral reefs systems in the world and should remain in that position for the immediate decades to come.

PREFACE

This document is part of the status report series of the Global Coral Reef Monitoring Network (GCRMN) founded in 1995 as part of the International Coral Reef Initiative (ICRI) to document the ecological conditions of coral reefs, to strengthen monitoring efforts, and to link existing organisations and people working with coral reefs around the world.

The GCRMN reports have sought to present the status of coral reefs of the world and of particular regions, the major threats to the reefs and their consequences, and the initiatives undertaken by the International Coral Reef Initiative (ICRI) or other organisational bodies to prevent coral reef decline and to foster coral reef recovery.

The first GCRMN report presenting both current status and long-term trends of coral reefs focused on the Caribbean region (Jackson et al. 2014), documenting trends for corals, macroalgae, sea urchins, groupers and parrotfish based on data from 90 reef locations (34 countries, states and territories) over the past 43 years. Following this, the Western Indian Ocean (WIO) report (Obura et al. 2017) was launched and presented the analysis of coral reef data from 9 countries. The present report mirrors the work achieved for the Caribbean in 2014 and the WIO in 2017, and focuses on the Pacific Island region, north and south, from the Republic of Palau to the Pitcairn Islands. It is thus the third in a series of reports dedicated to describing the present status and long-term trends of coral reefs, with one report for each biogeographic area. Plans for additional reports, including those for the Asia Pacific region and the Eastern Pacific region are currently underway. GCRMN regional reports will support compilation of a global report on coral reef status and trends, to be published in 2020.

The authors and editors are cognisant that the period of data (1999-2016) contributing to this report cannot fully assess impacts of the recent series of global coral bleaching events that have occurred since 2014. We expect that by 2020 the global synthesis report will note additional widespread major declines of the type now recorded nearby in the Great Barrier Reef, Australia. Future monitoring and reporting may also need to better assess impacts of ocean acidification and increasing frequency of severe tropical cyclones.

The Pacific report has been coordinated by the Centre de Recherches Insulaires et Observatoire de l'Environnement (CRIOBE–, PSL Université Paris-EPHE-CNRS-UPVD) located in both Moorea in French Polynesia (a French overseas territory) and Perpignan, France, when the ICRI Secretariat was hosted by France in 2016-2018.

The objectives of this work were:

1. To document the past trends and current status of corals, macroalgae, other invertebrates, and fish based on

available data from a range of bodies (research institutes, universities, private companies, individual scientists, regional organisations, non-governmental organisations, etc.);

2. To bring together data providers and regional experts for two international workshops to include them in execution of the report (Honolulu, Hawaii, October 2016, and Paris, France, October 2017);

3. To review coral reef data in light of geographic, environmental, management, and socio-economic data to better understand the factors responsible for coral reef change, the possible synergy among factors, and how the pressures put on the reefs could be alleviated;

4. To work with GCRMN partners in the Pacific Islands region to establish standardised protocols for the future simple and efficient monitoring and assessment of coral reefs;

5. To disseminate information and results to help guide member state policy and actions at local and global scales.

The results of this work, based on the methods used for the Caribbean and WIO regional analysis, provide a better understanding of the reasons why some reefs are in better condition than others, help identify actions that are beneficial or harmful to coral reefs, and communicate major findings in a straightforward manner to foster more effective conservation and management of coral reefs.

The challenge that arose during the completion of the report was to find and combine disparate datasets in the vast Pacific Island region to explore how the major components of the reef ecosystem interact at this large scale. More than 200 partners from all Pacific countries and territories were contacted to enquire about raw longitudinal data on coral reefs. In total, we collected data from 19,270 ecological surveys carried out by principal investigators and colleagues working in 19 countries, states, and territories throughout the Pacific Island region extending from the Republic of Palau to the Pitcairn Islands, in the northern and southern Pacific. A workshop was organised in October 2016 in Hawaii to bring together data providers to assist with data quality control, analysis, and synthesis. Feedback from the collaborators was sought throughout the completion of the report (relevancy of the analyses, layout of the results, concluding remarks, Country Reports, etc.). A second workshop with regional experts involved with the report was organised in Paris in October 2017 to review the analyses, major trends, prepare the format of the final version of the report, and provide the recommendations for coral reef sustainability in the Pacific.

This regional report is divided into two sections. Part I provides an overview of the overall status and trends and detailed analyses of the influential factors of coral reef condition in the Pacific. Based on the outcomes, it provides recommendations on several directions to improve coral reef conservation. Part II (i.e. country reports) provides detailed analyses of the status and trends of coral reef ecosystems in each of the 19 countries, states, and territories for which we gathered the data. Each country report includes maps indicating all locations monitored, a table of data sources, a brief paragraph with information on the country, a timeline of ecologically important events reported, and relevant references. Each country report was compiled in consultation with local experts. People who provided data, advice, and comments are listed as co-authors in each country report.

The editors are grateful to all the people who have generously provided data, advice and expertise throughout this work. We assume responsibility for the statements, conclusions and recommendations throughout the text.

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The executive summary was translated in French by Charlotte Moritz and Cécile Berthe. Jeanine Almany worked to improve the final version of the report.

Administration: Elodie Millet for assitance in organising the workshop in Paris ; Michelle Choe for assitance in organising the workshop in Hawaii ; Nathalie Tolou, Aurélie Mariotti, Marie-Louise Mascunano for assitance in organising the 32nd ICRI General Meeting in Nairobi in Kenya.

Supporting programs, data sharing: (Fiji surveys 2000 - 2010: Georgia Aquarium, Waikiki Aquarium, Walt Smith International, Aquarium Fish Fiji, and The Henry Foundation per Bruce Carlson)

Two workshops were held during the process of completing this report. The first workshop (Hawaii, USA, October 2016) was funded by the UN Environment Programme and the French Ministry for the Ecological and Inclusive Transition. The second workshop (Paris, October 2017) was funded by the Government of Sweden and the assistance of the French Foundation for the Research on Biodiversity (FRB, created in 2008 from an initiative of the Ministries of Research and Ecology), which mission is to support and act upon research to increase and transfer knowledge about biodiversity.

LIST OF ACRONYMS

ANOSIM analysis of similarity

CCA calcareous coralline algae

CNRS Centre National de la Recherche Scientifique

CNMI Commonwealth of the Northern Mariana Islands

CREP Coral Reef Ecosystem Program

CRIOBE Centre de Recherches Insulaires et Observatoire de l'Environnement

DAR Division of Aquatic Resources of the USA

DHW Degree Heating Week

EEZ Exclusive Economic Zone

FCRMN Fiji Coral Reef Monitoring Network

FSM Federated States of Micronesia

GBR Great Barrier Reef

GCRMN Global Coral Reef Monitoring Network

GDP gross domestic product

GIS geographic information system

HDI Human Development Index

ICRI International Coral Reef Initiative

IRD Institut de Recherche pour le Développement

KS Kolmogorov-Smirnov

MTES Ministère de la Transition Ecologique et Solidaire (Ministry for the Ecological and Inclusive Transition)

NMDS non-metric multidimensional scaling

NOAA National Oceanic and Atmospheric Administration

NPS National Park Service

PACN Pacific Island Network

PCA principal component analysis

PICRC Palau International Coral Reef Center

PRIA Pacific Remote Island Area

RORC Réseau d'Observation des Récifs Coralliens

RMI Republic of the Marshall Islands

SO CORAIL Service d'Observation CORAIL

SPREP Secretariat of the Pacific Regional Environment Programme

SPC Secretariat of the Pacific Community

UN Environment United Nations Environment Programme

STATUS AND TRENDS OF CORAL REEFS OF THE PACIFIC

EXECUTIVE SUMMARY

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INTRODUCTION

While covering only 0.02% (250,000 km^2) of the ocean surface, coral reefs provide shoreline protection, food, and income for over half a billion people. The basis for these ecosystem services is exceptional biodiversity and productivity as coral reefs are home to nearly 30% of all marine species. The social reliance on these important ecosystem services make coral reefs a priority for conservation.

The Pacific Ocean is the largest water mass on Earth, covering a third of the planet (about 166 million km2), bound by five continents, and home to more than 25,000 islands. The tropical Pacific region holds approximately 25% (about 66,000 km2) of the global coral reef area. Spread across such a large area, these reefs vary considerably in terms of proximity to continents, reef structure, and biodiversity, as well as frequency and intensity of natural disturbances.

Many coral reefs in the Pacific are often said to be in good health, largely because they are extremely isolated and/or are subject to fewer human impacts when compared to other regions such as the Caribbean (cf. World Resource Institute in 2011). For these isolated Pacific islands and atolls, it is assumed that the dominant drivers of coral reef state and ecosystem dynamics are presumably naturally-occurring acute events such as cyclones, crown-of-thorns starfish outbreaks, and bleaching (assuming, while unlikely, they are disconnected to climate change). In the absence of direct human stresses, reefs naturally recover at a rate that is dependent on the intensity and frequency of the disturbances. Nevertheless, catastrophic events such as tsunamis (eg, Samoa 2009) and severe tropical cyclones (eg, Evan, Winston, Pam, Gita) are appearing more frequently, which will likely create further stresses and long-term declines. Recovery of reefs since the devastating 2009 tsunami in Samoa has been very minimal.

However, over the past decade, several scientific studies have shown signficant declines in the coverage of live coral in some areas of the Pacific, especially in areas inhabited by humans. Coral reefs are susceptible to increased temperature stress irrespective of their proximity to human populations, as evident from the severe impacts that the global coral bleaching event has had in many localities within the Pacific since 2014. Growing evidence of widespread global coral reef degradation and the early-warning signs of Pacific reef decline call for a detailed assessment of the current status and trends of coral reefs of the

Pacific islands, in support of region-wide efforts towards the sustainable management of coral reefs.

Pacific islands and archipelagos include sovereign states as well as associated states or territories of continental countries. The human population has grown significantly over the last century, and islands of the Pacific Ocean now host ca. 8 million people, for whom coral reefs are an integral part of the culture and provide most of their food resources (25 to 100% of dietary protein). However, population density is not uniform across and within islands, with migration increasing populations in main cities, and decreasing populations in remote islands and outlying areas. The economic discrepancies are strong, with per capita Gross Domestic Product (GDP) ranging from 1,035 USD in Tokelau to 54,500 USD in Hawaii (United States of America). As a consequence, resources allocated to long-term coral reef management, conservation, monitoring, and research are often uneven among countries.

While biogeographic, ecological, and socio-ecological studies at fine to medium scale have become more common, a detailed assessment of the status and trends of Pacific coral reefs is lacking. The most recent regional report on the status of coral reefs in the Pacific, published in 2011 ('Status of Coral Reefs of the Pacific and Outlook'), included an analysis of the reef vulnerability for each country, but did not present a quantitative assessment of coral reef status and long-term change, which is the main goal of the present report.

THIS REPORT

Shedding light on past trends and current status of coral reefs is essential to establish appropriate long-term management practices, for the sustainability of coral reefs and local communities and in support of the development efforts for Pacific Island countries and territories. This report is the result of a regional collaborative effort initiated in 2015 to address this information gap, by compiling and analysing long-term coral reef biophysical data in order to assess status and trends of coral reefs at country and ocean-basin scales.

Time series data were compiled for countries and territories from the Republic of Palau in the west to the Pitcairn Islands in the east, including the southernmost islands of French Polynesia and the northernmost islands of Hawaii (Fig. 1). To obtain these data, we contacted more than 200 people in all Pacific nations or associated continental countries (e.g. France, USA). Data providers were from a broad range of institutions, including governmental agencies, universities, non-governmental organisations, and private companies, and also included independent researchers and consultants. This is the first Pacific-wide compilation of data of its kind, and all data were provided on a voluntary basis. This powerful resource has enabled an in-depth analysis on the status and trends of coral reefs of the Pacific.

The collected data were unevenly distributed across the region (Fig. 1). Datasets were obtained from most islands and territories, including some intensively monitored areas (e.g. New Caledonia and Guam). As no time series monitoring data were available from Niue, Nauru, Tuvalu, Tokelau, the Solomon Islands, and Matthew and Hunter Islands, these locations are not considered in this report.

This summary focuses primarily on the following components of the coral reef ecosystem: percent cover of live hard coral, percent cover of macroalgae, and herbivore fish biomass, which is considered a regulator of algal cover. The analysis encompassed datasets where the benthic component record included at least live hard coral cover. However, most datasets also included macroalgae cover. Calculation of herbivorous fish biomass was possible using taxon-specific length-weight relationships when abundance and individual size of fish were available. Data spanned approximately three decades, starting in 1983 with fish and in 1989 for the benthos. Most monitoring programs, however, started in the late 1990's, making it difficult to detect Pacific-wide trends prior to this time, and finished in 2016, limiting any detailed analysis of the last bleaching events (2014-2017).

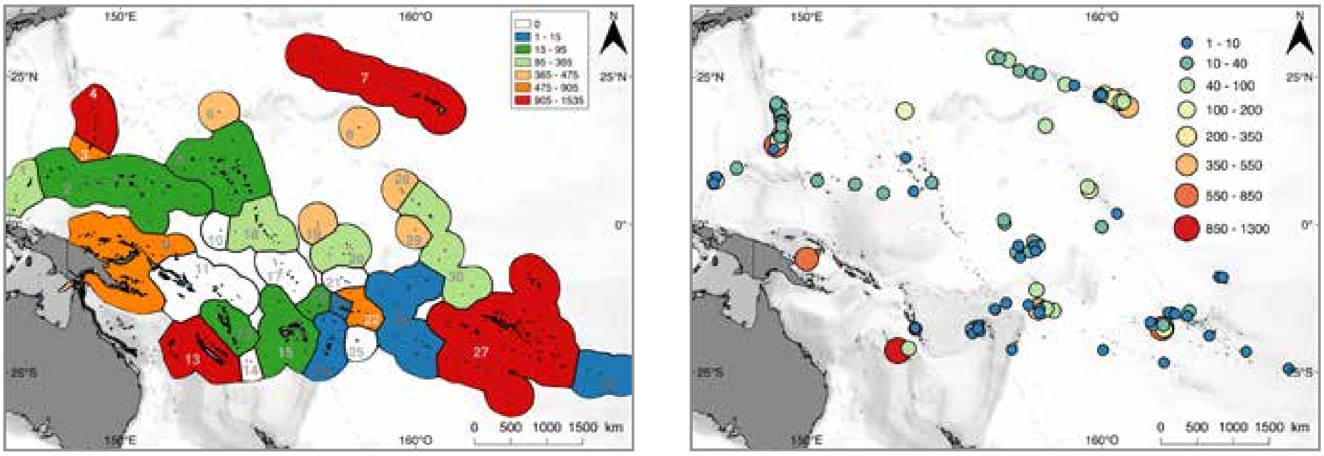


FIGURE 1

Left: Exclusive Economic Zones (EEZ) for each country or territory with colours indicating the sampling effort per territory (1: Palau; 2: Federated States of Micronesia; 3: Guam; 4: Commonwealth of the Northern Mariana Islands; 5: Republic of the Marshall Islands; 6: Wake Island (Pacific Remote Island Areas); 7: North-western & Main Hawaiian Islands; 8: Johnston Atoll (Pacific Remote Island Areas); 9: Papua New Guinea; 10: Nauru; 11: Solomon Islands; 12: Vanuatu; 13: New Caledonia; 14: Matthew & Hunter Islands; 15: Fiji; 16: Wallis & Futuna; 17: Tuvalu; 18: Republic of Kiribati - Gilbert Islands; 19: Howland & Baker Islands (Pacific Remote Island Areas); 20: Republic of Kiribati - Phoenix Islands; 21: Tokelau; 22: American Samoa; 23: Samoa; 24: Tonga; 25: Niue; 26: Cook Islands; 27: French Polynesia; 28: Kingman Reef & Palmyra Atoll (Pacific Remote Island Areas); 29: Jarvis Island (Pacific Remote Island Areas); 30: Republic of Kiribati - Line Islands; 31: Pitcairn Islands); Right: Sampling effort per island: circle size and colour represent the number of surveys (year dataset) at each island. Both maps represent the effort allocated for substrate monitoring.

Overall, data from 129 islands, covering 19 countries or territories, were collected, representing 19,270 individual surveys (year dataset). Datasets covered fringing, barrier, and fore reefs or island edges, from shallow reefs to a depth of 21 meters. Geographic, socio-economic, demographic, and environmental parameters were also compiled to identify the potential drivers of coral reef trends.

PATTERNS OF CORAL REEF CHANGE

Coral and macroalgae

The average live coral cover across all islands and all years monitored was 25.6% (SE±0.8%). The average live coral cover in 2016 (end of the study period) across all monitored islands was 21.3% (SE±3.3%) (Fig. 2). Live coral cover varied from year to year according to locations over the 28 years covered by this study (from 1989 to 2016). Overall, the average live coral cover across all islands over time has been remarkably stable across the Pacific (Fig. 2).

Prior to 1999, annual sampling covered less than 10 islands, corresponding to a maximum of 5 different archipelagos, located only in the southern hemisphere (French Polynesia). For this reason, pan-Pacific time trends are considered from 1999-2016 (17 years) only, after the onset of large-scale monitoring programs, such as NOAA and PACN. The 28-year time series from French Polynesia, however, offers the opportunity for a detailed assessment of coral reef recovery following a major disturbance event in 1991, and these are detailed later and in the full report.

A limited decline in percent of coral cover over time is evident, with a loss of about 3%

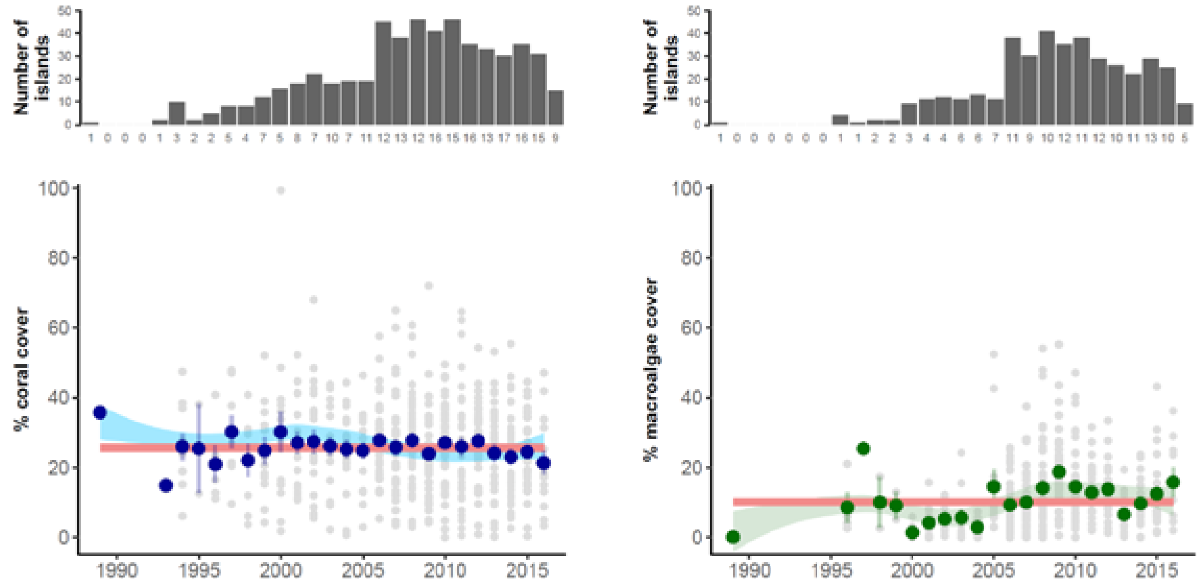


FIGURE 2

Average annual percent cover across islands (blue dots on the left panel: live hard coral; green dots on the right panel: macroalgae) and standard error (blue and green segments, respectively) between 1989 and 2016. Grey dots represent the average annual percent cover for each island. The red line represents the average percent cover across the study period. The shaded blue and green area, respectively, represents the 95% confidence interval of the fit of a linear mixed-effect model including 'islands' and 'datasets' as random factors to the coral and macroal-gae cover data. Black bars on the top graphs represent the number of islands monitored per year, and the number under each bar gives the number of archipelagos monitored per year.

over 15 years (linear model on annual averages between 1999 and 2016: p=0.017, R^2=0.31). However, this decline is weak, with values just above the mean between 2000 and 2004, oscillating around the mean between 2005 and 2011, and below the mean after 2012 (red line, Fig. 2, left panel).

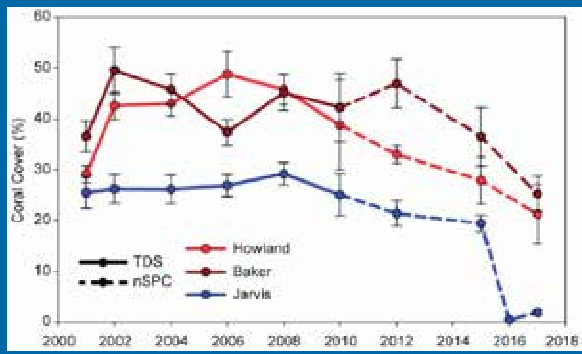
Together, these observations suggest that live hard coral cover has been relatively stable at the Pacific scale. However, substantial variation in coral cover across locations (as indicated by the spread of the data points per year, grey dots, Fig. 2) suggests that the average coral cover trend observed at the regional scale results from the combination of coral reef dynamics (i.e. trajectories) that are specific to each location. In many cases and over the long-term, reefs considered in this study recovered well after disturbances (see latter details in Boxes 2 and 3, and Country Reports).

Over the study period, macroalgae cover showed more variation around the mean of 10.3% SE±3.4% (red line, Fig. 2, right panel) than that observed for coral cover. Contrary to coral, there was a small but significant increase in macroalgal cover over time across the Pacific region (linear model on annual averages between 1999 and 2016: p=0.007, R2=0.37). Macroalgal cover was higher after 2005 than in previous years. This increase occurred in conjunction with an increase in the number of islands surveyed and also coincides with the beginning of NOAA's Pacific Reef Assessment and Monitoring Program, that sampled United States-affiliated Pacific Islands and atolls, allowing for a broader overview of the Pacific.

An analysis of data from the years where large-scale El Niño events and subsequent coral bleaching impacted the Pacific (e.g. 1997-1998, 2001-2002 and the 3-year period from 2014-2017) revealed no clear evidence of a regional decline in coral cover following these events shown in some country reports (French Polynesia, Fiji, Samoa, etc.). This result precipitated despite dramatic reductions in coral cover evident at more local scales, e.g. Jarvis Island (Box 1). The variation in benthic cover from one island to another or from one archipelago to another suggests that regional coral reef trajectories may be influenced by a variety of acute and chronic disturbances that are offsetting at the regional scale.

In general, across the Pacific and throughout the study period, average coral cover was consistently greater than average macroalgae cover. Notably, the data did not reveal large-scale or persistent coral and macroalgal shifts in response to the widespread bleaching events (i.e. El Niño and subsequent bleaching in 1997-98, 2001-02 and 2014-2017). Local (i.e. island or site scale) observations, however, showed that some islands were highly impacted by some or all of these bleaching events, but most of the reefs recovered within a decade (see Boxes 2 and 3 for specific examples). Signs of the most recent severe bleaching event (2014-2017) on the live coral and macroalgae cover are not yet clear since data were not available for about half of the locations after 2015. Further analysis will be of great interest once data become available.

The relatively stable trends observed at the Pacific scale were not consistent when examining some of the most abundant coral genera, i.e. Acropora, Pocillopora, and Porites. Indeed, the data showed a significant decrease in *Pocillopora spp.* (linear model on annual averages between 1993 and 2016: $p<0.001$, $R2=0.41$) and an increase in *Porites spp.* (linear model on annual averages be-tween 1993 and 2016: $p<0.001$, $R2=0.75$). While *Acropora spp.* were frequently reported in local studies as declining after stress events, their rapid regrowth was relatively stable in the long term (linear model on annual averages between 1993 and 2016: $p>0.05$; Fig. 3). This suggests that, while there appears to be a relative stability in total coral cover, the coral community is gradually changing towards dominant coral taxa that are likely more stress-resistant with massive growth forms, thick or less-integrated tissues, and slow growth rates. It is therefore likely that coral reefs will be different in the future, with less structural complexity and resilience to stressors such as high temperature, high energy and high sediment loads.



BOX1
Mean coral cover (%) and SE from 3 islands within NOAA's Pacific Reef Assessment and Monitoring Program (2001–08 from towed-diver surveys (TDS) at mean 15-m depth (solid lines); 2010–17 from stratified random point estimates (dashed lines). We can see that the evolution in Jarvis is different from that of Baker and Howland.

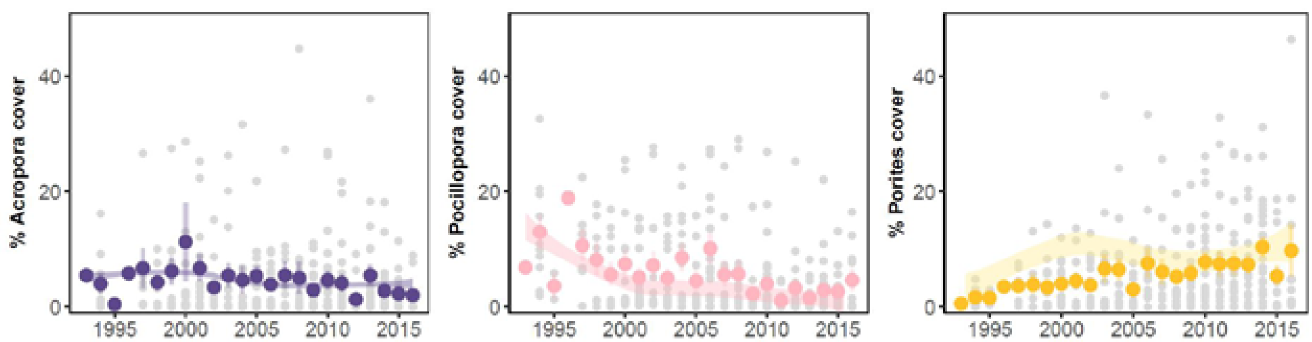


FIGURE 3
Average annual Acropora, Pocillopora, and Porites spp. percent cover across islands since 1993. Grey dots represent the average annual percent cover for each island. The shaded purple, pink, and orange areas represent the 95% confidence interval of the fit of a linear mixed-effect model including 'islands' and 'datasets' as random factors to Acropora, Pocillopora, and Porites spp. cover data, respectively.

Distinguishing trends for reefs around inhabited versus uninhabited islands may provide insights into the potential anthropogenic drivers of reef change (Fig. 4). Surprisingly, average coral cover on inhabited islands, which were more consistently surveyed, was very similar from year to year, and never varied by more than 10% across all years. Our analysis detected no significant difference between average coral cover on inhabited versus uninhabited islands over the study period (25.5% SE±0.76%; and 25.7% SE±1.80% respectively; t-test: $p=0.91$). Inhabited islands showed a slight but significant negative trend in coral cover over time (linear model on annual averages between 1999 and 2016: $p<0.016$, $R^2=0.31$) (Fig. 1). However, average values for uninhabited islands were much more variable from one year to another. No trend was detected for these islands, which was likely due to different islands being sampled in different years, skewing the average. Some uninhabited islands had average coral cover as high as 80% while young volcanic islands had coral cover as low as 5%.

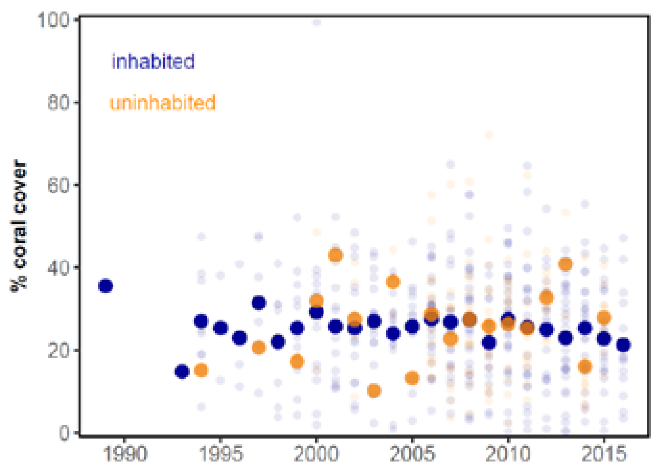


FIGURE 4
Average annual live hard coral percent cover across inhabited (blue) and uninhabited (red) islands between 1989 and 2016. Shaded dots represent the average annual percent cover for each island.

Fish biomass

Herbivorous fish are known to be an important component of coral reef ecosystems. Some fish species influence the benthic community by grazing algae and driving the competitive dynamics between coral and algae in favour of corals. We consider in this report the most important herbivorous fish species, i.e. parrotfish (Scaridae), surgeonfish (Acanthuridae), and rabbitfish (Siganidae).

Our analysis of the herbivore fish community revealed a marginally significant decrease in biomass over time (linear model on annual averages: $p=0.054$, $R^2=0.30$; Fig. 5). The decrease in herbivore fish biomass was mainly driven by the decline in surgeonfish biomass likely due to overfishing.

Average herbivore fish biomass over the study period was not significantly different between inhabited and uninhabited islands (inhabited: 34.0 SE±4.0 g.m-2; uninhabited: 23.1 SE±6.5 g.m-2; t-test: $p=0.33$). However, the herbivore fish biomass of inhabited islands significantly declined between 2004 and 2016 (linear model on annual averages: $p=0.013$, $R^2=0.44$), whereas no significant trend was observed on uninhabited islands ($p>0.05$). The declining trend in herbivorous fish biomass observed only in the inhabited islands suggests that these species are subject to strong fishing pressure by local populations. In the Pacific, many species of herbivorous fish are strongly targeted by local fisheries.

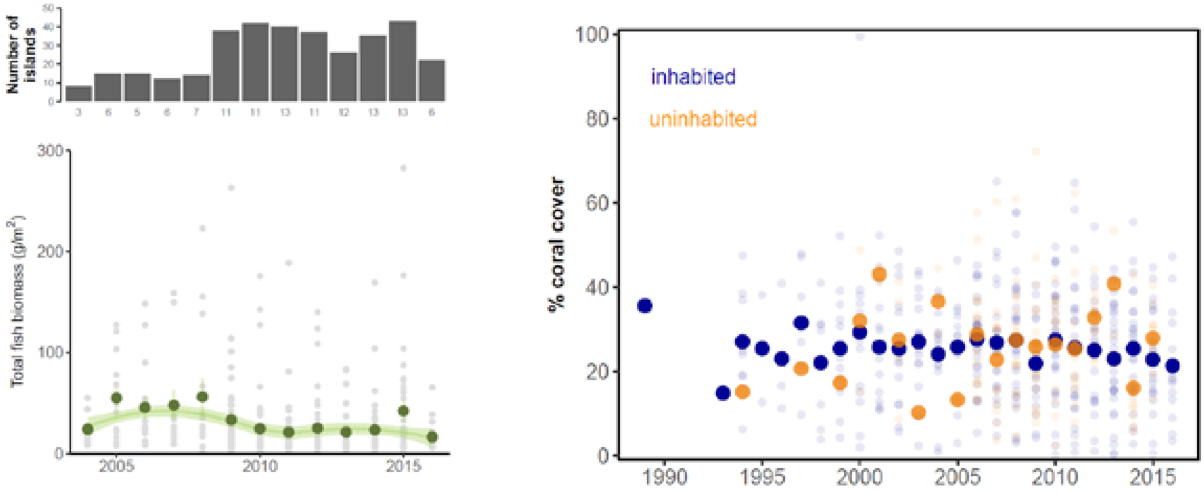


FIGURE 5

Left: Average herbivore fish biomass across islands between from 2004 to 2016. Grey dots represent the average annual biomass for each island. The shaded green area represents the 95% confidence interval of the fit of a linear mixed-effect model including 'islands' and 'datasets' as random factors to herbivore fish biomass data. Black bars on the top graph represent the number of islands monitored per year, and the number under each bar gives the number of archipelagos monitored per year. Right: Comparison of average annual herbivore fish biomass across inhabited (green) and uninhabited (red) islands between 2004 and 2016. Shaded dots represent the average annual percent cover for each island.

DRIVERS OF CHANGE

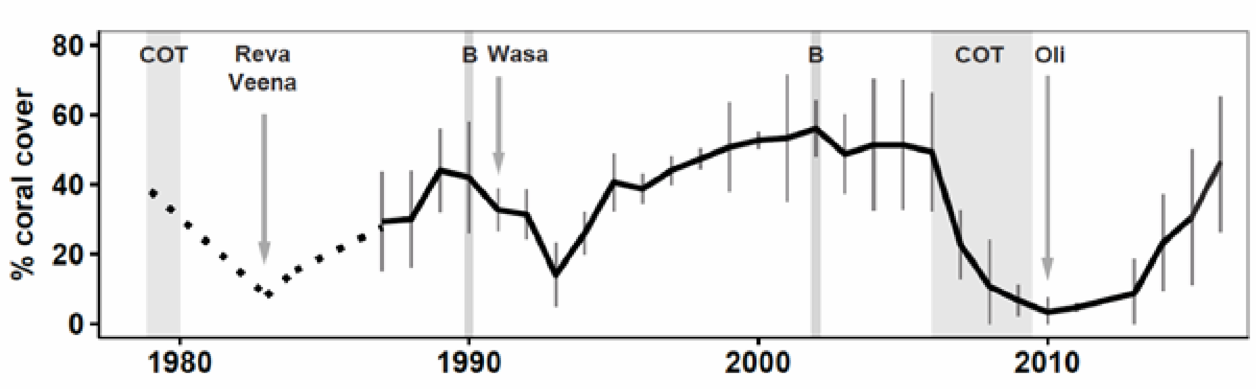
This report identifies some potential drivers of change for coral reefs in the Pacific. We used correlative approaches between available environmental and socio-economic variables and coral reef metrics. We also used specific localised case studies (see boxes 2 and 3) to look at the response to management and the recovery potential from disturbance events.

Global climate change impacts on coral reefs

The major medium to long-term threats to coral reefs at the global level arises from climate change-driven intensification of the disturbance regime, including increasing sea surface temperature and frequency of severe tropical cyclones. The impact of rising sea surface temperatures in particular leads to an increase in frequency and severity of coral bleaching events as reported in several reef areas. Corals are sensitive to changes in sea temperature, and anomalies of 1-2°C greater than normal summer highs can cause severe coral bleaching, a stress response that breaks the zooxanthellae-coral symbiotic relationship and may result in coral mortality depending on the intensity and duration of the warming event.

While our data indicate a relative stability in the Pacific regional-scale coral cover over time, clearly bleaching and mortality that occurred at numerous locations impacted the reefs at this smaller scale. Information of impacted reefs at this smaller scale are provided in the Country Reports (see the Timeline section presenting the occurrence of bleaching and other events) which show that, to date, most reefs have demonstrated a strong capacity to recover after bleaching and other acute events such as cyclones and predator invasions (Box 2). However, the datasets included in this study do not all cover the most recent bleaching event that started in the Northern hemisphere (Hawaii) in 2014 and continued until May 2017 in several islands of the Pacific. Therefore, continued monitoring efforts are essential to quantify the extent of the impacts of the largest global coral bleaching event ever recorded on overall reef ecosystem as well as for specific coral taxa.

Future projections of conditions that induce coral bleaching, based on climate change models, suggest that in a near future most reefs in the Pacific will be subject to some level of bleaching every year (after the next 15 years according to last modelling). With increasing frequency and intensity of bleaching events, the near future coral reefs in the Pacific may struggle to recover quickly enough between



BOX 2
Coral cover on Tiahura fore reef (Moorea, Society Islands, French Polynesia) over the past 40 years, highlighting the recovery phases after major disturbances (ca. 5 to 7 years of recovery process after major coral cover drops). COT: crown-of-thorns outbreak, B: bleaching event; cyclones are indicated by an arrow and their name is given. (Redrawn from Galzin et al, 2016)

consecutive events, leading to an accelerated rate of coral reef decline. In addition, sensitivity to bleaching varies between coral genera and species. Therefore, subsequent mortality of bleaching-sensitive corals (e.g. Pocillopora) and higher survivorship or recovery of thermally-resistant corals (e.g. Porites) will likely shape the biological assemblages and landscapes of reef habitats over time.

These projections also indicate that some areas might be refuges where the onset of bleaching will annual bleaching a few decades later than elsewhere (e.g. French Polynesia in 40 years). These refuges should represent conservation priorities because they are likely to provide ecosystem services longer than more vulnerable reefs and could be viewed as future sources of larvae to replenish extinct populations. With rigorous and regular monitoring efforts, these changes can be tracked to better understand the geographic vulnerabilities and the potential refugia for coral reefs.

Warmer oceans are also likely to lead to more powerful cyclones, which can damage the reef structure and also disrupt sedimentation processes thereby affecting the physiological functions of corals. Ocean acidification, driven by anthropogenic carbon dioxide emissions, is also proven to slow the growth of coral skeletons, and may in the longer term significantly affect reef growth at large scales. Both of these threats will require more attention, as only few studies exist in the Pacific Island Region to date.

Local impacts - Coastal development and overfishing

Coastal development is still limited on many Pacific islands, and is often centralized around major population hubs on larger islands. Coastal development differs among developed and developing countries, and is often dependent on island size (smaller islands tending to be less urbanised and populated). The impacts of coastal development on reefs include direct effects such as mechanical damage to coral reef (e.g. from seawalls, land filling, coral mining for road construction, building works, embankments, tourism development, etc.) and hydrodynamics modifications, as well as indirect effects such as changes in sedimentation rates and pollution from land which can affect the health of reef organisms and ultimately alter reef biota and ecosystem functions. Nutrient pollution associated with runoff (from agriculture and levelling works required on volcanic islands with a narrow coastal plain) can increase coral disease prevalence and growth of macroalgae, both directly and indirectly impacting corals. Turbidity and increased sedimentation rates also reduce available light needed for coral growth and survival, cause burial of coral colonies, especially in shallow lagoons, and affect physiological functions of other organisms.

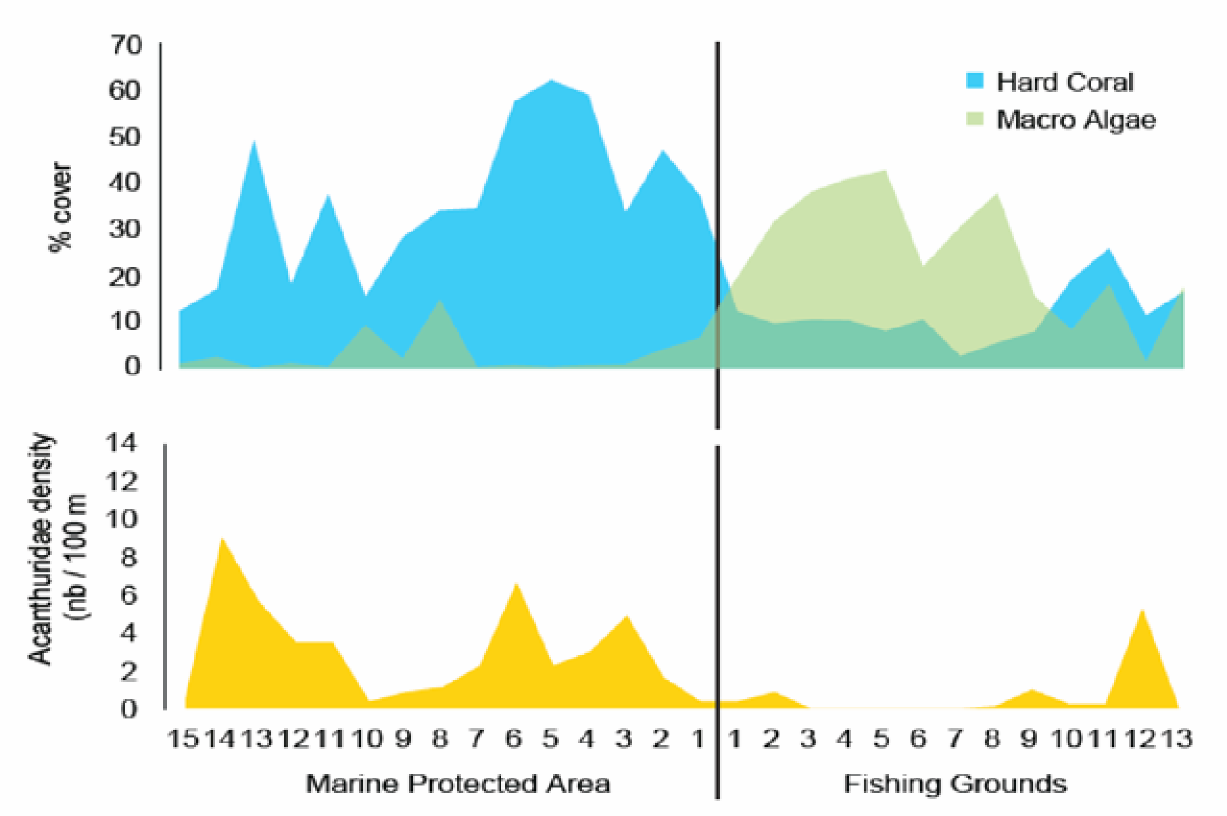
Fisheries, including reef fisheries, provide important livelihoods and sustain food security to Pacific island local communities. Overfishing contributes to coral reef degradation by altering key ecosystem processes (such an example is provided in Box 3 for a Fijian coral reef). The removal of herbivorous fish, which graze on algae that compete with corals and thereby ensure habitat suitability for coral growth, will limit recovery from bleaching events and cyclones and may contribute to long-term decline in coral cover. Our analysis showing that the biomass of herbivorous fish gradually decreased nearly by half over the last 12 years in inhabited islands (Fig. 5) suggests continuing heavy fishing pressure on reef fishes by the local communities. While a region-wide, significant shift from coral towards algal dominated reefs has not been observed, the gradual decrease in coral cover since 1999 concomitant to the increase in macroalgae during the same period is cause for concern, especially in the view of predicted increasing frequency of acute, climate change related disturbances. Anecdotal evidence of such changes is increasing at several locations that are outside of the survey locations included in the current analysis. Such a decrease of herbivorous fish biomass might be a signal of fishing pressure and should lead to conservation planning including the establishment of herbivore-specific protected areas.

Major conservation initiatives and activities

At the time of writing (2017), there were about 921 marine protected areas (MPA) in the Pacific, encompassing 8,960 km2 of coral reefs, or about 13% of the total coral reef area of the Pacific. However, only about 20% of these MPAs are considered to be enforced or effectively managed.

Because of the concern regarding reef health and in an effort to protect and preserve the remaining intact coral reefs, a number of major conservation initiatives have been undertaken in the Pacific region over the past ten years. This includes several large-scale protected areas also listed as World Heritage sites, such as the Papahānaumokuākea Marine National Monument in the Northwestern Hawaiian Islands and the lagoons of New Caledonia. In Kiribati, the Phoenix Islands Protected Area (PIPA) is one of the largest no-take marine protected areas in the world and is the largest marine conservation effort of its kind by a Least Developed CounTry. PIPA is also the largest and deepest UNESCO World Heritage Site. The Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security includes the Solomon Islands and Papua New Guinea. The Micronesia Challenge, launched by the Northern Mariana Islands, Guam, Palau, the Federated States of Micronesia and the Marshall Islands, includes a commitment to have 30% of coastal waters and 20% of the land area under conservation management by 2020. As a party to the United Nations Convention on Biological Diversity (CBD), Fiji has committed to making progress against the CBD Strategic Plan Aichi Targets, including Target 11 to achieve protection of 17% of terrestrial and 10% of marine areas by 2020, and has made a further commitment to protect 30% of its seas by 2020.

At a local scale, several traditional societies have a history of implementing an ancestral system of temporary closures of specific reef areas, and bans on fishing specific species during certain times of the year, for instance "rahui" (meaning to put in place a temporary ritual prohibition, closed season, ban, or reserve) in French Polynesia. Tabu areas within in locally managed marine areas (LMMAs) across Melanesia serve a similar purpose. However, while this system successfully sustained local, sometimes large, human populations during many generations, it has now been abandoned in many locations. Some communities recognise the need to revitalise these more traditional management systems. For instance, in Hawaii, community-based initiatives are integrated with governmental-level marine resource management on a common joint conservation effort for nearshore reef ecosystems at regional scale.



BOX 3
Coral and macroalgae cover and herbivore surgeonfish (i.e. Acanthuridae) density in 15 and 13 sites of, respectively, a marine protected area (MPA) and an area open to fishing in Fiji. The community-managed MPA was declared over a 900 m long section of shallow fringing reef in April 1998. After 11 years of protection from fishing, 3 sets of surveys were carried out within a 12 month period to measure coral and macroalgae percent cover, and the abundance of key herbivorous fish across the MPA and the neighbouring fishing grounds. Acanthuridae were numerous across the MPA, and dropped to almost none in the fished area. The shift from algal dominance to coral dominance occurred exactly at the MPA boundary. Coral heads in the fished area were overgrown with macroalgae, whereas those in the MPA were clean and had new coral recruits on their surface. (Data from H. Sykes)

CONCLUSION

The present analysis is the first of its kind for the Pacific Island Region, gathering nearly 20,000 surveys across most of the island nations. This analysis showed small changes over the last two decades for the major indicators and metrics used to monitor the reef ecosystem; live coral percent cover remained relatively stable, i.e. close to 25%. The estimated annual percent of coral cover was also systematically above the estimated annual percent of macroalgae cover, an observation that differs from several previous alarming observations (mainly in the Caribbean) that indicated a switch from coral dominance to algal dominance. However, attention should be drawn to the small but statistically significant decline in coral cover from 1999 to present at the scale of the Pacific Islands area. Interestingly, we also observed a change in dominant coral taxa, a decrease in biomass of herbivorous fish, especially on inhabited islands, and highly variable macroalgal cover within the period surveyed. These results differ from what has been observed in the Caribbean, in the Western Indian Ocean, and on the Great Barrier Reef, but are not surprising given the vast size of the Pacific, biogeographically-driven variation exists along the large latitudinal gradient across both northern and southern hemispheres, in addition to the western-eastern gradients in species diversity, and the diversity of geomorphology of the islands sampled.

The change in dominance of coral taxa may be a sign of a changing coral reef community structure, while the decrease in herbivore fish biomass may be a sign of human impact (i.e. fishing). Together these patterns suggest that, even at the Pacific scale, in an area considered less impacted than other regions in the world, coral reefs are changing. There are indications of slight decreases in coral cover and changes in the structure of coral reefs towards dominance by massive corals that provide different ecological functions. Quantifying how much the present functions of coral reefs will be affected, and how many services to humans will be altered, forms a real challenge that local communities have to face. Some concerning issues to be addressed will be: future growth and erosion of reefs and their contribution to shoreline protection (absorbing energy of ocean swells and storm waves); impacts on food productivity under modified reef habitat structures and food chains

Despite the general Pacific-wide patterns, it is important to note that, at individual locations, the reefs have been under the influence of occasional acute disturbances, with strong reduction in coral cover, but have often recovered well. Such disturbances, and recoveries, were not uniform across the Pacific Island region. This explains why the impact of each of the mass bleaching events affecting coral cover and community structure is not evident in region-wide averages, with coral cover losses in a specific area being compensated by gains in another area. The local, island-specific dynamics suggests that local-scale management actions can help to mitigate the inevitable effects of global change at least in the near future. Coral reefs in the Pacific are dynamic and recovery is likely to occur comparatively rapidly as long as local pressures and disturbance are well managed. Given the changes highlighted in coral reefs at the Pacific scale and the high variability of the reef dynamics at local scale, local management actions should be strengthened and adapted to each case to help sustain the biological reef communities.

Finally, whilst the report helps to interpret the more visibly obvious impacts of climate change (sea surface temperatures, coral bleaching) and human pressures (overfishing and land-run-off), we wish to alert readers to the seriousness of less visible but potentially more insidious stressors associated with ocean acidification. Ocean acidification should also be considered when interpreting current and future changes to coral reefs.

RECOMMENDATIONS

This compilation and analysis of coral reef time series data in the Pacific provides the basis for a number of conclusions and recommendations regarding coral reef management and policy, how monitoring is conducted in order to enhance its usability as well as research applications of the dataset that was compiled.

Data on coral reef status and trends is a valuable resource. It can support environmental planning and management decisions at multiple levels. It can contribute to and underpin ecological research, enhancing our understanding of coral reefs, their biota and their ecosystem services. It also provides a basis for informing society of the fate of an ecosystem on which people, livelihoods and economies depend. Because of this, coral reef status and trend data and reporting can directly and concretely contribute to measuring progress towards established environmental and societal goals, including the 2030 Development Agenda and specifically the Sustainable Development Goal 14. Altogether, we identified 10 recommendations in different areas as described below.

Management and policy responses

It is well known that coral reef change is driven by both local and global pressures, and that maintaining coral reef health in the longer term requires addressing these pressures of disparate scales. In the broadest sensealthough this regional analysis has found little limited change in coral reef cover, and limitedno evidence of regional-scalewide decline, but a concerning change in the coral community structure and herbivore fish biomass would call for immediate attention. Importantly, Aat the regional scale, major events of acute stress (such as bleaching episodes and crown of thorns starfish outbreaks) have to date not led to region-wide declines in coral cover. Importantly, lLocal factors are thus important in have strongly influenced resilience to pulse impact events and controlling observed long term reef trends, and this points to the need for increased attention to managing local human impacts on Pacific island reefs.

The changes in reef structure and community ecology discussed above, plus additional impacts at locations not covered under existing monitoring programmes, are evidence of declines that other regions faced in earlier years, and are therefore critical elements of concern for the Pacific.

By emphasising a reduction of local anthropogenic pressures, Pacific Islands can have a very significant influence over coral reef health and ecosystem service provision. Pacific nations have already taken steps to manage reefs, but the size of the region and extent of its reefs, combined with comparatively modest human population, have also likely contributed to less reef decline than has been observed, in other regions such as the Caribbean. Bearing in mind current regional development as well as global climate change trends, strengthened efforts are needed to keep reefs healthy into the future. Recommendations based on this are:

1. Identify, prioritise and implement actions that reduce local, chronic pressures on coral reefs arising from land use, land use change and coastal development.

Stress reduction efforts need to address nutrient, sediment and other pollution arising from land, including agriculture, farming, coastal development and associated wastewater. Specific measures should be identified, prioritised and implemented based on their importance in bolstering reef recovery. This will also require specific considerations of coral reefs in broader, integrated development and management planning processes at national level.

2. Bring use of coral reefs to sustainable levels by strengthening implementation

of fisheries legislation regulation and enforcement; with a particular focus on halting the decline in herbivorous fish, and by further expanding marine area-based management.

Most Pacific nations have relatively well-developed fisheries policy frameworks and regulations including gear and species-specific restrictions, but are often lacking in implementation, compliance and enforcement. It is therefore recommended that fisheries management efforts are strengthened to enhance compliance with existing regulations, and that regulations relating to herbivorous fish are further strengthened where relevant. Further expanding the use of marine managed areas will enhance coral reef resilience, biodiversity conservation, and fisheries productivity as well as recreational/tourism opportunities, thereby also contributing to blue economy development.

Strengthening coral reef monitoring and reporting

Coral reef monitoring in the Pacific has evolved significantly, especially over the last decade. Coral reefs in most Pacific island nations and territories have been covered by at least some ecological surveys, and regular monitoring programs now operate in most of them. However, a number of gaps and challenges remain that reduce the utility and representativeness of monitoring for regional and national level reporting, reduce the extent to which monitoring data can be used for policy and management decisions, as well as limits its use in informing society of environmental change or supporting research.

Coral reef monitoring is in general stronger in terms of coverage, variables, and frequency or regularity of measurement in developed countries and where there is international conservation or development support. Monitoring programs have been established in most Pacific Small Island Developing States (SIDS) at some point, but maintaining continuity is challenging, for example where monitoring is dependent on external project funding.

The situation in the Pacific is, in other words, similar to that documented in the Caribbean by GCRMN, where monitoring was found to be "scattered, disorganised and largely ineffective". Key recommendations in addressing the specific gaps and challenges related to coral reef monitoring and reporting in the Pacific include the following:

3. Ensure coherence and data compatibility in coral reef monitoring across the Pacific region, through the development and adoption of common monitoring indicators and data formats.

This may be pursued through GCRMN, and may entail establishment of common minimum standards, tiered to accommodate different levels of monitoring (e.g. drawing on experiences from GCRMN's work in the Caribbean). Intergovernmental adoption or endorsement of the recommended standard at the regional level will facilitate broad uptake and use among national monitoring programs as well as among other initiatives, organisations and projects. Specific consideration should be given to common data and metadata formats, common variables/indicators for coral reef monitoring, common methodological requirements, key physical parameter, and opportunities offered by new or increasingly cheap technology, such as increased use of digital imagery as well as enhanced use of microsensors where possible.

4. Strengthen data management as well as access to data and data products, through the development of a regional data repository.

A regional data platform, developed based on clearly defined principles for data contribution, access and sharing, and hosted and maintained by competent regional institutions, will strengthen coral reef monitoring and reporting and their impact, including by:

- Providing data management services to monitoring programmes that do not have sufficient capacity to operate fully fledged data systems and storage;

- Enhancing access to coral reef data, as well as a range of data products, for the advancement of environmental management and other decision making, reporting in the context of regionally or globally established targets, research, and awareness raising;
- Enabling the further development of data and reporting products, including enhanced periodic reporting on coral reef status and trends in the region, and contributions towards global syntheses;
- Ensuring data quality through the implementation of standardised meta-data and routine publication of data and data reporting.

5. Fill key geographic gaps in coral reef monitoring, with a focus on areas where monitoring is absent or highly intermittent.

This may be pursued by relevant on-going monitoring programs, as well as through establishment of new programs where required, which is likely to require additional support in terms of targeted technical assistance, capacity building, and funding. It is recognised that many locations are unlikely to be regularly surveyed through long-term monitoring programs, bearing in mind the size of the Pacific, the remoteness of some islands, and the extent of the coral reef area. Because of this, data from surveys that do not form part of a monitoring program (e.g. those conducted through various research, development or other projects) constitutes an important resource for long-term coral reef monitoring and reporting in the Pacific.

6. Support regional networking to strengthen monitoring and reporting, including exchange of expertise and capacity building, by (re-)establishing a regional GCRMN committee.

The process for preparing this report has re-energised regional communication and collaboration in relation to coral reef monitoring. Recommendations provided herein, especially in relation to monitoring, require follow-up, and many countries and territories will benefit from continued exchange of experiences and expertise, training, peer-to-peer learning, etc. Establishment of a regional network or committee (e.g. similar to the GCRMN Committee in the Caribbean) is recommended, hosted and convened by a competent regional institution.

7. Provide continuing support, including financial support, for both long-term coral reef monitoring and reporting, as well as the ability to rapidly respond and assess unexpected events.

The analysis illustrates the importance of continuous coral reef monitoring in tracking of ecosystem status and trends, and in enabling analysis of the longer-term implications of perturbations such as bleaching. Commitment to strengthening long-term monitoring across the region, including capacity building, is therefore needed. In addition, there is a need to provide rapid response funds to allow monitoring agencies and scientists to readily mobilise (and deviate from their long-term monitoring cycles) to respond and assess unexpected and transient events affecting coral reefs, such as the 2013 crown-of-thorn starfish outbreak in American Samoa, or the 2014-2017 coral bleaching event.

Further research

The dataset compiled provides a valuable resource that can be further queried, as well as enhanced by the addition of remaining data that were not possible to include in this analysis.

8. Pursue further and more in-depth analyses of the dataset, including in relation to pressures/drivers of reef change, and develop collaborative research projects for this purpose.

The dataset compiled lends itself to further analyses, beyond what was possible to do within the scope of this report. Such analyses may delve further into identifying appropriate pressure metrics and datasets, in order to gain a better understanding of the processes that control reef change in the Pacific and further sharpen recommendations for management.

9. Support greater understanding of bleaching sensitivity and other climate and human induced impacts on Pacific coral reefs, including by enhancing observation of bleaching mortality and recovery, and impacts of ocean acidification, etc.

Coral bleaching events in the Pacific have caused significant local impacts on coral cover, (see Country Reports), but region-wide coral reef decline driven by bleaching was not found in this study when analysing the large-scale trends. For the purposes of reef management planning, the speed of recovery from a bleaching event is more important than the immediate impact in terms of amount of coral bleached. In other words, good regular monitoring has greater management application than bleaching observation. However, in view of projections of future temperature stress expected to induce bleaching, it is important to enhance understanding of whether and how temperature tolerance of Pacific corals may change, and how this may impact reef communities in the longer term.

Dissemination of findings

10. Raise awareness about report findings, conclusions and recommendations, in the context of the International Year of the Reef 2018.

This analysis provides new findings on coral reef status and trends as well as a number of recommendations relevant to specific target audiences, including the general public, national policy makers, coral reef management practitioners, entities engaged in monitoring as well as researchers. Dissemination utilising a broad range of media is therefore important.

STATUS ET ÉVOLUTION DES RECIFS CORALLIENS DU PACIFIQUE

RÉSUMÉ ÉXÉCUTIF

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INTRODUCTION

Alors qu'ils ne couvrent que 0,02% (250 000 km²) de la surface des océans, les récifs coralliens assurent la protection des côtes et fournissent nourriture et revenus pour plus de 500 millions de personnes. Leur capacité à fournir ces services écosystémiques, associée à une forte biodiversité (30% de l'ensemble des espèces marines) et des forts taux de productivité, font de ces récifs coralliens une priorité pour la conservation des écosystèmes.

Le Pacifique est la plus grande masse d'eau de la planète, couvrant un tiers de sa surface (environ 165,25 millions de km²), bordée par cinq continents et comportant plus de 25 000 îles. La région tropicale du Pacifique abrite environ 25% des récifs coralliens du globe, soit environ 66 000 km². Dispersés sur une étendue aussi vaste, les récifs varient considérablement de l'un à l'autre en termes de proximité aux continents, de structure récifale, de biodiversité aussi bien qu'en fréquence et intensité des perturbations naturelles subies.

Les récifs coralliens du Pacifique sont généralement considérés comme étant en bonne santé, notamment parce qu'ils sont très isolés et soumis à des impacts anthropiques relativement faibles en comparaison avec d'autres régions du monde comme les Caraïbes (World Resource Institute, 2011). Dans les îles et atolls du Pacifique, les facteurs influençant l'état des récifs et leur dynamique sont majoritairement des événements d'origine naturelle comme les cyclones, les invasions d'étoiles de mer *Acanthaster planci* ou le blanchissement corallien (présumant que ces événements sont déconnectés des changements climatiques, ce qui semble peu probable). En l'absence de stress anthropique direct, les récifs récupèrent naturellement en fonction de l'intensité et de la fréquence de ces perturbations. Toutefois, les événements catastrophiques tels que les tsunamis (par ex. Samoa 2009) et les cyclones tropicaux intentes (par ex. Evan, Winston, Pam, Gita) surviennent de façon plus fréquente, ce qui va vraisemblablement créer des stress supplémentaires et des déclins à long-terme. Depuis le tsunami dévastateur de 2009 aux Samoa, le rétablissement des récifs a été très faible.

Cependant, lors des dernières décennies, plusieurs études scientifiques ont indiqué un déclin des récifs dans certaines régions du Pacifique, en particulier dans les îles habitées. De plus, les récifs coralliens sont sensibles à l'élévation de température quelle que soit leur distance à une population humaine comme le démontrent les impacts importants de l'événement majeur de blanchissement corallien dans plusieurs régions du Pacifique depuis 2014. La dégradation globale des récifs coralliens ainsi que les signes précurseurs du déclin des récifs du Pacifique appellent à la nécessité d'établir l'état actuel et l'évolution des récifs coralliens des îles du Pacifique en soutien aux efforts régionaux de gestion durable des récifs coralliens.

Les îles et archipels du Pacifique comprennent des états souverains aussi bien que des états ou territoires associés à des pays continentaux. La population humaine a augmenté significativement au cours du siècle passé et les îles du Pacifique comptent actuellement environ 8 millions d'habitants, pour lesquelles les récifs font partie intégrante de la culture et leur fournissent une grande partie de leur nourriture (de 25 à 100% des ressources en protéines). Cependant, la population n'est pas uniformément répartie entre les îles, et les migrations vers les centres urbains tendent à dépeupler les zones les plus éloignées. Les divergences économiques entre les pays et territoires du Pacifique sont également fortes, avec un Produit National Brut (PNB) par habitant variant de 1,035 USD pour Tokelau à 54 500 USD pour Hawaï (USA). Par conséquent, les ressources allouées à la conservation, au suivi et à la recherche dans les récifs coralliens sont souvent très différentes entre les pays.

Alors que le nombre d'études biogéographiques, écologiques et socio-écologiques de petite à moyenne échelle a augmenté ces dernières années, un état des lieux détaillé de l'état et de l'évolution des récifs coralliens du Pacifique manque encore. La dernière étude, menée en 2011 ('Status of Coral Reefs of the Pacific and Outlook'), comprenait une analyse de la vulnérabilité des récifs de chaque pays, mais elle ne présentait pas une évaluation quantitative de l'état des récifs et des changements à long-terme. C'est l'objectif principal de ce rapport.

OJECTIFS DU RAPPORT

Mettre en lumière les tendances passées et l'état actuel des récifs coralliens est essentiel pour établir des pratiques de gestion durables pour le maintien des récifs coralliens et des communautés locales, venant en soutien au développement des efforts de pays et territoires du Pacifique. Ce rapport est le résultat d'un effort collaboratif régional initié en 2015 pour combler ce manque informatif, en compilant et analysant les données biophysiques des récifs coralliens afin d'évaluer l'état et l'évolution de ces récifs à l'échelle des pays et des bassins océaniques.

Les séries temporelles des pays allant de Palau à l'est, à Pitcairn à l'ouest, et des îles les plus au sud de la Polynésie française aux Îles Hawaï du Nord (Fig. 1) ont été compilées. Pour collecter ces données, plus de 200 personnes ont été contactées dans toutes les nations du Pacifique ainsi que dans les États continentaux associés (par exemple la France et les États-Unis). Ces collaborateurs font partie d'un panel d'institutions comprenant des structures gouvernementales, des universités, des compagnies privées, et des organisations non gouvernementales ainsi que des chercheurs ou consultants indépendants. C'est la première compilation de données de ce type à l'échelle du Pacifique, et toutes les données ont été fournies sur la base du volontariat. Cette ressource précieuse a permis une analyse en profondeur de l'état et de l'évolution des récifs coralliens de la région Pacifique.

Les données collectées sont distribuées de façon hétérogène à travers la région Pacifique (Fig. 1). Des jeux de données ont été obtenus pour la plupart des îles et territoires, avec certaines zones intensivement étudiées (comme la Nouvelle Calédonie ou Guam). Puisqu'aucune série temporelle n'a pu être trouvée pour Niue, Nauru, Tuvalu, Tokelau, les îles Salomon et les îles Matthew & Hunter, celles-ci n'ont donc pas été prises en compte dans ce rapport.

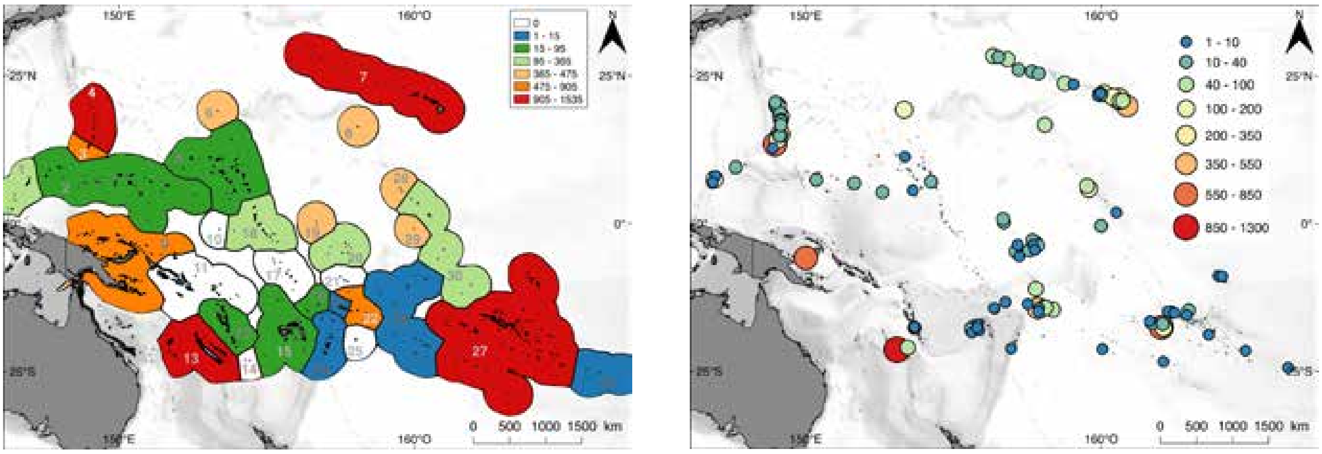


FIGURE 1
Gauche : effort d'échantillonnage (nombre d'unité d'échantillonnage) indiqué pour la Zone Économique Exclusive (ZEE) de chaque pays et territoires (1 : Palau ; 2 : États Fédérés de Micronésie ; 3 : Guam ; 4 : Commonwealth des Îles Mariannes du Nord ; 5 : République des Îles Marshall ; 6 : Wake (Pacific Remote Island Areas) ; 7 : Îles Hawaï et Îles Hawaï du Nord ; 8 : Johnston (Pacific Remote Island Areas) ; 9 : Papouasie Nouvelle Guinée ; 10 : Nauru ; 11 : Îles Salomon ; 12 : Vanuatu ; 13 : Nouvelle-Calédonie ; 14 : Îles Matthew & Hunter ; 15 : Fidji ; 16 : Wallis & Futuna ; 17 : Tuvalu ; 18 : République des Kiribati - Îles Gilbert ; 19 : Howland & Baker (Pacific Remote Island Areas) ; 20 : République des Kiribati - Îles Phoenix ; 21 : Tokelau ; 22 : Samoa Américaines ; 23 : Samoa ; 24 : Tonga ; 25 : Niue ; 26 : Îles Cook ; 27 : Polynésie française ; 28 : Kingman Reef & Palmyra (Pacific Remote Island Areas) ; 29 : Jarvis (Pacific Remote Island Areas) ; 30 : République des Kiribati - Îles de la Ligne ; 31 : Pitcairn) ; Droite: Effort d'échantillonnage par île : la taille des cercles et la couleur représentent le nombre d'études (jeu de données annuel) pour chaque île. Les deux cartes représentent l'effort alloué au suivi du substrat.

Ce résumé se focalise sur les composantes suivantes du récif corallien ; le pourcentage de recouvrement en corail vivant, la couverture algale et la biomasse de poissons herbivores, considérés comme des régulateurs dans la compétition corail-algue. L'analyse compilait des jeux de données comprenant au minimum la couverture en corail scléractiniaire (dur) vivant. Le calcul de la biomasse des poissons herbivores a été rendue possible à partir d'une relation taille-poids spécifique à chaque taxon quand l'abondance et la taille individuelle des poissons étaient disponibles. Les données couvrent environ trois décennies, l'année la plus ancienne étant 1983 pour les poissons et 1989 pour le benthos. La plupart des programmes d'observation, cependant, a commencé vers la fin des années 1990, ce qui rend difficile la détection de tendances évolutives à l'échelle du Pacifique avant cette période, et s'arrêtent en 2016, ce qui limite l'analyse du dernier événement de blanchissement massif (2014-2017).

Au total, les données de 129 îles, appartenant à 19 pays et territoires, ont été collectées, représentant 19 270 suivis distincts (jeu de données annuel). Les jeux de données couvrent le récif frangeant, la barrière récifale et la pente externe ou le tombant océanique des îles, avec des profondeurs allant de 0 à 21 m. Des paramètres géographiques, socio-économiques et environnementaux ont également été collectés afin d'identifier les facteurs influençant potentiellement l'évolution des récifs coralliens.

PATRONS DE CHANGEMENT DES RECIFS CORALLIENS

Coraux et macroalgues

La couverture moyenne en corail vivant sur l'ensemble des îles et de la période d'échantillonnage était de 25,6% (SE±0.8%). La couverture moyenne en 2016 (fin de la présente étude) était de 21,3% (SE±3.3%) (Fig. 2). La couverture corallienne a varié au cours des années en fonction des sites sur les 28 années concernées par la présente étude (1989 à 2016). Globalement la couverture moyenne en corail vivant a été remarquablement stable à travers tout le pacifique (Fig. 2).

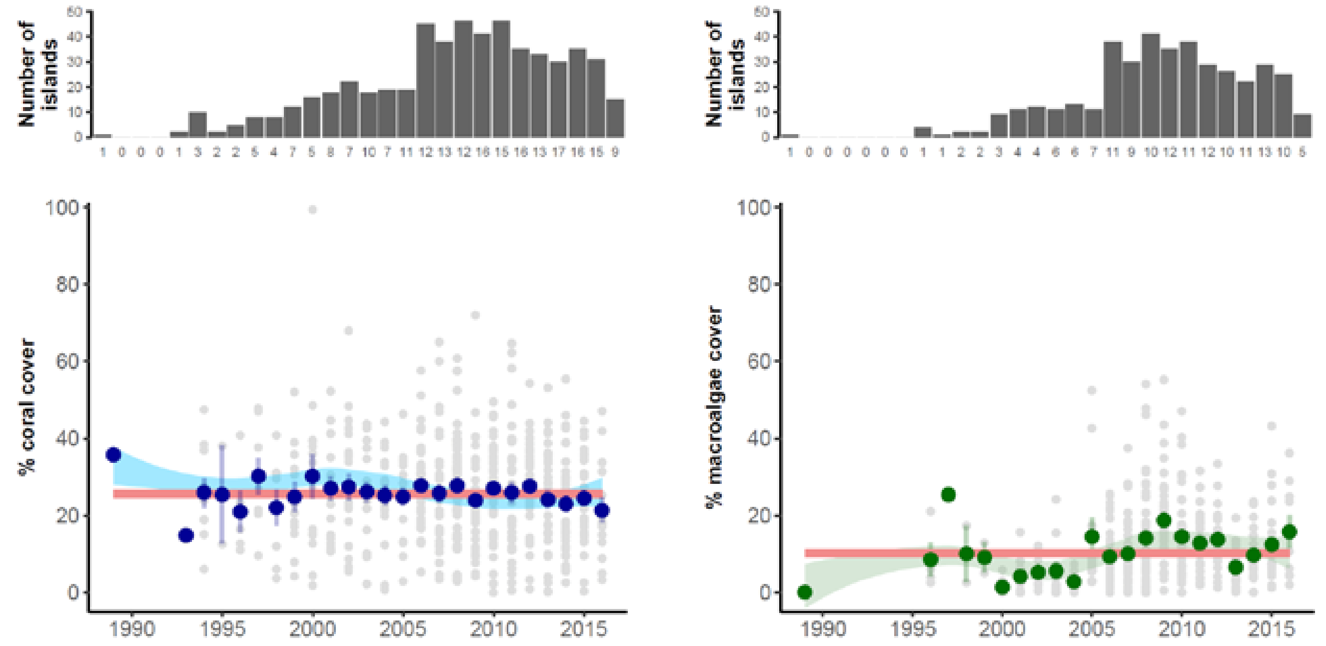


FIGURE 2

Pourcentage annuel moyen en couverture corallienne par île (points bleus sur le panneau de gauche : coraux durs vivants ; points verts sur le panneau de droite : macroalgue) et erreur standard (segments bleus et verts, respectivement) entre 1989 et 2016. Les points verts représentent le pourcentage moyen annuel en couverture corallienne par île. La ligne rouge représente le pourcentage moyen de couverture corallienne pour la période étudiée. Les zones bleue et verte, respectivement, représentent les 95% d'intervalle de confiance de l'ajustement du modèle linéaire à effet mixte comprenant « île » et « jeu de donnée » comme facteurs aléatoires pour les données de couverture corallienne et algale. Les barres noires sur les graphiques du haut représentent le nombre d'île suivies par année, et le nombre sous chaque barre, donne le nombre d'archipels suivis par années.

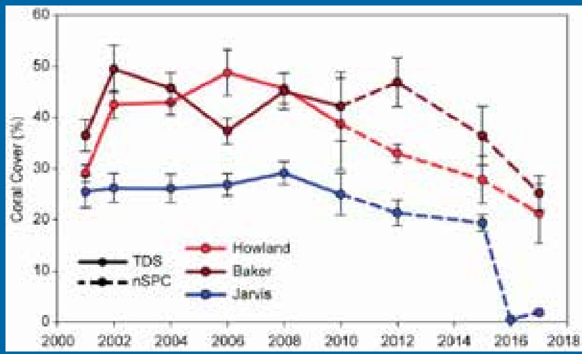
Avant 1999, l'échantillonnage annuel couvrait moins de 10 îles appartenant à cinq archipels différents maximum, situées dans l'hémisphère sud (en Polynésie française uniquement). Pour cette raison, les tendances temporelles transpacifiques sont considérées seulement de 1999 à 2016 (17 ans), après le lancement de programmes de suivis à large échelle, tels que la NOAA ou PCAN. La série temporelle sur 28 années de Polynésie française offre néanmoins une opportunité d'évaluation détaillée de la résilience des récifs coralliens après une perturbation majeure en 1991, ceci étant détaillé ci-après et dans le rapport complet.

Un déclin limité du pourcentage de couverture corallienne à travers le temps est évident, avec une perte d'environ 3% en 15 ans (modèle linéaire sur des moyennes annuelles entre 1999 et 2016 : $p=0.017$, $R^2=0.31$). Cependant, ce déclin est faible, avec des valeurs juste au-dessus de la moyenne entre 2000 et 2004, oscillant autour de la moyenne entre 2005 et 2011 et sous la moyenne après 2012 (ligne rouge, Fig. 2, panneau de gauche).

Ces observations analysées ensemble suggèrent que la couverture en corail scléractiniaire vivant a été relativement stable dans le Pacifique. Cependant des variations substantielles de la couverture corallienne à travers les sites (comme l'indique l'entendue des points par années, points verts, Fig. 2) suggèrent que la tendance moyenne en couverture corallienne observée à l'échelle régionale est le résultat de la combinaison des dynamiques des récifs coralliens spécifiques à chaque site. Dans de nombreux cas et sur le long-terme, les récifs considérés dans cette étude ont bien récupèrent après une perturbation (voir les encadrés 2 et 3).

Sur la période étudiée, la couverture algale a montré une variation plus importance autour de la moyenne de 10,3% SE±3.4% (ligne rouge, Fig. 2, panneau de droite) que celle observée pour la couverture corallienne. A l'inverse des coraux, il y a eu une augmentation faible mais significative de la couverture algale au cours du temps à travers le Pacifique (modèle linéaire sur les moyennes annuelles entre 1999 et 2016 : $p=0.007$, $R^2=0.37$). La couverture algale a été plus élevée après 2005 que les années précédentes. Cette augmentation s'est faite en conjonction avec l'augmentation du nombre d'îles suivies et coïncide également avec le début du programme de suivi et d'évaluation des récifs du Pacifique de la NOAA, échantillonnant les îles et atolls du Pacifique affiliés aux Etats-Unis d'Amérique, ce qui a fourni un plus large aperçu du Pacifique.

Lors de l'examen des années ayant connu les événements El Niño à grande échelle et des événements de blanchissement corallien consécutifs dans le Pacifique, à savoir 1997-1998, 2001-2002 et la période 2014-2017, notre analyse des jeux de données considérés dans cette étude ne révèle aucune évidence claire de déclin régional en couverture corallienne consécutif de ces événements, et cela malgré des chutes drastiques évidentes de la couverture corallienne à des échelles plus locales, par exemple pour l'île de Jaris (encadré 1). La variation qui existe au niveau de la couverture bentique entre les îles ou entre les archipels suggèrent que les trajectoires régionales des récifs coralliens peuvent être influencées par une variété de perturbations aigües et chroniques masquées à l'échelle régionale.



ENCADRÉ 1
Couverture corallienne moyenne (en %) et écart-type pour trois îles du programme d'évaluation et de suivi des récifs du Pacifique de la NOAA (de 2001 à 2008 les suivis sont réalisés par des plongeurs tractés à une moyenne de 15 mètres de profondeur (lignes pleines); de 2010 à 2017 la technique a évolué et les suivis sont réalisés à partir d'un échantillonnage stratification aléatoire (lignes pointillées)). Nous pouvons y voir l'évolution différente pour l'île de Jarvis, comparé aux îles Baker et Howland.

De manière générale, à travers le Pacifique et la période d'étude considérée, la couverture moyenne en corail vivant a été constamment supérieur à celle en macroalgues. Il est à noter que les données ne reflètent pas les changements d'état entre la dominance corallienne ou algale à grande échelle ou persistants, en réponse aux événements de blanchissement majeurs précédemment cités. Des observations à l'échelle locale (à l'échelle de l'île ou de sites d'étude) ont néanmoins montré que certaines îles étaient fortement touchées par l'un ou les trois événements de blanchissement corallien, mais la plupart des récifs ont récupéré en une décennie (voir encadrés 2 et 3 à titre d'exemple). Des signes de l'événement de blanchissement corallien majeur de 2014-2017 sur la couverture corallienne ou algale ne sont pas encore clairs, les données n'étant pas encore disponibles pour près de la moitié des sites au moment de la rédaction de ce rapport. Des analyses futures seront d'une extrême importance une fois les données accessibles. De manière générale, les observations de blanchissement corallien provenant de sites distincts montrent des impacts hautement contrastés.

Les tendances relativement stables à l'échelle du Pacifique n'étaient pas constantes à l'analyse de certains genres coralliens les plus abondants, tel que Acropora, Pocillopora et Porites. Les données ont montré un déclin significatif de Pocillopora (Modèle linéaire sur les moyennes annuelles entre 1993 et 2016 : $p=0.001$, $R^2=0.41$) et une augmentation de Porites (modèle linéaire sur les moyennes annuelles entre 1999 et 2016 : $p=0.001$, $R^2=0.75$). Alors que les espèces du genre Acropora ont fréquemment été rapportées comme déclinant après des événements de stress dans des études locales, leur croissance rapide entraîne une relative stabilité sur le long-terme (modèle linéaire sur les moyennes annuelles entre 1999 et 2016 : $p=0.005$, Fig. 3). Alors qu'il existe une relative stabilité dans la couverture corallienne globale, ces résultats suggèrent que la communauté corallienne est en train de changer

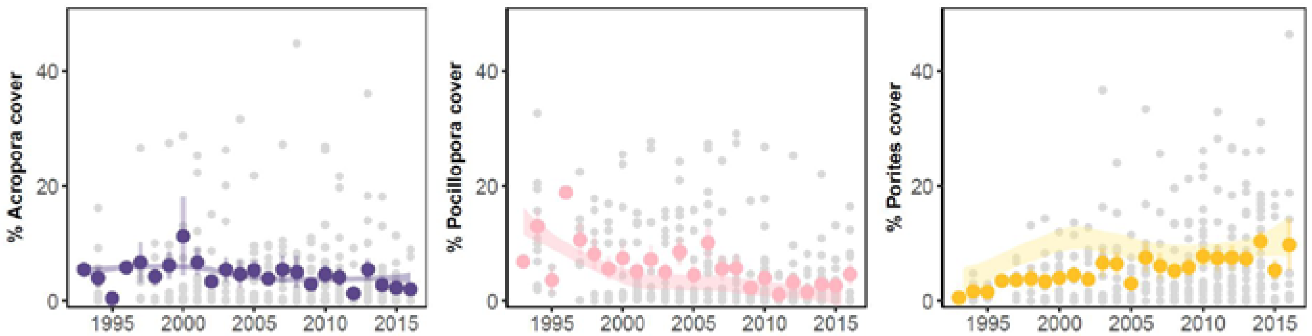


FIGURE 3
Pourcentage moyen annuel de la couverture corallienne pour les genres Acropora, Pocillopora, et Porites à travers les îles depuis 1993. Les points gris représentent le pourcentage moyen annuel de couverture corallienne pour chaque île. Les zones violettes, rose, et orange représentent les 95% d'intervalle de confiance de l'ajustement du modèle linéaire à effet mixte comprenant « île » et « jeu de donnée » comme facteurs aléatoires pour les données de la couverture corallienne des genres Acropora, Pocillopora et Porites respectivement.

progressivement avec des taxons coralliens dominants, notamment ceux plus résistants au stress, plutôt de forme massive, ou ayant des tissus épais et des taux de croissance lents. Il est alors vraisemblable que les récifs coralliens soient différents dans le futur, avec moins de complexité architecturale et de résilience faces à des stress comme l'augmentation de la température, l'augmentation des houles ou l'augmentation des apports en sédiments.

Comparer les tendances des récifs entre les îles habitées et celles inhabitées peut fournir des informations sur les facteurs anthropiques potentiellement responsables de changements dans les récifs (Fig. 4). De façon surprenante, la couverture corallienne moyenne dans les îles habitées, étudiées de façon plus constantes, a été très similaire d'année en année et n'a jamais varié de plus de 10% sur toutes les années. Nos analyses n'ont détecté aucune différence significative de la couverture corallienne moyenne entre les îles habitées et les îles inhabitées sur toute la période d'étude (25.5% SE±0.76%; et 25.7% SE±1.80% respectivement; t-test: $p=0.91$). Les îles inhabitées ont montré une légère tendance significative à la baisse de la couverture corallienne au cours du temps (modèle linéaire sur les moyennes annuelles entre 1999 et 2016 : $p=0.016$, $R^2=0.31$) (Fig. 1). Cependant les valeurs moyennes étaient beaucoup plus variables d'une année sur l'autre. Aucune tendance n'a été détectée dû au fait que différentes îles ont été échantillonnées sur différentes années, biaisant ainsi la moyenne – certaines îles inhabitées ont une couverture corallienne moyenne de plus de 80% tandis que de jeunes îles volcaniques ont en-dessous de 5% de recouvrement corallien.

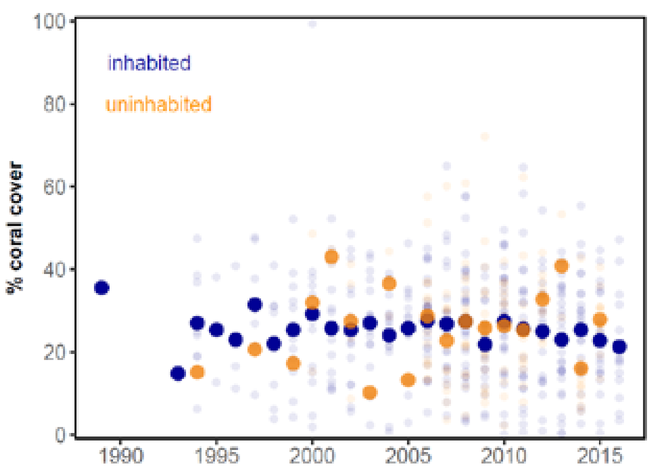


FIGURE 4
Pourcentage moyen annuel de la couverture en corail vivant dur pour les îles habitées (en bleu), et les îles inhabitées (en rouge) entre 1989 et 2016. Les points gris représentent le pourcentage moyen annuel de la couverture corallienne pour chaque île.

Biomasse des poissons

Les poissons herbivores sont connus pour être une composante importante des écosystèmes coralliens. Ils influencent la communauté benthique par leur action de broutage d'algues et régulent ainsi en faveur des coraux la dynamique concurrentielle entre les coraux et les algues. Dans ce rapport, nous nous sommes concentrés sur les espèces suivantes : les poissons perroquet (Scaridae), les poissons chirurgiens (Acanthuridae) et les poissons lapins (Siganidae).

Nos analyses sur la communauté des poissons herbivores révèlent un déclin significatif marginal en biomasse à travers le temps (modèle linéaire sur les moyennes annuelles : p=0.054, R^2=0.30 ; Fig. 5). Ce déclin est principalement dû au déclin de la biomasse des poissons chirurgiens, vraisemblablement victimes de la surpêche.

La biomasse moyenne des poissons herbivores sur la période d'étude n'est pas significativement différente entre les îles habitées et celles inhabitées (habitées : 34.0 SE±4.0 g.m-2, inhabitées : 23.1SE±6.5 g.m-2; t-test: p=0.33). Cependant la biomasse des poissons herbivores des îles habitées décline de façon significative entre 2004 et 2016 (modèle linéaire sur les moyennes annuelles : p=0.013, R^2=0.44), tandis qu'aucune tendance n'est observée pour les îles inhabitées (p>0.05). La tendance à la baisse de la biomasse des poissons herbivores, observée uniquement pour les îles habitées, suggère que ces espèces sont soumises à de fortes pressions de pêche par les populations locales. Dans le Pacifique, les poissons herbivores sont effectivement des espèces cibles pour les pêcheries.

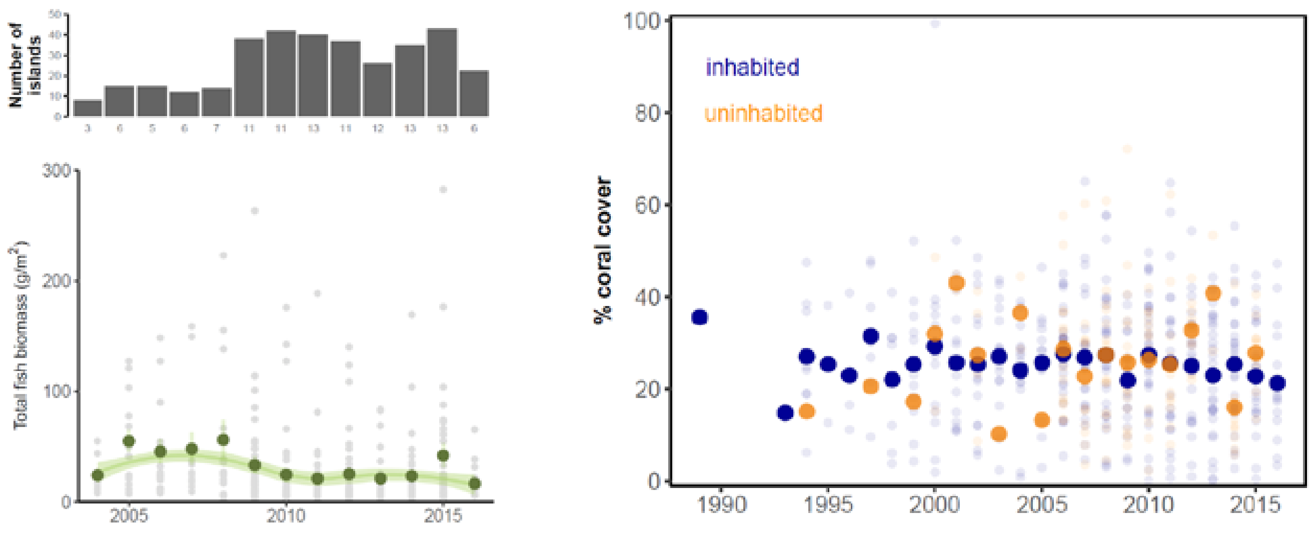


FIGURE 5

A gauche : Biomasse moyenne des poissons herbivores à travers les îles entre 2004 et 2016. Les points gris représentent la biomasse moyenne annuelle pour chaque île. La zone verte représente les 95% d'intervalle de confiance de l'ajustement du modèle linéaire à effet mixte comprenant « île » et « jeu de donnée » comme facteurs aléatoires pour les données de biomasse des poissons herbivores. Les barres noires en haut du graphique représentent le nombre d'îles suivies chaque année et le nombre sous les barres donne le nombre d'archipels suivis chaque année. A droite : Comparaison entre la biomasse moyenne annuelle des poissons herbivores des îles habitées (en vert) et des îles inhabitées (en rouge) entre 2004 et 2016. Les points gris représentent le pourcentage moyen annuel de la couverture corallienne pour chaque île.

FACTEURS DE CHANGEMENT DES RÉCIFS CORALLIENS

Ce rapport identifie des facteurs potentiellement responsables des changements des récifs coralliens du Pacifique. Nous avons corrélé nos mesures des récifs coralliens à certaines variables environnementales et socio-économiques. Nous avons utilisé des cas d'études localisés (voir encadrés 2 & 3) pour regarder la réponse à des mesures de gestion ou le rétablissement potentiel après des événements perturbateurs.

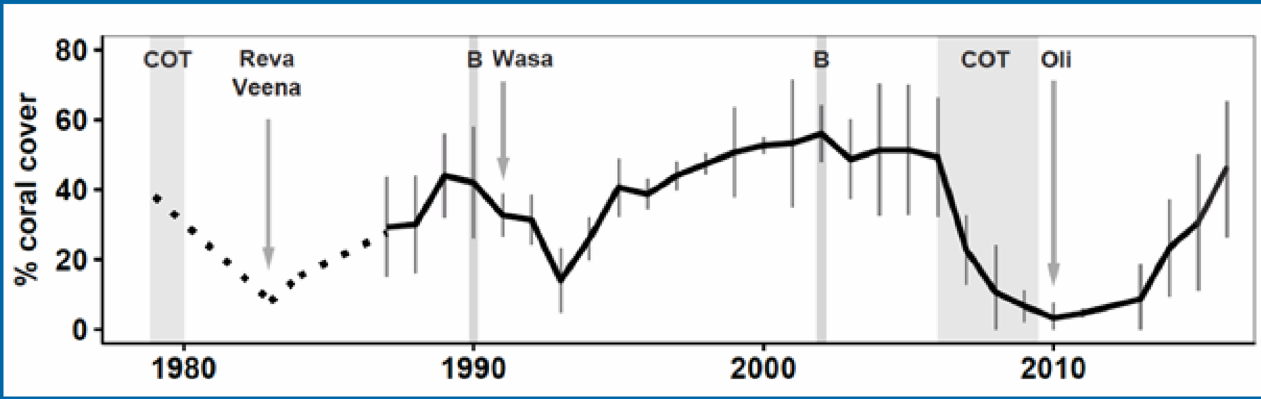
Changements globaux

Les principales menaces pesant sur les récifs coralliens à moyen et long terme proviennent de l'intensification du régime de perturbations causée principalement par le changement climatique global, comprenant l'augementation de la température des eaux de surface et l'intensité de cyclones tropicaux sevères. L'impact de l'augmentation de la température de surface des océans en particulier est responsable de l'augmentation de la fréquence et de l'intensité des évènements de blanchissement du corail comme reporté dans de nombreuses îles du Pacifique. Les coraux sont sensibles au changement de température et des anomalies prolongées de températures de 1-2˚C plus fortes que les normales saisonnières peuvent causer un blanchissement sévère, une réponse physiologique du corail qui expulse les algues symbiotiques (zooxanthelles) du polype à la suite du stress thermique, pouvant entraîner sa mort selon l'intensité et la durée de l'événement.

Alors que nos données montrent une relative stabilité dans la couverture corallienne à travers le temps à l'échelle du Pacifique, il est évident que des blanchissements coralliens et de la mortalité ont eu lieu dans de nombreux sites. A l'échelle locale, les informations fournies dans les sections par pays (section Timeline indiquant les phénomènes de blanchissement et autres phénomènes affectant les récifs) indiquent que, jusqu'à maintenant, la plupart des récifs ont démontré une forte capacité à récupérer après un événement de blanchissement corallien ou autres événements importants tels que les cyclones ou les invasions de prédateurs (encadré 2). Cependant les jeux de données inclus dans cette étude ne couvrent pas l'épisode de blanchissement récent qui a commencé dans l'hémisphère nord (Hawaii) en 2014 et qui s'est poursuivi jusqu'en mai 2017. Par conséquent, il est essentiel de poursuivre les efforts de suivi pour quantifier les dommages causés aux récifs, tant au niveau de l'écosystème que pour des taxa spécifiques.

Les projections concernant la fréquence des phénomènes de blanchissement, basées sur les modèles de changement climatique, suggèrent que les récifs du Pacifique vont être sujets à l'avenir à des événements de blanchissement annuels (chaque année suite aux 15 prochaines années, selon les dernières modélisations). Avec l'augmentation de l'intensité et de la fréquence des événements de blanchissement, il est probable que les récifs coralliens du Pacifique ne puissent pas récupérer suffisamment rapidement entre deux perturbations, ce qui accélérait le processus de déclin généralisé des récifs. De plus, la sensibilité au blanchissement varie entre les genres et les espèces de coraux. Par conséquent, la mortalité due au blanchissement des taxa sensibles (par exemple Pocillopora) et la survie ou la récupération des coraux résistants (par exemple Porites) sont susceptibles de modifier la structure des communautés et des paysages coralliens.

Ces projections indiquent également que certaines zones pourraient être des refuges où les récifs coralliens seront touchés par des événements de blanchissement annuel quelques décennies après les autres (par ex : la Polynésie française dans 40 ans). Ces refuges doivent constituer des priorités de conservation, puisqu'ils vont vraisemblablement fournir des services écosystémiques plus longtemps que les récifs plus vulnérables et pourraient servir de sources de larves coralliennes pour repeupler les populations de coraux décimées. Grâce à des efforts d'échantillonnages réguliers



ENCADRÉ 2
Couverture corallienne sur la pente externe de Tiahura (Moorea, Archipel de la Société, Polynésie française) au cours des 40 dernières années. Les phases de récupération après des perturbation majeures sont mise en évidence (environs 5 à 7 ans pour récupérer après une perturbation majeure). COT : explosion d'Acanthaster ; B : blanchissement ; les cyclones sont indiqués par une flèche avec leurs noms au dessus. (Revu à partir de données publiées dans Galzin et al, 2016)

et rigoureux, nous serons capables de suivre ces changements pour mieux comprendre la vulnérabilité des récifs à différentes échelles géographiques et les refuges potentiels pour les récifs coralliens.

Le réchauffement des océans peut également engendrer la formation de cyclones plus intenses qui peuvent fortement affecter la structure des récifs et perturber les processus de sédimentation, affectant ensuite indirectement les fonctions physiologiques des coraux. L'acidification des océans, due à l'émission anthropique de dioxyde de carbone, est un autre processus qui ralentit la croissance des squelettes des coraux et affecte de manière significative la croissance des récifs coralliens à large échelle. Ces deux types de menaces nécessitent plus d'attention car peu d'études existent encore au niveau de la région des îles du Pacifique.

Impacts locaux - Aménagement côtier et surpêche

L'aménagement des côtes est encore relativement limité dans plusieurs îles du Pacifique et est souvent localisé au niveau des centres urbains des îles les plus grandes. L'aménagement côtier diffère entre les pays développés et ceux en développement, et est souvent dépendant de la taille de l'île (les petites îles étant, en général, moins sujettes à l'urbanisation). Les impacts de l'aménagement côtier sur les récifs comprennent les effets directs, comme les dommages mécaniques (murs, remblais, extraction de corail pour la construction des routes, travaux de construction, digues, développement de structures touristiques, etc.) qui modifient l'hydrodynamisme des lagons et altèrent le rôle protecteur des récifs contre l'érosion, et les effets indirects comme par exemple les changements de taux de sédimentation, les écoulement d'eaux usées chargées en polluants qui affectent la santé des organismes et altèrent les fonctions biologiques et écosystémiques des récifs. L'excès de nutriments associés aux écoulements issus de l'agriculture et des travaux de terrassement, souvent observés sur les îles volcaniques à plaine côtière étroite, favorisent la prévalence des maladies des coraux et la croissance des macroalgues, affectant directement et indirectement les coraux. La turbidité et l'augmentation des taux de sédimentation réduit la luminosité nécessaire à la croissance et à la survie des coraux, cause l'enfouissement des colonies coralliennes, en particulier dans les lagons peu profonds, et affecte les fonctions physiologiques des autres organismes.

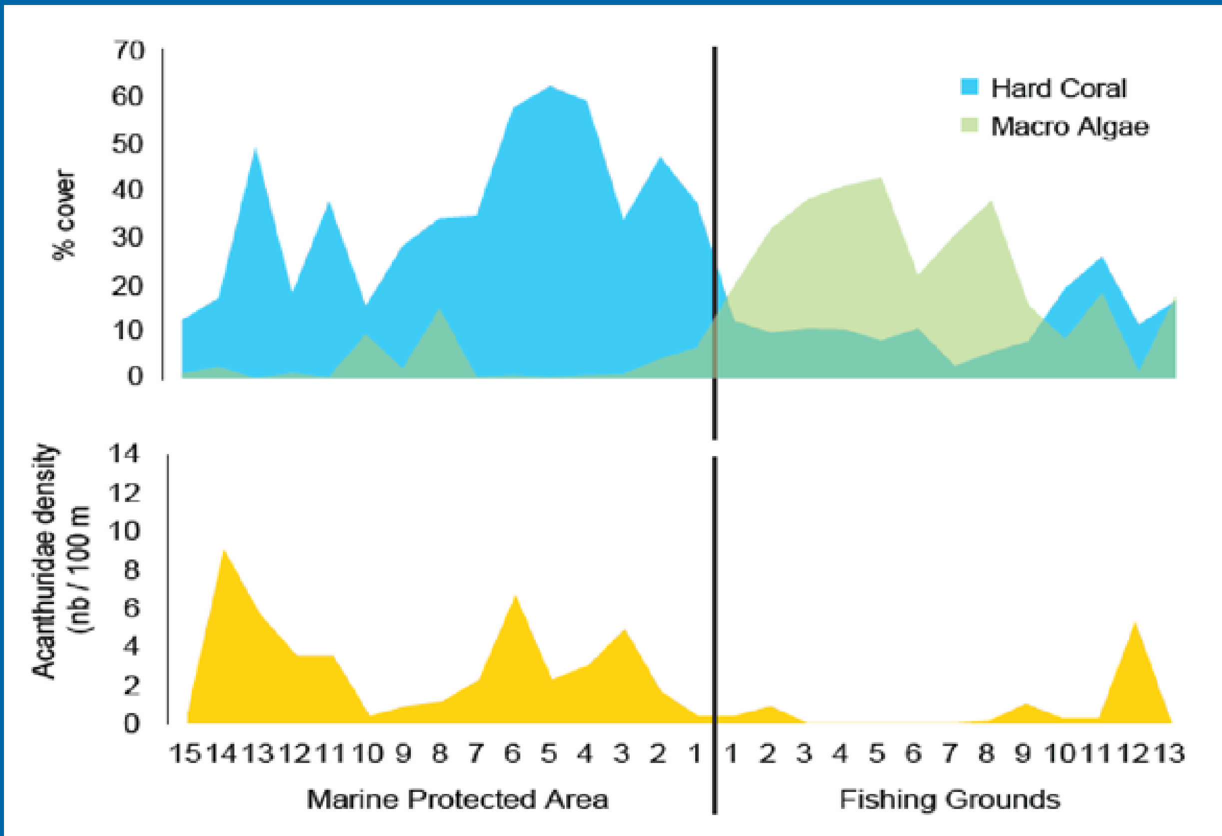
Les pêcheries, y compris les pêcheries de poissons de récif, fournissent des moyens de subsistance et maintiennent une sécurité alimentaire pour de nombreuses communautés du Pacifique. La surpêche contribue à la dégradation des récifs coralliens en altérant les processus clés des écosystèmes (un exemple est fourni dans l'encadré 3 pour un récif corallien des îles Fidji). La capture des herbivores, qui se nourrissent des algues en forte compétition avec les coraux, assurant ainsi le recrutement larvaire sur le substrat et leur croissance, va limiter la capacité de récupération après un événement de blanchissement ou un cyclone et pourrait, à long-terme, contribuer au déclin de la couverture corallienne. L'analyse présentée ici montre un déclin de la biomasse des poissons herbivores de moitié sur les 12 dernières années dans les îles habitées (Fig. 5), suggérant une pression de pêche élevée et continue sur les poissons de récifs par les communautés locales. À ce jour, les récifs coralliens à l'échelle du Pacifique n'ont pas été supplantés par les algues, mais le déclin général en corail vivant observé depuis 1999, conjointement à l'augmentation des algues, est inquiétant, en particulier si l'on considère la pression croissante exercée sur les récifs par l'intensification du régime des perturbations. Les preuves anecdotiques de tels changements sont de plus en plus nombreuses dans plusieurs endroits qui ne sont pas inclus dans la présente analyse. Une telle tendance pourrait être un signal de la trop forte pression de pêche exercée sur les récifs et devra mener à des mesures de gestion, y compris la mise en place d'aires marines protégées pour préserver la biomasse de ces poissons herbivores.

Initiatives et activites majeures pour la conservation des récifs coralliens

A l'heure de l'écriture de ce rapport (2017), il existe environ 921 aires marines protégées (AMPs) dans le Pacifique, couvrant 8,960 km2 des récifs coralliens, ou 13% de la totalité des récifs coralliens du Pacifique. Cependant, seulement 20% de ces AMPS sont considérées comme étant efficacement gérées.

Qu'elles soient liées aux problématiques de conservation des récifs coralliens à l'échelle glo-bale, issues des sommets en écologie notamment, et dans un besoin de préserver les récifs coralliens encore intacts, d'importantes initiatives de conservation des récifs coralliens ont été entreprises dans le Pacifique ces dix dernières années. Cela comprend des initiatives à grande échelle, listées au Patrimoine Mondiale de l'Humanité, comme le Papahānaumokuākea Marine National Monument qui couvre les Îles Hawaï du Nord ou les lagons de Nouvelle-Calédonie. Aux Kiribati, l'aire marine des îles Phoenix est l'une des zones de protection intégrale les plus grandes au monde et représente le plus grand effort de conservation marine tenu par un pays en voie de développement. C'est également le site le plus grand et le plus profond inscrit au Patrimoine Mondial de l'UNESCO. Le *Coral Triangle Initiative on Coral Reefs - Fisheries and Food Security* inclue les Îles Salomon et la Papouasie Nouvelle Guinée. Le Micronesia Challenge, lancé par les Îles Mariannes de Nord, a pour objectif de protéger 30% des eaux côtières et 20% des terres avant 2020. Lors de la Convention sur la diversité biologique des Nations Unies (CBD) les îles Fidji se sont engagées vis-à-vis des objectifs d'Aichi pour la biodiversité, en particulier le but stratégique 11, à assurer la protection de 17% des zones terrestres et 10% des zones marines d'ici à 2020, et ont même renforcé leur engagement afin de protéger 30% de ses zones marines d'ici à 2020.

À l'échelle locale, plusieurs sociétés traditionnelles ont pour habitude de mettre en place un système ancestral de fermeture temporelle de zones récifales et d'interdiction de pêche de certaines espèces à certaines périodes de l'année, tel que le «rahui» (rituel tempo-raire d'interdiction) en Polynésie française. Les zones «tabu» (interdites) que l'on retrouve dans le cadre des aires marines gérées localement (LMMAs - Locally Managed Marine Areas) en Mélanésie ont le même rôle. Cependant, ce système, qui a fait ses preuves en permettant de soutenir durablement de nombreuses générations d'îliens, a été abandonné au fil des générations dans de nombreuses îles. Néanmoins, certaines communautés envisagent sérieusement de retourner au système de gestion traditionnel. Par exemple, aux Hawaii, les initiatives émanant des communautés sont intégrées au niveau gouvernemental pour la gestion des ressources marines.



ENCADRÉ 3
Evolution de l'abondance des herbivores (i.e. abondance en Acanthuridae) et dans la couverture corallienne et algale dans et autour d'une AMP des îles Fidji.Une aire marine protégée gérée par la communauté a été déclarée sur plus de 900m de long sur le récif frangeant en avril 1998. Après 11 années de protection contre la pêche, trois suivis ont été entrepris sur une période de 12 mois, pour mesurer l'impact du le pourcentage de couverture corallienne et algale, et l'abondance d'espèces de poissons herbivores significatives dans l'AMP et dans les zones de pêchées périphériques. Les poissons herbivores de la famille des Acanthuridae étaient abondant dans l'AMP alors qu'il était quasiment absent dans les zones pêchées périphériques. Les formations coralliennes dans les zones périphériques pêchées étaient couvertes de macro-algues, tandis que dans l'AMP, elles étaient nettes et couvertes de nouvelles recrues coralliennes. Le changement entre la dominance algale et la dominance corallienne s'opère très rapidement à la bordure de l'AMP. (H. Sykes, personnel data)

CONCLUSION

La présente étude est la première du genre dans la zone insulaire du Pacifique, rassemblant près de 20 000 suivis. Cette analyse a montré peu de changement à travers les deux dernières décennies pour les indicateurs importants utilisés dans le suivi de l'état de santé des récifs ; la couverture corallienne reste relativement stable, proche des 25%. L'estimation annuelle du pourcentage de recouvrement corallien était également toujours au-dessus de l'estimation annuelle du pourcentage de la couverture algale, une observation qui diffère de précédentes observations alarmantes (principalement aux Caraïbes) quant à la dominance des algues sur les coraux. Cependant, une attention particulière doit être donnée au lent mais significatif déclin de la couverture corallienne depuis 1999 jusqu'à aujourd'hui à l'échelle du Pacifique. Plusieurs aspects intéressants sont à noter, comme le changement de taxa dominant, la chute de la biomasse des poissons herbivores, en particulier dans les îles habitées, et la haute variabilité de la couverture algale sur la période observée. Ces résultats diffèrent de ceux provenant des Caraïbes, de l'océan Indien occidental et de la Grande Barrière de Corail. Ceci n'est pas surprenant au regard de la vaste étendue qu'est le Pacifique et de la variation biogéographique qui existe le long des gradients latitudinaux entre l'hémisphère nord et l'hémisphère sud et les gradients est-ouest dans la diversité des espèces.

Le changement de taxa dominant peut être le signe d'un changement de structure dans la communauté récifale, tandis que le déclin de la biomasse en poissons herbivores est un signe de l'activité humaine (la pêche par exemple). Réunis, ces patrons suggèrent que, même à l'échelle du Pacifique, une région considérée comme la moins impactée du monde, les récifs coralliens sont en train de changer. Ces changements observés indiquent qu'à une large échelle les régions font tampon, mais il reste des indications d'un léger déclin de la couverture corallienne et d'un changement dans la structure des récifs coralliens vers une dominance des coraux massifs, fournissant des fonctions écologiques très différentes. Quantifier à quel point les fonctions présentes des récifs coralliens vont être affectées et à quel point les services rendus aux Hommes vont en être altérés représente un véritable défi auquel les communautés locales doivent faire face. Les principales inquiétudes seront : la croissance et l'érosion à venir et leur contribution à la protection côtière (absorption de l'énergie de la houle océanique and des vagues de tempête); impacts sur les ressources alimentaires suite à la modification de la structure de l'habitat récifal et de la chaîne trophique.

Malgré les patrons généraux à l'échelle du Pacifique, il est important de noter qu'à l'échelle locale les récifs ont été sous l'influence de perturbations ponctuelles importantes, avec une forte réduction de la couverture corallienne, mais ont souvent bien récupéré. De tels impacts ne sont pas uniformes à l'échelle du Pacifique. Ceci explique pourquoi l'impact de chacun des événements massifs de blanchissement corallien affectant la couverture corallienne et la structure des communautés ne montre pas de signal fort dans les moyennes régionales, avec des pertes dans certaines régions compensées par des gains dans d'autres. L'évolution spécifique à chaque île laisse penser que des actions de gestion locales peuvent aider à modérer les effets inévitables du changement global au moins dans un futur proche. Les récifs coralliens du Pacifique sont dynamiques et la récupération est relativement rapide dans la mesure où les pressions et perturbations locales sont bien gérées. Etant donné les changements mis en lumière dans les récifs coralliens à l'échelle du Pacifique et la haute vulnérabilité des dynamiques récifales à l'échelle locale, des actions de gestion locales doivent être renforcées et adaptées à chaque cas pour aider à la durabilité des communautés biologiques récifales.

Alors que ce rapport aide à interpreter les impacts les plus visibles du changement climatique (température des eaux de surface, blanchissement corallien) et les pressions humaines (sur-pêche et ruissellements), nous souhaitons alerter les lecteurs au caractère sérieur de facteurs de stress moins évidents mais potentiellement plus insidieux associés à l'acidification des océans. L'acidification des océans devrait également être prise en compte dans l'interprétation des changements actuels et à venir des récifs coralliens.

RECOMMANDATIONS

Cette compilation et analyse de séries temporelles sur les récifs coralliens fournit une base pour un certain nombre de conclusions et de recommandations à l'égard de la gestion des récifs coralliens, de la façon dont les suivis doivent être conduits afin d'améliorer leur utilisation ainsi que des applications scientifiques des jeux de données qui ont été compilés.

Les données sur les statuts et l'évolution des récifs coralliens sont une ressource importante. Elles peuvent venir en appui à des prises de décisions de gestion et de planification environnementales à plusieurs niveaux. Elles peuvent contribuer à renforcer la recherche en écologie, améliorant notre compréhension des récifs coralliens, de leur biotope et des services écosystémiques qui en résultent. Elles permettent également de sensibiliser la société au sort d'un écosystème dont dépendent des populations, des moyens de subsistance et des économies. En cela, les données et rapports sur l'état et l'évolution des récifs coralliens peuvent directement et concrètement contribuer à mesurer les progrès accomplis en vue de réaliser les objectifs environnementaux et sociétaux établis, comme ceux fixés par l'Agenda de Développement 2030 et en particulier l'objectif 14 concernant la gestion durable des océans. Nous avons identifié 10 recommandations au total, dans différentes zones, décrites ci-dessous.

Gestion et réponses politiques

Le changement dans les récifs coralliens est mené par des pressions à la fois locales et globales. Ainsi, maintenir un récif corallien en bonne santé sur le long-terme requière de connaître ces pressions à différentes échelles. Bien que cette analyse régionale ait trouvé des changements limités dans la couverture corallienne et peu de preuves de déclin à l'échelle régionale, un changement inquiétant dans la structure des communautés et dans la biomasse en poissons herbivores demande une attention particulière. A l'échelle régionale les événements majeurs de stress (comme le blanchissement corallien ou les invasions d'étoiles de mer *Acanthaster planci*) n'ont pour le moment mené à aucun déclin marqué de la couverture corallienne. Il est également important de noter que les facteurs locaux ont affecté d'une part la résilience face à l'impact des événements ponctuels et d'autre part l'évolution sur le long terme du récif, et ceci renforce le besoin de prendre plus en compte la gestion des impacts humains locaux sur les récifs des îles du Pacifique.

Les changements de structures récifales et de communautés écologiques mentionnés précédemment, auxquels s'ajoutent des impacts dans des zones non couvertes par les programmes de suivi existants, sont tout autant de preuves de déclins auxquels d'autres régions ont eu à faire face au cours des années précédentes et représentent des préoccupations critiques à considérer dans le Pacifique.

En mettant l'accent sur la réduction des pressions anthropiques locales, les îles du Pacifique peuvent avoir une influence non négligeable sur la santé des récifs coralliens et des biens et services fournis. Les nations du Pacifique ont déjà commencé à prendre en main la gestion des récifs, mais la taille de la région et l'étendue de ses récifs combinée à une faible population ont vraisemblablement contribué à minimiser la perte des récifs par rapport à d'autres endroits comme dans les Caraïbes. Tout en tenant compte du développement régional actuel autant que des tendances au changement climatique global, des efforts renforcés sont nécessaires pour garder les récifs en bonne santé à l'avenir.

Les recommandations basées sur ces informations sont les suivantes:

1. Identifier, prioriser et mettre en place des actions qui réduisent les pressions locales chroniques sur les récifs coralliens qui pourraient venir de l'aménagement du territoire, des changements d'utilisation des sols et des développements côtiers.

Les efforts de réduction des stress

doivent concerner les nutriments, la sédimentation et autres pollutions terrigènes y compris, l'agriculture, l'élevage, le développement côtier et les eaux résiduelles associées. Des mesures spécifiques doivent être identifiées, priorisées et mises en place en fonction de leur importance à renforcer la récupération des récifs. Ceci nécessitera également des considérations spécifiques des récifs coralliens en général, un développement intégré et un processus de gestion à l'échelle nationale.

2. Rendre l'utilisation des récifs coralliens durable, par la mise en place de régulations et législations renforcées des pêcheries, avec une attention particulière à l'arrêt du déclin des poissons herbivores, et en élargissant les zones marines gérées.

La plupart des nations du Pacifique ont un réseau de pêche relativement bien développé et des régulations comprenant des restrictions d'engins et d'espèces, mais elles manquent généralement de mise en œuvre, de respect et de maintien des règles. C'est pourquoi il est recommandé que les efforts de gestion des pêcheries soient renforcés pour améliorer le respect des réglementations avec des régulations déjà existantes, et que les régulations liées aux poissons herbivores soient davantage renforcées le cas échéant. Accroître l'utilisation des aires marines gérées va favoriser la résilience des récifs coralliens, la conservation de la biodiversité et la productivité des pêcheries ainsi que les opportunités touristiques, contribuant ainsi au développement de l'économie bleue.

Renforcer la surveillance et les comptes-rendus sur les récifs coralliens

Le suivi des récifs coralliens dans le Pacifique a évolué significativement, en particulier depuis plus de 10 ans. La plupart des récifs coralliens des nations et territoires insulaires du Pacifique sont concernés par au moins quelques suivis écologiques, et des programmes de suivis réguliers sont maintenant opérés dans la majorité d'entre eux. Cependant il reste un certain nombre de manques et de défis à relever, qui réduisent l'utilité des suivis pour des rapport régionaux ou nationaux, réduisent l'étendue à laquelle des données de suivi pourraient être ou sont utilisées pour des décisions politiques et de gestion, et limitent également leurs usages à des fins de communication vers la société sur les changements environnementaux ou en appui à la recherche.

Le suivi des récifs coralliens est en général plus fort en termes de couverture, de variables et de fréquence ou régularité des mesures dans les pays développés et là où il existe un soutien international à la conservation et au développement. Des programmes de suivis ont été mis en place dans la plupart des petits États insulaires en développement du Pacifique (PEIDP) à un certain moment, mais la continuité des programmes est un vrai défi, par exemple là où le suivi est dépendant de soutiens financiers extérieurs.

La situation dans le Pacifique est sur ce point similaire à celle observée par le GCRMN dans les Caraïbes, où les suivis sont « parsemés, désorganisés et généralement inefficaces ». Des recommandations clés pour combler les manques et répondre aux défis spécifiques aux récifs coralliens du Pacifique peuvent être les suivantes :

3. Assurer la cohérence et la compatibilité des données des suivis des récifs coralliens dans la région Pacifique, à travers le développement et l'adoption d'indicateurs de suivis et des formats de données communs.

Ceci pourrait être mise en place au travers du GCRMN, et entraîner la mise en place de standards minimums communs, différenciés pour s'adapter à différents niveaux de suivis (par exemple, sur la base des expériences du GCRMN dans les Caraïbes). L'adoption ou le renforcement intergouvernemental des standards recommandés à un niveau régional facilitera l'adhésion et l'utilisation générales parmi les programmes de suivis nationaux autant qu'au sein d'autres initiatives, associations ou projets. Une considération particulière devrait être donnée aux formats communs des données et métadonnées, aux variables/indicateurs communs pour le suivi des récifs coralliens, aux prérequis méthodologiques communs, au paramètres clés et aux opportunités offertes par les innovations ou les technologies toujours moins chères, comme l'usage d'imagerie numérique ou de micro-capteurs dans la mesure du possible.

4. Augmenter la gestion des données, autant que leur accès et leur production, à travers le développement d'un registre régional des données.

Une plateforme régionale des données, développée sur des principes clairs concernant l'attribution, l'accès et le partage de ces données, et hébergée et mise à jour par des institutions régionales compétentes, renforcera les suivis et comptes-rendus sur les récifs coralliens et leur impact, incluant :

- L'accès à des services de gestion de données pour les programmes de suivi qui n'ont pas les capacités suffisantes pour exploiter un système de données et de stockage à part entière ;
- Améliorer l'accès aux données sur les récifs coralliens, ainsi qu'aux résultats de ces données, pour l'aide à la prise de décision en matière de gestion de l'environnement et autres décisions, rapporté au contexte régional ou global des objectifs établis, de la recherche et du travail de sensibilisation ;
- Rendre possible le développement futur de données et rapports, en favorisant les comptes-rendus périodiques sur l'état de santé et l'évolution des récifs coralliens dans la région et en favorisant les contributions au travers de synthèses globales.
- Assurer la qualité des données par la mise en place de métadonnées standardisées et la publication régulière de données et rapports.

5. Remplir les manques géographiques dans le suivi des récifs coralliens, avec une attention particulière sur les zones où les suivis sont inexistants ou occasionnels.

Cela peut être mené au travers de programmes efficace actuels ou par la mise en place de nouveaux programmes quand cela est nécessaire. Ceci entraîne forcément la nécessité de soutiens additionnels en termes d'assistance techniques ciblées, de renforcement des compétences et de financement. Il est entendu que de nombreuses zones ne pourront malheureusement pas être étudiées au travers de programmes de suivi à long-terme, compte-tenu de la taille du Pacifique, de l'éloignement de certaines îles et de l'étendue de la zone de récifs coralliens. En cela, les données provenant d'études ne faisant pas partie d'un programme de suivi (par exemple, les données obtenues à travers différents projets de recherche, de développement et autres) constituent une source importante pour le suivi des récifs coralliens à long-terme dans le Pacifique.

6. Encourager le réseau local pour renforcer la surveillance et les rapports, y compris au travers d'échange d'expertises, de renforcement des compétences, en mettant (à nouveau) en place un comité régional GCRMN.

Le processus de préparation de ce rapport a redynamisé la communication régionale et les collaborations en termes de suivi des récifs coralliens. Les recommandations formulées ici, en particulier celles concernant la surveillance, requièrent une continuité, et de nombreux pays et territoires pourront bénéficier des échanges continus d'expérience et d'expertises, de formation, d'apprentissage par les pairs, etc. La mise en place d'un comité ou d'un réseau régional GCMRN (comme celui établi dans les Caraïbes) est recommandé, organisé et constitué d'une institution régionale compétente.

7. Fournir un soutien régulier, comprenant un soutien financier, pour le suivi à long-terme et l'état des lieux des récifs coralliens, et assurer la capacité à répondre rapidement en cas d'événements inattendus afin de procéder à leur évaluation.

La présente analyse illustre l'importance d'un suivi continu des récifs coralliens en surveillant l'état et l'évolution des écosystèmes et en permettant l'analyse des implications sur le long-terme de perturbations telles que le blanchissement corallien. Un engagement sur le renforcement des suivis à long-terme à travers la région, comprenant le renforcement des compétences, est donc nécessaire. Par ailleurs, il est essentiel de pouvoir fournir des réponses financières rapides permettant aux agences de suivis et aux scientifiques de se mobiliser rapidement (et de dévier ainsi sur leur cycle de monitoring à long-terme) afin d'évaluer des événements inattendus et temporaires affectant les récifs coralliens, comme l'invasion de l'étoile de mer *Acanthaster planci* aux Samoa en 2013 ou le blanchissement corallien de 2014-2017.

Perspectives de recherches

Le jeu de données compilé ici fournit une source de qualité qui peut être complétée ou améliorée par l'addition de données qu'il n'a pas été possible d'inclure dans la présente analyse.

8. Poursuivre des analyses plus approfondies du jeu de données, incluant la relation des changement récifaux aux pressions/facteurs de stress, et développer pour cela des projets de recherche collaborative.

Le jeu de données compilées se prête de lui-même à des analyses supplémentaires, au-delà de qu'il était possible de réaliser dans le cadre de ce rapport. Des analyses pourraient approfondir l'identification de mesures de pressions et des jeux de données appropriés , afin de développer une meilleure compréhension des processus qui contrôlent les changements récifaux dans le Pacifique et aiguiser les recommandations de gestion.

9. Soutenir une meilleure connaissance de la sensibilité au blanchissement corallien et tous autres impacts climatiques ou anthropiques sur les récifs coralliens du Pacifique, incluant l'amélioration de l'observation de la mortalité due au blanchissement et du rétablissement qui s'en suit, les impacts de l'acidification des océans, etc.

Les événements de blanchissement corallien dans le Pacifique sont responsables d'impacts locaux significatifs sur la couverture corallienne (voir les sections par pays), mais les facteurs de déclins par blanchissement des récifs à l'échelle régionale n'ont pas été trouvés dans cette étude, lors de l'analyse des tendances à large échelle. Pour planifier la gestion des récifs coralliens, la vitesse de rétablissement est plus importante que l'impact immédiat en termes de coraux blanchis. En d'autres termes, un suivi régulier a de meilleures applications de gestion que l'observation du blanchissement. Cependant, et à la vue des projections des futurs stress de température attendus, il est important d'améliorer la compréhension des changements de la tolérance de température par les coraux du Pacifique et et comprendre comment cela peut impacter les communautés récifales sur le long-terme.

Diffusion des résultats

10. Accroître la connaissance sur les rapports, les conclusions et les recommandations, dans le contexte de l'Année Internationale pour les Récifs Coralliens 2018.

Cette analyse fournit de nouveaux résultats sur l'état et l'évolution des récifs coralliens ainsi qu'un certain nombre de recommandations pertinent pour des publics cibles, comprenant le grand public, les décideurs politiques, les gestionnaires de récifs coralliens, les entités engagées dans les suivis ainsi que les scientifiques. Une diffusion utilisant un large panel de média est donc primordiale.

PART I. OVERVIEW AND SYNTHESIS FOR THE PACIFIC ISLAND REGION

Detecting changes in natural ecosystems requires monitoring of their biological components and an analysis of their long-term trends. To understand how these changes impact human societies, the change must then be measured, the potential sources of change must be identified and the effects they have on ecosystem services must be quantified. Minimizing the negative impacts on human societies requires that the human-derived sources for these change must be identified. Appropriate conservation actions must also be implemented to curb these changes and maintain natural ecosystem health and resilience. This challenge of modern ecology is the one that scientists must face in order to influence decision-making for long-term conservation of natural ecosystems on the planet. To address this challenge, the GCRMN status and trends report for the Pacific Island region provides an accurate description of the main changes in coral reef ecosystems over the last three decades, seeks to identify the drivers of these changes, and provides recommendations and conservation actions for the long-term management of coral reefs.

The tropical Pacific region is home to approximately 25% (about 66,000 km2) of the coral reefs on the planet and is dotted with thousands of islands that differ climatically and geologically (Goldberg 2018) from one another. Many of these reefs are considered to be in good health because of their remote location and low exposure to human impacts. Still, these reefs are impacted by a range of disturbances including cyclones (and hurricanes), crown-of-thorns starfish outbreaks, and coral bleaching (Osborne et al. 2011, Hughes et al. 2018a), whether they are natural or intensified by global warming (Birkeland et al. 2008). Island-scale observations show that after such disturbances the reefs can recover within a decade (Golbuu et al. 2007, Lamy et al. 2015, Gouezo et al. 2016, Lamy et al. 2016, Martin et al. 2017) (Fig. 1).

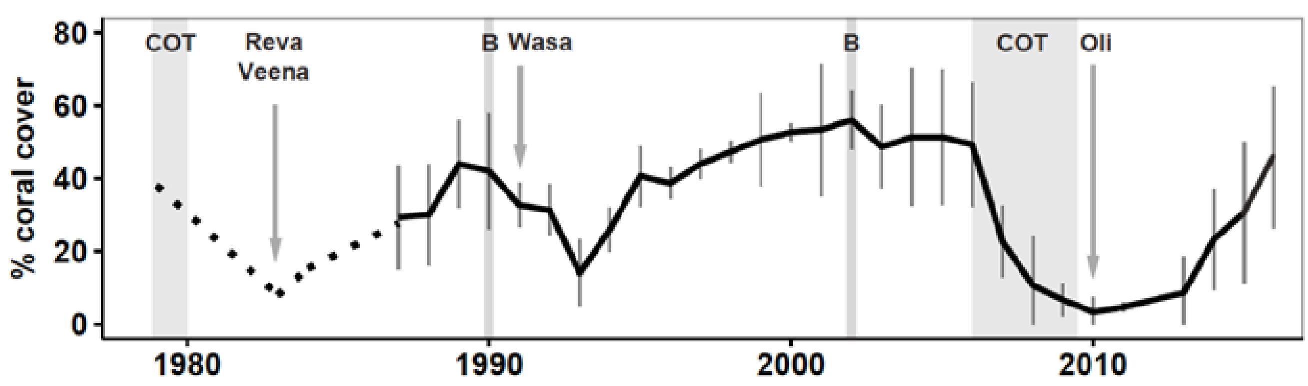


FIGURE 1
Coral cover on Tiahura fore reef (Moorea, Society Islands, French Polynesia) over the past 40 years, highlighting the recovery phases after major disturbances (ca. 5 to 7 years of recovery process after major coral cover drops). COT: crown-of-thorns outbreak, B: bleaching event; cyclones are indicated by an arrow and their name is given. (Redrawn from Galzin et al, 2016)

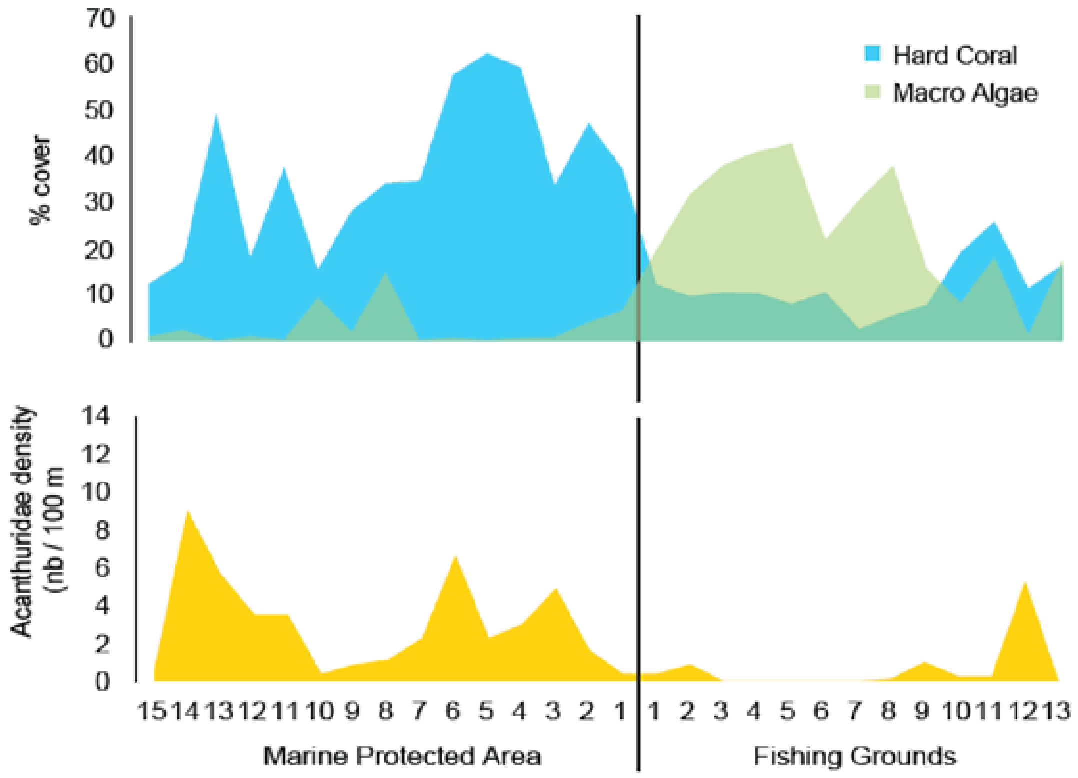


FIGURE 2
Coral and macroalgae cover and herbivore surgeonfish (i.e. Acanthuridae) density in 15 and 13 sites of, respectively, a marine protected area (MPA) and an area open to fishing in Fiji. The community-managed MPA was declared over a 900 m long section of shallow fringing reef in April 1998. After 11 years of protection from fishing, 3 sets of surveys were carried out within a 12 month period to measure coral and macroalgae percent cover, and the abundance of key herbivorous fish across the MPA and the neighbouring fishing grounds. Acanthuridae were numerous across the MPA, and dropped to almost none in the fished area. The shift from algal dominance to coral dominance occurred exactly at the MPA boundary. Coral heads in the fished area were overgrown with macroalgae, whereas those in the MPA were clean and had new coral recruits on their surface. (Data from H. Sykes)

Other observations, however, are more alarming, documenting a degraded state of coral reefs around inhabited islands, as opposed to uninhabited ones (Williams et al. 2015, Heenan et al. 2016, Smith et al. 2016, Zgliczynski and Sandin 2017). Observations from several islands spanning a vast area of the Pacific revealed that low reef builder cover (i.e. coral and coralline calcareous algae) and higher fleshy algae cover were observed on reefs around inhabited islands (Smith et al. 2016), and that densely-populated islands had lower shark and carnivore biomass (Ruppert et al. 2018). In contrast, for uninhabited islands, fish were larger, probably as a result of the weak or absence of fishing pressure (Zgliczynski and Sandin 2017), and can support high fish abundances even post-bleaching (Mangubhai et al. 2014). These observations are in contrast to what was presented in the 2011 «Coral Reefs at Risk Revisited» (Chin et al. 2011) which stated that coral reefs of the Pacific appeared to be exposed to limited threats and were less impacted by anthropogenic stressors than those present, for instance, in the Caribbean and South-East Asia (Bruno and Selig 2007, Jackson et al. 2014). Furthermore, the isolated and relatively less impacted nature of coral reefs in the Pacific does not afford any protection from widespread temperature stress, as evidenced from the impacts that the recent global coral bleaching events (2016-2017) had on some areas of the Pacific (e.g. Heron et al. 2016, Hughes et al. 2017, Couch et al. 2017, Hughes et al. 2018b, Brainard et al. 2018) (Fig. 3). It should be noted that the Pacific report does not include the large coral mortality on the Great Barrier Reef, that was observed following 2016 and 2017 bleaching events that removed, up to 50% of the live coral in some sections (Hughes et al. 2018b).

FIGURE 3
Bleached coral during a bleaching event in Samoa in 2016 (© Paul Marshall)

Only a few references exist for the historical trends of coral reefs at large-scale in the Pacific. Global and regional reports that included Pacific countries were published since 1998 (Wilkinson 1998, Wilkinson 2000, Wilkinson 2002, Wilkinson 2004, Wilkinson 2008). These reports included a description of the status of coral reefs for each country, providing qualitative descriptions of the major characteristics (e.g. coral cover) and events that affected the reefs through time, but did not provide a quantitative meta-analysis of coral reef trends at either the large or mesoscale. Therefore, no generalization of the trends at the scale of the Pacific has ever been produced. Nevertheless, one publication provided a quantitative analysis showing that, on average, live coral cover declined in the Indo-Pacific region (Bruno and Selig 2007). However, this trend was not the same between regions within the Pacific (Bruno and Selig 2007, Lamy et al 2015, Lamy et al 2016), and most of the data compiled in Bruno and Selig (2007) were from one-time surveys, rather than from long-term monitoring programs. Overall analyses at the Pacific scale and descriptions of temporal trends are therefore still infrequent, and the different reports and publications all point to significant lack of long-term, standardised data for several areas, countries, and time bins, making it difficult to appropriately quantify past trends on a continuous basis at the Pacific scale.

To address missing data over such a wide area, projections and extrapolations can be performed using available data. For instance, Heron et al. (2016) used satellite temperature data to quantify spatial variations in warming trends, thermal stress events and temperature variability at the reef scale (i.e. 4 km) for several coral reef regions. New techniques are also tested to regionally map, detect, and predict change in coral reefs at the dominant benthos scale (Collin et al. 2012). However, these analyses are often performed at high resolution and may not be appropriate for the description and study of small-scale reef configuration and processes. As such, further testing is required to determine their efficacy at multiple scales (Van Wynsberge et al. 2017). Therefore, although such models increase in power, their validity at the regional scale may be questioned because of the great diversity of coral reefs in the Pacific Island region and the problems associated with extrapolation methods and use of proxies (bias, approximations, etc.). Thus, it is important to actually measure changes instead of depending solely on models. The goal of this report is therefore to document the trends of Pacific reefs using quantitative data recorded before 2017 to provide the basis for effective actions to prevent or reduce the decline of marine populations on coral reefs. It should be noticed that this report includes data up to 2016, and therefore does not consider all data following the bleaching events of 2016 and 2017 that lead to coral mortality in several locations of the Pacific Island region, such as Samoa, some of the Marshall Islands, and some of the French Polynesian islands.

Considering the dynamics of ecosystem patterns and trends in biodiversity, the greatest challenge of coral reef studies is to disentangle the drivers of coral reef change, that is, to differentiate the effects induced by chronic anthropogenic disturbances (pollution, overpopulation, overfishing, etc.) from those induced by acute disturbances (cyclones, sea star *Acanthaster planci* outbreaks, coral bleaching) that were initially natural but are intensified by ocean warming and acidification due to the burning of fossil fuels (Hughes et al. 2017, Hughes et al. 2018a, Hughes et al. 2018b).

Both kinds of disturbances have comparable measurable effects, such as the loss of corals, increase in disease occurrence, increase in macroalgae, and fish stock depletion (Fig. 2). Pacific-wide studies to detect what drives coral reef changes are still infrequent (e.g. Mangubhai et al. 2014, Smith et al. 2016, Zgliczynski and Sandin 2017, Ruppert et al. 2018), and implementing analyses at a large scale using relevant data can help to disentangle the causes inducing changes in coral reefs.

The major goals of this report are thus threefold:

– To analyze the region-wide historical trends of coral reefs in the Pacific (meta-analysis);
– To identify the potential drivers of these trends;
– To describe these trends at smaller scale (Country Reports).

These results will provide insights in understanding the fate of coral reefs in the Pacific compared to those from other regions in the world (Jackson et al. 2014, Obura et al. 2017), as well as details for small-scale areas (per country or territory) to understand why some reefs may deviate from the overall trend, and may serve as a baseline for any future analysis to investigate natural resilience processes.

Part I of the report is divided into five main sections:

1. Data, methods, and analysis;
2. Description of quantitative changes in the status and trends of major components of Pacific coral reefs (corals, macroalgae, and other primary substrate categories, and major fish trophic groups) for the past three decades ;
3. Analysis of the drivers of coral reef change to highlight their past and present impact on the reefs, to better assess their potential impacts in the future;
4. Synthesis of the results;
5. Recommendations for management.

Part II of the report is devoted to Country Reports to document local status and trends in each Pacific country and territory. This section is only descriptive for each territory and does not intend to provide any interpretation of the observed trends.

1. DATA, METHODOLOGY, AND ANALYSIS

1.a. Scope of the data

Data collection involved contacting more than 200 people across all Pacific countries and territories, and exchanging thousands of e-mails to gather and process raw longitudinal ecological data on coral reefs. Large monitoring programs exist in the Pacific, predominantly led by governmental research institutes (e.g. NOAA, CRIOBE-CNRS, etc.). These programs started on different dates and provide quantitative data in the medium and long term. Given the recent awareness for the need to increase monitoring effort in the Pacific, especially in developing countries, new monitoring programs have been initiated, such as that associated with the Micronesia Challenge which involves the Federated States of Micronesia, the Commonwealth of the Northern Mariana Islands, the U.S. island territory of Guam, the Republic of the Marshall Islands, and the Republic of Palau.

Two major problems were encountered during the data search phase: 1. Some data were from snapshot surveys (single point in time for one or a group of sites), and 2. Data were still buried in grey literature and government reports, or did not exist electronically. These types of data were not considered in this study given the additional time that would have been required to process them. Future work will include these data in the analysis, and an effort will be made to help countries digitise these data in an appropriate format for future use, and to help promote the continuation of existing monitoring programs.

Data searches were performed by contacting managers of large monitoring programs from a broad range of governmental bodies, research institutes, universities, non-governmental organisations, regional organisations, private companies, independent researchers and consultants. These included, among others, NOAA (USA), the CRIOBE (French Polynesia), the PACN Inventory and Monitoring Program from the NPS (USA), the RORC (New Caledonia), the Micronesia Challenge (FSM, RMI, CNMI, Guam and Palau), the BEQC Marine Monitoring Program (CNMI), the DAR marine monitoring program (USA), the Fiji Coral Reef Monitoring Network (FCRMN), and the PICRC (Palau).

Once a substantial number of datasets were gathered, a workshop was organised in Honolulu (Hawaii, USA, 12-14 October 2016) to meet with the main representative of each dataset or program and the GCRMN Pacific project funders (French MTES, SPREP and UN environment). This workshop was dedicated to setting up the strategy for the analysis of the data and to establish a timeline for the completion of the report.

We obtained data from more than one hundred principal investigators, collaborators, and technical staff, which accounts for 19,270 surveys of corals, macroalgae, fish, and macroinvertebrates, compiled into 49 datasets distributed among 129 islands and reef structures in 19 countries, states or territories of the Pacific Island region (Table 1, Fig. 4, 5). Thus comprising the largest and longest pool of time-series data ever compiled for this region.

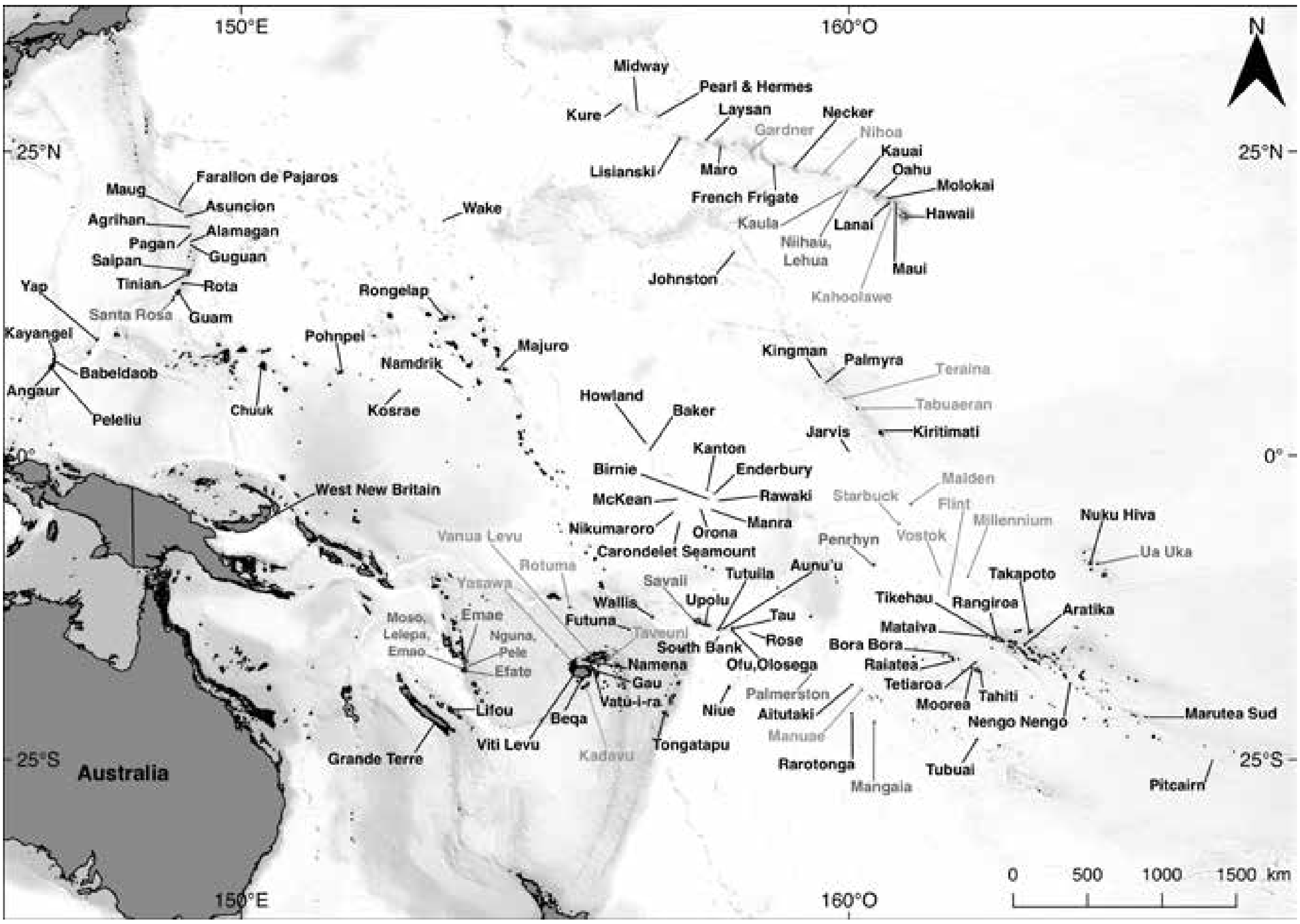


FIGURE 4
Location of the 129 islands and reef structures analyzed in this study. Black font indicates that data was available for substrate and fish; dark grey font, for substrate only; and light grey font, for fish only.

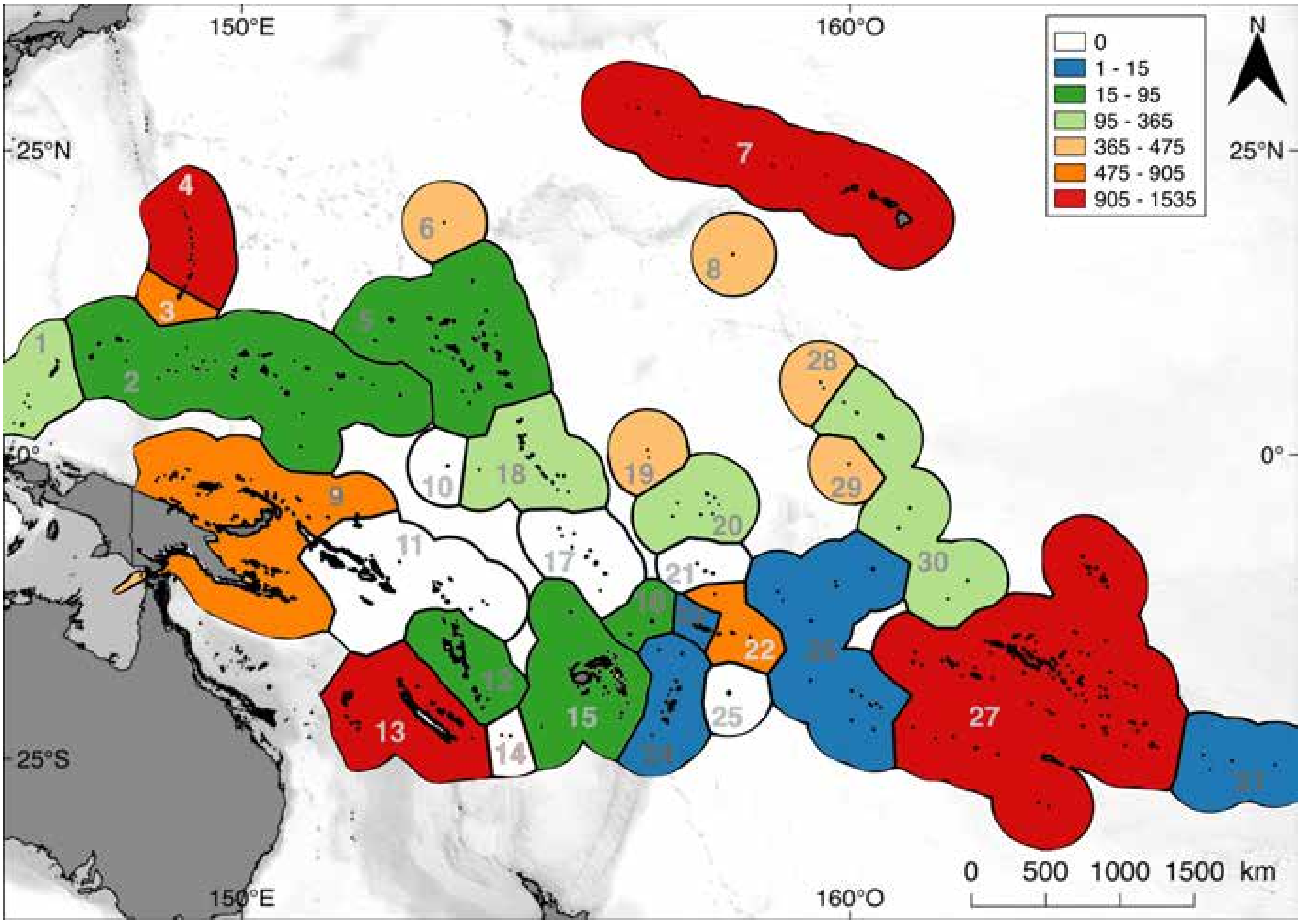


FIGURE 5

Exclusive Economic Zones (EEZ) of each country or territory with colours expressing the sampling effort per territory (1: Palau; 2: Federated States of Micronesia; 3: Guam; 4: Commonwealth of the Northern Mariana Islands; 5: Republic of the Marshall Islands; 6: Wake Island (Pacific Remote Island Areas); 7: North-western & Main Hawaiian Islands; 8: Johnston Atoll (Pacific Remote Island Areas); 9: Papua New Guinea; 10: Nauru; 11: Solomon Islands; 12: Vanuatu; 13: New Caledonia; 14: Matthew & Hunter Islands; 15: Fiji; 16: Wallis & Futuna; 17: Tuvalu; 18: Republic of Kiribati - Gilbert Islands; 19: Howland & Baker Islands (Pacific Remote Island Areas); 20: Republic of Kiribati - Phoenix Islands; 21: Tokelau; 22: American Samoa; 23: Samoa; 24: Tonga; 25: Niue; 26: Cook Islands; 27: French Polynesia; 28: Kingman Reef & Palmyra Atoll (Pacific Remote Island Areas); 29: Jarvis Island (Pacific Remote Island Areas); 30: Republic of Kiribati - Line Islands; 31: Pitcairn Islands). Only the effort allocated for substrate monitoring is represented.

TABLE 1

Geographic and socio-economic data for all islands used in the report (listed alphabetically by island). Data compiled from the World Wide Web based on the recent most census of resident data found. HDI: Human Development Index.

Country	Territory	Island	Size (km²)	Human presence	Population	Population density (nb/km²)	HDI	Per capita GDP	Nb tourists per year
Cook Islands	Cook Islands	Aitutaki	24.1	Inhabited	2200	91.28	829	15002	121207
Cook Islands	Cook Islands	Mangaia	51.8	Inhabited	744	14.36	829	15002	121207
Cook Islands	Cook Islands	Manuae	7.4	Uninhabited, visited occasionally	0	0	829	15002	121207
Cook Islands	Cook Islands	Palmerston	2.6	Inhabited	62	23.84	829	15002	121207
Cook Islands	Cook Islands	Penrhyn	9.8	Inhabited	357	36.42	829	15002	121207
Cook Islands	Cook Islands	Rarotonga	67.6	Inhabited	10572	156.39	829	15002	121207
Federated States of Micronesia	Chuuk State	Chuuk	93.07	Inhabited	36158	388.50	0.64	2960	13737
Federated States of Micronesia	Kosrae	Kosrae	110	Inhabited	6616	60.14	0.64	2960	13737
Federated States of Micronesia	Pohnpei	Pohnpei	334	Inhabited	35000	104.79	0.64	2960	13737
Federated States of Micronesia	Yap	Yap	105.4	Inhabited	11377	107.94	0.64	2960	13737
Fiji	Fiji	Beqa	36	Inhabited	NA	NA	727	5112	660590
Fiji	Fiji	Cakau Levu	NA	NA	NA	NA	727	5112	660590
Fiji	Fiji	Gau	136.1	Inhabited	NA	NA	727	5112	660590
Fiji	Fiji	Kadavu	450.3	Inhabited	10167	22.57	727	5112	660590
Fiji	Fiji	Lomaiviti (province)	411	Inhabited	16.461	40.05	727	5112	660590
Fiji	Fiji	Mamanuca Islands	NA	Inhabited	NA	NA	727	5112	660590
Fiji	Fiji	Namena	0.4	Inhabited	NA	NA	727	5112	660590
Fiji	Fiji	Rotuma	44	Inhabited	2002	45.50	727	5112	660590
Fiji	Fiji	Taveuni	442.1	Inhabited	9000	20.35	727	5112	660590
Fiji	Fiji	Vanua Levu	5587.1	Inhabited	136000	24.34	727	5112	660590
Fiji	Fiji	Vatu-i-ra	NA	Uninhabited	0	0	727	5112	660590
Fiji	Fiji	Viti Levu (Lautoka)	10531	Inhabited	600000	56.97	727	5112	660590
Fiji	Fiji	Wakaya	8	Inhabited	450	56.25	727	5112	660590
Fiji	Fiji	Yasawa	32	Inhabited	NA	NA	727	5112	660590
France	French Polynesia	Aratika	8.3	Inhabited	160	19.27	737	20098	180602
France	French Polynesia	Bora Bora	21.9	Inhabited	9598	438.26	737	20098	180602
France	French Polynesia	Marutea Sud	14	Inhabited	178	12.71	737	20098	180602
France	French Polynesia	Mataiva	16	Inhabited	280	17.50	737	20098	180602
France	French Polynesia	Moorea	132	Inhabited	16191	122.65	737	20098	180602
France	French Polynesia	Nengo Nengo	9	Uninhabited, visited occasionally	0	0	737	20098	180602
France	French Polynesia	Nuku Hiva	345	Inhabited	2966	8.59	737	20098	180602
France	French Polynesia	Raiatea	173.3	Inhabited	12245	70.65	737	20098	180602
France	French Polynesia	Rangiroa	43	Inhabited	2567	59.69	737	20098	180602
France	French Polynesia	Tahiti	1068	Inhabited	183645	171.95	737	20098	180602
France	French Polynesia	Takapoto	23	Inhabited	380	16.52	737	20098	180602
France	French Polynesia	Tetiaroa	12.8	Inhabited	20	1.56	737	20098	180602
France	French Polynesia	Tikehau	20	Inhabited	529	26.45	737	20098	180602
France	French Polynesia	Tubuai	47.1	Inhabited	2170	46.07	737	20098	180602
France	French Polynesia	Ua Uka	82.4	Inhabited	621	7.53	737	20098	180602
France	New Caledonia	Grande Terre	16648.4	Inhabited	247600	14.87	789	39391	107187
France	New Caledonia	Lifou	1146.2	Inhabited	9275	8.09	789	39391	107187
France	Wallis-and-Futuna	Alofi	32	Uninhabited	0	0	763	12640	NA
France	Wallis-and-Futuna	Futuna	62.3	Inhabited	3613	57.99	763	12640	NA
France	Wallis-and-Futuna	Wallis/Uvea	82.4	Inhabited	10731	130.23	763	12640	NA
Kiribati	Kiribati	Birnie	0.2	Uninhabited	0	0	0.59	1631	3531
Kiribati	Kiribati	Carondolet seamount	NA	Uninhabited	0	0	0.59	1631	3531

Country	Territory	Island	Size (km²)	Human presence	Population	Population density (nb/km²)	HDI	Per capita GDP	Nb tourists per year
Kiribati	Kiribati	Enderbury	5.1	Uninhabited	0	0	0.59	1631	3531
Kiribati	Kiribati	Flint	3.2	Uninhabited	0	0	0.59	1631	3531
Kiribati	Kiribati	Kanton	9.1	Inhabited	24	2.63	0.59	1631	3531
Kiribati	Kiribati	Kiritimati	321	Inhabited	6447	20.08	0.59	1631	3531
Kiribati	Kiribati	Kuria	12.7	Inhabited	1043	82.12	0.59	1631	3531
Kiribati	Kiribati	Malden	39.3	Uninhabited	0	0	0.59	1631	3531
Kiribati	Kiribati	Manra	4.4	Uninhabited	0	0	0.59	1631	3531
Kiribati	Kiribati	McKean	0.6	Uninhabited	0	0	0.59	1631	3531
Kiribati	Kiribati	Millenium	3.8	Uninhabited	0	0	0.59	1631	3531
Kiribati	Kiribati	Nikumaroro	4.1	Uninhabited	0	0	0.59	1631	3531
Kiribati	Kiribati	Orona	3.9	Uninhabited	0	0	0.59	1631	3531
Kiribati	Kiribati	Rawaki	0.5	Uninhabited	0	0	0.59	1631	3531
Kiribati	Kiribati	Starbuck	16.2	Uninhabited	0	0	0.59	1631	3531
Kiribati	Kiribati	Tabuaeran	33.73	Inhabited	1960	58.10	0.59	1631	3531
Kiribati	Kiribati	Teraina	9.55	Inhabited	1690	176.96	0.59	1631	3531
Kiribati	Kiribati	Vostok	0.3	Uninhabited	0	0	0.59	1631	3531
Marshall Islands	Marshall Islands	Majuro	9.71	Inhabited	27797	2862.71	738	3947	2727
Marshall Islands	Marshall Islands	Namorik	2.6	Inhabited	772	296.92	738	3947	2727
Marshall Islands	Marshall Islands	Rongelap	7.8	Inhabited	20	2.56	738	3947	2727
Palau	Palau	Angaur/Ngeaur	8.4	Inhabited	119	14.16	788	11067	104988
Palau	Palau	Babeldaob	374.1	Inhabited	6000	16.03	788	11067	104988
Palau	Palau	Kayangel/ Ngcheangel	1.7	Inhabited	140	82.35	788	11067	104988
Palau	Palau	Peleliu/Beliliou	12.7	Inhabited	700	55.11	788	11067	104988
Papua New Guinea	Papua New Guinea	West New Britain	35144.6	Inhabited	513926	14.62	516	2220	164993
Samoa	Samoa	Savai'i	1717.6	Inhabited	43142	25.11	702	4293	124350
Samoa	Samoa	Upolu	1125.1	Inhabited	143418	127.47	702	4293	124350
Tonga	Tonga	Tongatapu	259.3	Inhabited	75416	290.84	717	4121	46005
United Kingdom	Pitcairn	Pitcairn	4.2	Inhabited	68	16.19	909	NA	NA
United States	American Samoa	Aunuíu	1.52	Inhabited	443	291.44	827	13000	20300
United States	American Samoa	Ofu	7.5	Inhabited	289	38.53	827	13000	20300
United States	American Samoa	Ofu & Olosega	12.9	Inhabited	505	39.14	827	13000	20300
United States	American Samoa	Olosega	5.4	Inhabited	216	40	827	13000	20300
United States	American Samoa	Rose	0.1	Uninhabited	0	0	827	13000	20300
United States	American Samoa	SOB (South Bank)	NA	Uninhabited	0	0	827	13000	20300
United States	American Samoa	Swains/Olosega	3.6	Inhabited	17	4.72	827	13000	20300
United States	American Samoa	Tau	45.7	Inhabited	790	17.28	827	13000	20300
United States	American Samoa	Tutuila	142.3	Inhabited	55876	392.66	827	13000	20300
United States	Guam	Guam	541	Inhabited	159358	294.56	901	30500	1510000
United States	Hawaii	French Frigate	938	Uninhabited	0	0	5.53	57220	8282680
United States	Hawaii	Gardner	2.4	Uninhabited	0	0	5.53	57220	8282680
United States	Hawaii	Hawaii	10434	Inhabited	185079	17.73	5.53	57220	8282680
United States	Hawaii	Kahoolawe	115.5	Uninhabited	0	0	5.53	57220	8282680
United States	Hawaii	Kauai	1434.6	Inhabited	65689	45.78	5.53	57220	8282680
United States	Hawaii	Kaula	0.64	Uninhabited	0	0	5.53	57220	8282680
United States	Hawaii	Kure	862	Uninhabited	0	0	5.53	57220	8282680
United States	Hawaii	Lanai	358.4	Inhabited	3102	8.65	5.53	57220	8282680
United States	Hawaii	Laysan	4	Uninhabited	0	0	5.53	57220	8282680
United States	Hawaii	Lehua	1.15	Uninhabited	0	0	5.53	57220	8282680
United States	Hawaii	Lisianski	1.55	Uninhabited	0	0	5.53	57220	8282680
United States	Hawaii	Maro Reef	1.93	Uninhabited	0	0	5.53	57220	8282680

Country	Territory	Island	Size (km²)	Human presence	Population	Population density (nb/km²)	HDI	Per capita GDP	Nb tourists per year
United States	Hawaii	Maui	1903.3	Inhabited	144444	75.89	5.53	57220	8282680
United States	Hawaii	Molokai	677.9	Inhabited	7345	10.83	5.53	57220	8282680
United States	Hawaii	Necker	183	Uninhabited	0	0	5.53	57220	8282680
United States	Hawaii	Nihoa	0.8	Uninhabited	0	0	5.53	57220	8282680
United States	Hawaii	Niihau	182.8	Inhabited	130	0.71	5.53	57220	8282680
United States	Hawaii	Oahu	1583.3	Inhabited	76372	48.23	5.53	57220	8282680
United States	Hawaii	Pearl and Hermes reef	0.32	Uninhabited	0	0	5.53	57220	8282680
United States	Midway	Midway	6.2	Inhabited	40	6.45	0.92	57220	NA
United States	Northern Mariana Islands	Agrihan	40	Uninhabited	0	0	875	13300	501179
United States	Northern Mariana Islands	Aguijan	7	Uninhabited	0	0	875	13300	501179
United States	Northern Mariana Islands	Alamagan	11	Uninhabited	0	0	875	13300	501179
United States	Northern Mariana Islands	Asuncion	7.4	Uninhabited	0	0	875	13300	501179
United States	Northern Mariana Islands	Farallon de Pajaros	2	Uninhabited	0	0	875	13300	501179
United States	Northern Mariana Islands	Guguan	4	Uninhabited	0	0	875	13300	501179
United States	Northern Mariana Islands	Maug Islands	2	Uninhabited	0	0	875	13300	501179
United States	Northern Mariana Islands	Pagan	46.6	Uninhabited	0	0	875	13300	501179
United States	Northern Mariana Islands	Rota	95.7	Inhabited	2477	25.88	875	13300	501179
United States	Northern Mariana Islands	Saipan	122.9	Inhabited	48220	392.35	875	13300	501179
United States	Northern Mariana Islands	Santa Rosa	NA	Uninhabited	0	0	875	13300	501179
United States	Northern Mariana Islands	Sarigan	4.9	Uninhabited	0	0	875	13300	501179
United States	Northern Mariana Islands	Tinian	102	Inhabited	3136	30.74	875	13300	501179
United States	PRIA	Baker	1.2	Uninhabited	0	0	0.92	57220	NA
United States	PRIA	Howland	1.5	Uninhabited	0	0	0.92	57220	NA
United States	PRIA	Jarvis	4.4	Uninhabited	0	0	0.92	57220	NA
United States	PRIA	Johnston	2.67	Inhabited	10	3.74	5.53	57220	8282680
United States	PRIA	Kingman Reef	12	Uninhabited	0	0	0.92	57220	NA
United States	PRIA	Palmyra	6.6	Uninhabited	40	6.06	0.92	57220	NA
United States	Wake Island	Wake	6.5	Inhabited	150	23.07	0.92	57220	NA
Vanuatu	Vanuatu	Efate	899.5	Inhabited	65829	73.18	594	3137	108161
Vanuatu	Vanuatu	Emae	32	Inhabited	743	23.21	594	3137	108161
Vanuatu	Vanuatu	Emao	NA	Inhabited	NA	NA	594	3137	108161
Vanuatu	Vanuatu	Lelepa	1.6	Inhabited	387	242	594	3137	108161
Vanuatu	Vanuatu	Moso	3.6	Inhabited	237	65.8	594	3137	108161
Vanuatu	Vanuatu	Nguna	24.5	Inhabited	1255	51.22	594	3137	108161
Vanuatu	Vanuatu	Pele	4.3	Inhabited	220	51.16	594	3137	108161

The sampling effort associated with Exclusive Economic Zones (EEZ) shows that six regions are particularly well monitored: the Mariana Islands (including Guam, USA), the Main Hawaiian Islands (USA), New Caledonia (France), American Samoa (USA), and French Polynesia (France) (Fig. 5 et 6). This highlights the lack of monitoring programs held by independent island nations of the Pacific (e.g. Kiribati), as well as of some territories (e.g. Wallis and Futuna, France). Several countries, including Tuvalu, Niue, Tokelau, Nauru, the Solomon Islands and Matthew & Hunter, are not represented in this report, as time series were not available. Specific monitoring efforts should therefore be promoted for these countries, and a broader search should be conducted to identify additional data as some NGOs may have data that have not yet been included in these analyses. Some other countries are well represented, but with sampling only featuring a limited number of islands (such as for Papua New Guinea where only one long time series on one island exists). Other countries, such as Fiji, are less represented, but the sampling effort is distributed over a large number of islands (see in Country Report).

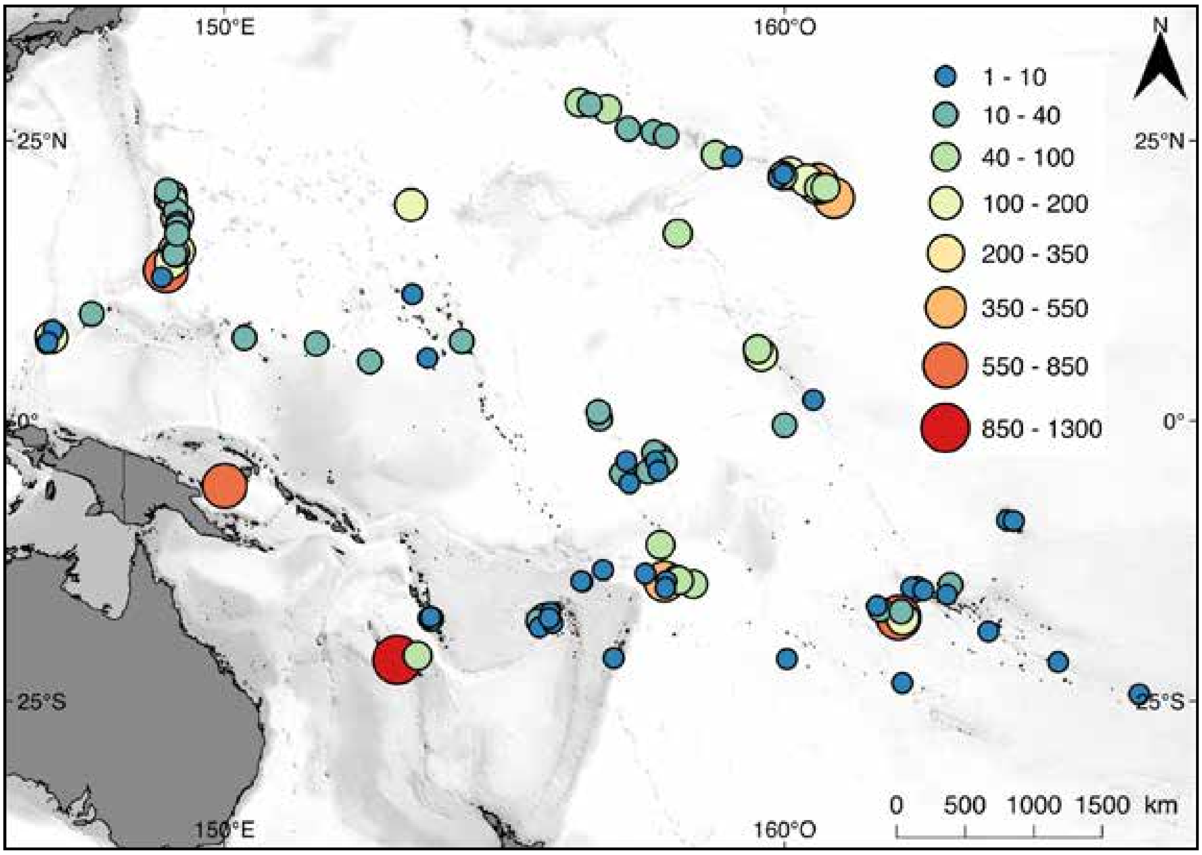


FIGURE 6
Sampling effort per island: circle size and colour represent the number of surveys at each island. Only the effort allocated for substrate monitoring is represented.

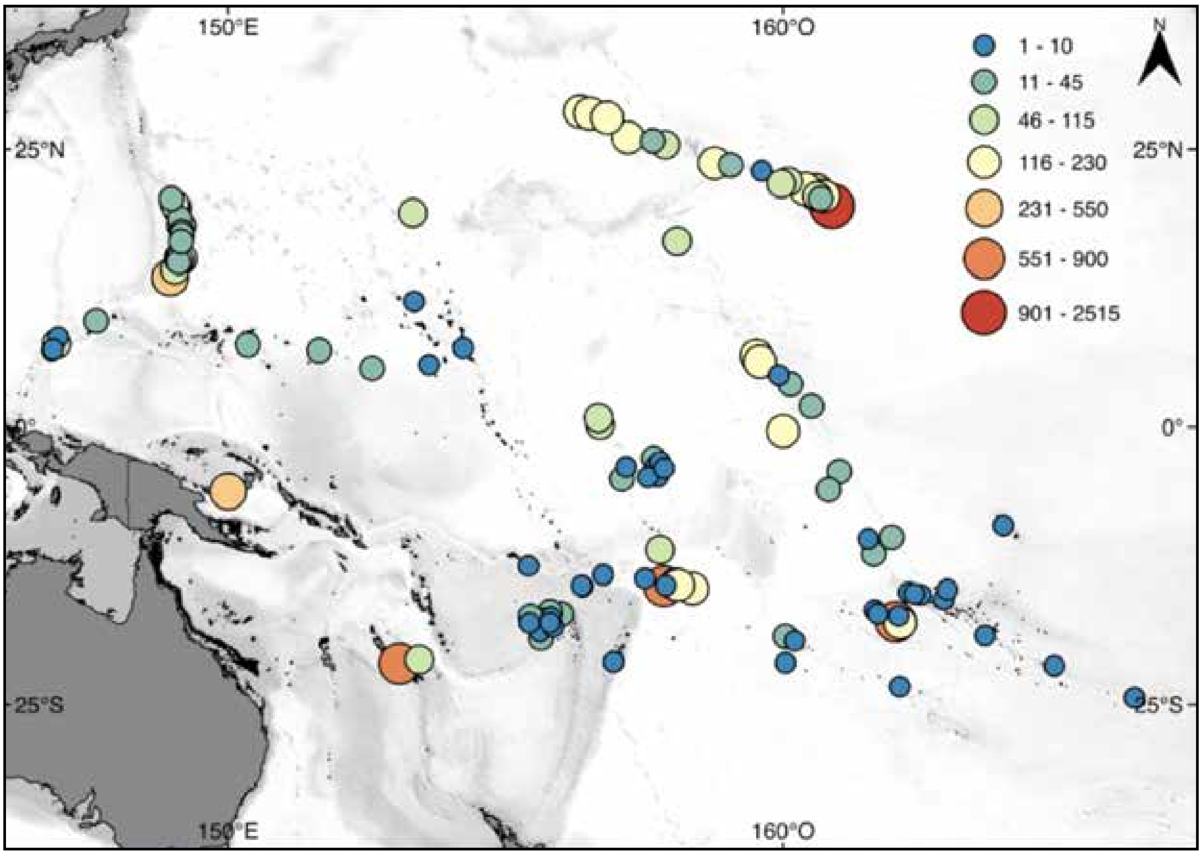


FIGURE 7
Sampling effort per island: circle size and color represent the number of surveys at each island. Only the effort allocated for fish monitoring is represented.

In addition to biological data, we also collated environmental, geographic, and socio-economic data for each country and each island surveyed. These data include island size, island type (e.g. low atoll, high island), proximity to other islands and continents, occupation (inhabited versus uninhabited), population density, Human Development Index (HDI), number of tourists per year, and per capita gross domestic product (GDP) that are provided in the Country Reports.

The number of Degree Heating Weeks (DHW) was gathered for each site and each year surveyed between 2001 and 2016 from https://coralreefwatch.noaa.gov/satellite/hdf/index.php. All possible data were gathered but we were constrained by data availability prior to 2001. Where possible, collaborators also provided data for major disturbances (see Timeline in the Country Reports). These disturbances included mass coral bleaching events, cyclones, *Acanthaster planci* outbreaks, algal blooms, dredging and filling activities, major effluents, and ship groundings.

Delineation of the sampling units to analyse the data approximately mirrored that of the Caribbean report (Jackson et al. 2014), but was adapted to coincide with the characteristics of the Pacific datasets obtained. The delineation was as follows:

Survey: a set of replicate data points collected at a unique reef site, date, depth, or short range of depths. Individual surveys are composed of replicates or averaged values for a series of replicates within datasets at a unique site, date, and depth.

Dataset: an individual data collection of substrate (i.e. biological and/or non-biological components) or fish by a single researcher or research team in a particular country, territory, or state.

Site: one or more surveys at the same depth and GPS coordinates on the same reef.

Island: an isolated island or reef structure, or group of one main island and its islets.

Country, state, or territory: an independent nation (e.g. Fiji) or political entity attached to or within a single country (e.g. French Polynesia belonging to France), either of which may be further subdivided to reflect geographic isolation (e.g. Pacific Remote Island Area from the USA).

The compilation of the data presented a challenge regarding data organisation and management given the various formats of the datasets obtained. These datasets were based on diverse sampling designs and methodologies.

The choice of the sites in the sampling design varied from selective to random (see database structure in Appendix I). We acknowledge that these methods may lead to some differences in the reef metrics recorded (e.g. higher coral cover may be observed in a site selected for its coral presence than in a random site on a habitat composed of mixed sand and coral head patches). However, this difference was not accounted for in this report because of the great difference in reef morphology already present across the region. Since it is indicated in the database, it is nevertheless possible to include this sampling design factor in further analyses to account for the potential bias in sampling method.

The methods comprised mainly point intercept transects and photo quadrats for the substrate, and belt transects and stationary point counts for fish. Several studies showed that, for substrate and fish, using different methods leads to similar estimates of reef metrics. With respect to coral, all of the methods used in this study are reportedly a good estimate of cover on a reef (Jokiel et al. 2015). Detecting the number of coral species may however differ between methods, with the quadrat method allowing closer examination of small and cryptic coral species that are not detected by other less accurate methods (Jokiel et al. 2015). Thus, datasets measuring coral cover by different methods could be legitimately combined, as done in previous studies (Franklin et al. 2013, Jackson et al. 2014, Obura et al. 2017), all the more that most of our substrate data were collected using the accurate point intercept transect and quadrat methods. For fish, a study showed that species point count typically recorded more individuals than belt transect surveys, but that this pattern varied greatly among species (Colvocoresses and Acosta 2007)) and recent work question this point (Donovan 2017, Friedlander et al, 2018). Given the complexity of these differing estimations between the methods and species, added to the observer bias (Thompson and Mapstone 1997, Williams et al. 2006), we did not apply any correction factor to our fish data to avoid introducing any additional bias.

The datasets collected here were therefore collated after appropriate transformation of the original data (e.g. metrics calculated as percentage or abundance per unit surface). Datasets also reported various ecological and environmental parameters, and used different categories for reported variables (e.g. turf and macroalgae pooled together or not). Therefore, each database was converted into a standardised format in which GIS information, sampling methodology, environmental and management parameters were incorporated (Appendix I). Additional information was gathered from dataset providers when needed. A considerable amount of work was therefore performed to check, edit, reformat and compile all the datasets into one meta-database.

The majority of the data gathered concerned the substrate, especially corals, macroalgae, other benthic components such as invertebrates other than scleractinian corals (e.g. soft corals, sponges), and fish. For most sites or islands where substrate was monitored, it was possible to obtain data for fish (Fig. 7). Fish data was also recorded at sites or islands not covered by benthic sampling (Fig. 4). A substantial number of datasets presented high taxonomic resolution, i.e. species or genera for the benthic categories, and species for fish.

Data on macroinvertebrates such as echinoderms, molluscs, or crustaceans were not considered in this report. While these types of data exist for some localities in the region, and although we acknowledge the important role of these organisms in both coral reefs (Klumpp and Pulfrich 1989, Bak 1994, Jackson et al. 2014) and as a food source for the local communities (Gillett 2011), the sampling methods were too disparate to allow for the collation of the datasets (e.g. monitoring of sea urchin only, monitoring of large invertebrates only, monitoring of threatened groups only, etc.). Given this gap, we advocate for a better standardisation of the monitoring methods across the Pacific Islands region for this group.

Benthic data comprised 26 datasets including 7940 individual surveys. Because turf algae were not recorded consistently among datasets (e.g. depending on its size, turf can be recorded as rock or turf or macroalgae), we obtained the definitions of turf from all data contributors and appropriately reassigned the categories when necessary for uniformity. For this study, macroalgae were not considered at the species level even if indicated in the original datasets. We defined macroalgae as erect fleshy or calcified algae taller than 2 cm, including *Lobophora* and *Peyssonnelia spp.* These include, among many others, *Halimeda*, *Sargassum*, *Liagora*, *Dictyota*, *Turbinaria* and *Padina spp*.

Fish data were included in 23 datasets accounting for 11 330 individual surveys. Most fish datasets provided individual size as well as abundance. Some fish datasets only recorded certain groups such as parrotfish, groupers, rabbitfish, etc., however the identification of

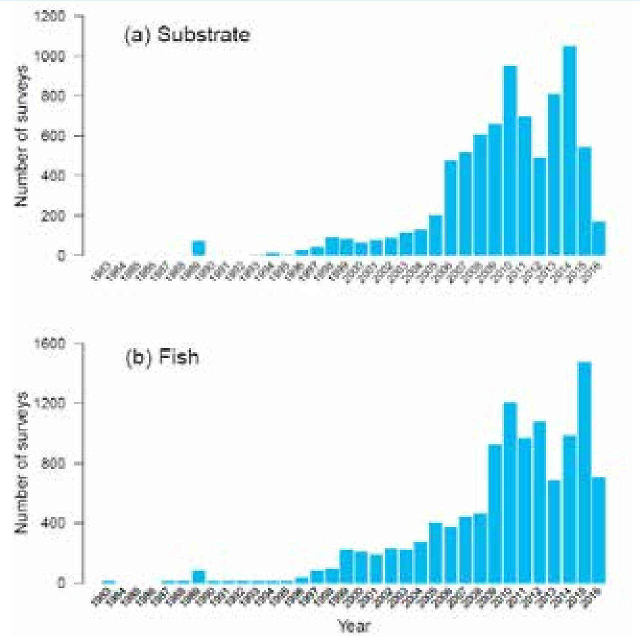


FIGURE 8
Number of surveys per year in the (a) substrate and (b) fish data.

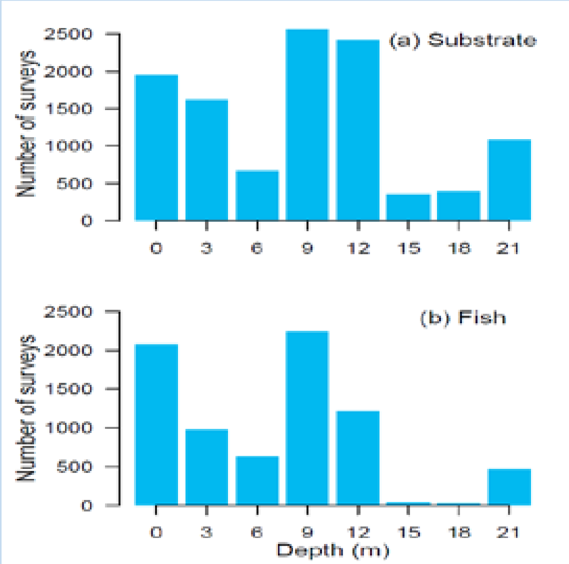


FIGURE 9
Number of surveys per class of depth in the (a) substrate and (b) fish data.

these groups appeared to be generally good, making the datasets reliable. Considerable energy was invested in assigning each fish taxon recorded (whatever the resolution) to a specific trophic group (the four main groups being herbivore, carnivore, corallivore, and planktivore) using reliable sources (www.fishbase.org, Galzin and Harmelin-Vivien 2000, Kulbicki et al. 2005, Sandin and Williams 2010).

The histograms of the number of surveys per year highlight the paucity of surveys before the 2000s (Fig. 8). For both coral and fish, the great majority of the surveys were made after 2005. There were also fewer surveys in the datasets for recent years (2015, 2016) compared to 2014 and before because the data was not made available (time required by some institutes before making their data available) or not yet digitally processed. We noticed however that long-term monitoring programs have become increasingly common after the 2000s, and most of the monitoring programs used in this report are planned to continue in the following years (personal communication from the dataset providers).

Data were obtained from a range of depths and reef zones (lagoon, back reef, fore reef or onshore slopes) (Fig. 9). Most surveys were in the 9-12 m depth range (reef slopes) or at shallow depths (lagoons or barrier reefs between 0 and 3 m depth). Only a minority

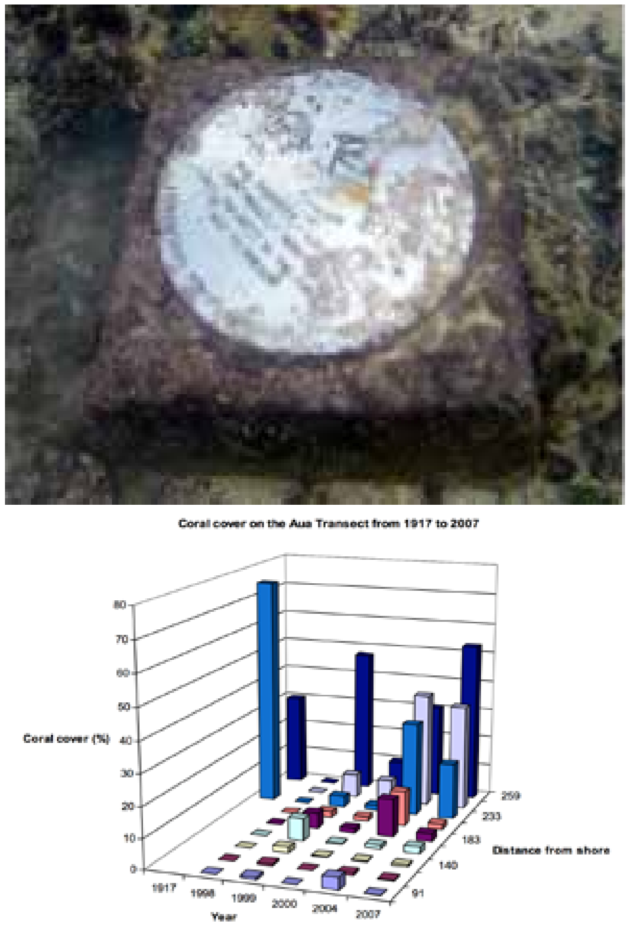


FIGURE 10
Top: The Aua Transect (© Charles Birkeland). Alfred Mayor from the Carnegie Institute established a permanent 247-m transect in 1917 for a quantitative study of corals across a reef flat near the village of Aua in Pago Pago Harbor (American Samoa). Permanent markers were placed at the ends of the transect by the US Coast and Geodetic Survey. The transect was resurveyed in 1973, 1980, 1995, 1998, 1999, 2000, 2004, 2007, and 2017. The inner third of the transect was eliminated by dredging out the sand for road construction in the 1950s. The living coral cover and diversity severely decreased, probably when the two large tuna canneries began to operate in late 1950s. However, there was rapid recovery of acroporids after 1991 when the tuna canneries were required to pipe their wastewater out to the open sea. Although the recovery was relatively rapid on solid substrata, recovery has taken decades on sand and rubble (Birkeland et al 2013).
Bottom: Percent of live coral cover through time along the Aua quantitative permanent transect.

of surveys were conducted deeper than 15 m mainly because sampling at these depths is significantly more complicated as it introduces greater risks associated with diving.

Most sites were selected using a random stratified sampling design, with transects or quadrats either placed haphazardly at the same site or fixed. For instance, the 30-year old Polynesia Mana program surveys fixed quadrats in five different countries or territories of Central South Pacific. The NOAA CREP conducts large-scale surveys in many remote islands of the American states and territories using random-stratified selected sites to avoid repeated observations at the exact same geographic point. Surveys of the different monitoring programs used here were also conducted with varying frequency, from four times a year to every other year or sometimes even less, as a consequence of the remoteness and accessibility of some Pacific Islands and/or the lack of funding or staff allocated to monitoring programs. A few programs changed methods over time and were therefore considered as separate datasets.

The longest time series recorded in the Pacific is the AUA transect in American Samoa, initially set up by Alfred Mayor (Fig 10). This time series clearly highlights the long-term effects of anthropogenic activities on coral reefs. However, due to the very different methods used to record the substrate compared to all other datasets, it could not be used in this meta-analysis.

The longest time series used in this report was the Tiahura transect for fish (34 years, see Galzin et al. 2016, Fig 11) and the Polynesia Mana for corals (24 years), both implemented by CRIOBE (French Polynesia).

FIGURE 11
Photographs of the Tiahura transect in 1971 (© Bernard Salvat) and in 2014 (© Cécile Berthe).

1.b. Spatio-temporal analysis for benthic organisms

The major long-term trends in reef benthic components were estimated at different levels (replicates, surveys, and islands). The trends were also modelled using linear mixed-effect models (LMMs). LMMs are statistical models that contain both fixed effects and random effects. They are particularly useful for these kinds of studies where repeated measurements are made on the same statistical units, or where measurements are made on clusters of related statistical units. ‘Year’ was included as a fixed effect to check for significance (p-value threshold: 0.05). To ensure that each island within each dataset was treated as a repeated measure over time (i.e. account for temporal and spatial autocorrelation) we added random components of ‘island’ and ‘dataset’. Predicted values were calculated from the LMMs for each combination of dataset, island, and year. Yearly estimates at the Pacific scale were then calculated by averaging all predicted values per year, and the smoothed trend was plotted. These models were similarly used to estimate the long-term trend in percent cover of live coral, macroalgae, turf, CCA, abiotic substrate (i.e. sand, rubble, pavement, rock, etc.), invertebrates other than scleractinian corals (e.g. clams, sponges, soft corals). The three main coral genera Acropora, Pocillopora and Porites were segregated in some analyses. The models were also used to compare the trends in percent cover of live coral in inhabited versus uninhabited islands, and and in three different habitats: the lagoon (made of the fringing reefs along the coast and the reef structures between the coast and the barrier reef), the barrier reef or back reef (defined as the reef at the edge of a lagoon, facing the inside of the lagoon), and the fore reef (defined as the external slope of the barrier reef, facing the ocean, or the slope at the edge of the fringing reef in islands with reef system only made of fringing reef or platform, with no lagoon identified).

Relationships between average annual coral cover per island and environmental (e.g. DHW) and socio-economic (e.g. population density per island) data were also explored.

Relative frequency distributions of percent coral cover per survey were calculated for different time bins, and accounted for a comparable number of surveys in each time bin. Time bin distributions were compared one by one using a non-parametric two sample Kolmogorov-Smirnov (KS) test (p-value threshold: 0.05), that compares the cumulative distributions of two data sets. The null hypothesis in a KS test is that both groups are sampled from populations with identical distributions. It tests for any violation of that null hypothesis (i.e. different medians, different variances, or different distributions).

Multivariate ordination was performed to investigate the patterns of change in the benthic community composition. We implemented this analysis at the survey level in order to reflect the coral community composition change at the site level rather than at the island level. Surveys were included in a Principal Coordinate Analysis (PCA, i.e. a statistical procedure used to emphasise variation and highlight strong patterns in a dataset) using Euclidean distances when data were available for percent cover of corals at the genus level. The total amount of variance explained along the axes was calculated.

A non-metric multidimensional scaling (NMDS) using Gower distances was performed to explore the change in benthic assemblage composition over time at the survey level, to graphically highlight the time bins of relatively similar taxa composition and cover. An analysis of similarity (ANOSIM) was performed to compare the variation in benthic composition between the identified time bins (p-value threshold: 0.05).

All statistical analyses were conducted using the open-source software program R version 3.3.0 (R Development Core Team 2016), and the associated *vegan* (Oksanen et al. 2016) and lme4 (Douglas et al. 2015) packages. The vegan package allows performing statistical analyses for ecological data, and the lme4 package allows implementing LMMs. Such packages are commonly used in ecological data analysis and were used more specifically in the Caribbean report (Jackson et al. 2014)

1.c. Spatio-temporal analysis for fish

Densities (i.e. the number of individuals per unit surface) were systematically calculated from the abundance and the sampling area given in each dataset, in order to have a consistent metric across datasets. Biomass was then calculated using the length-weight relationship as in Kulbicki et al. 2005 when both abundance and individual fish size were provided in the datasets.

Trends in fish biomass (weight per unit surface) were estimated using LMMs. The models were implemented similarly to how they were implemented for benthic reef components and were used to estimate the long-term trends in abundance and biomass of the total fish community, but also by trophic groups (herbivores, corallivores, planktivores, carnivores), and for two major families that are known to influence the coral-algae competition, the parrotfish (Scaridae) and the surgeonfish (Acanthuridae).

2. OVERALL CHANGES IN BIOLOGICAL ABUNDANCE

We discuss the status and trends of all benthic components, with a focus on live hard corals and macroalgae, which are the major sessile components of reef communities in terms of cover and ecological functions in the ecosystem. We then highlight the changes that occurred in the genera composition of the coral community over the study period. Finally, we discuss the major long-term trends in fish biomass to understand how they may correlate with changes in the benthos over past decades.

2.a. Patterns of change for corals, macroalgae, and other benthic categories

i. Long-term changes in corals, macroalgae, and other benthic categories

The boxplots for all coral and macroalgae survey replicates (see definition in the Methods) represent the distribution of the data at the replicate level based on their minimum, first quartile, median (i.e. half of the observations above, half below), third quartile, maximum, and outliers (Fig. 12). It clearly shows that some replicates had no live coral recorded (0% in live coral cover), whereas some rare replicates showed coral cover up to 100%. Few datasets (i.e. surveys and replicates) are available before 1997 from the pool of data that we were able to gather, and concerned mainly sites in French Polynesia and New Caledonia Therefore, these early observations may not be representative of the coral reef status at the Pacific scale at the beginning of the study period. More specifically, the increase in the medians between 1993 and 1996 reflects the recovery of reefs in French Polynesia after a cyclone and a bleaching event (see Country Reports). After 1997, when replicates from additional regions were included, the median became stable until 2006 (Fig. 12). However, the limited amount of data for this period prevents from providing an accurate interpretation of these results. For macroalgae, an increase in the median is observed from 2005 up to 2008 as well as an increase in replicates having high macroalgae cover (up to 100%, Fig. 12). Similarly to coral cover, this graph is useful to display the distribution of the data but does not allow any strong temporal trend assessment.

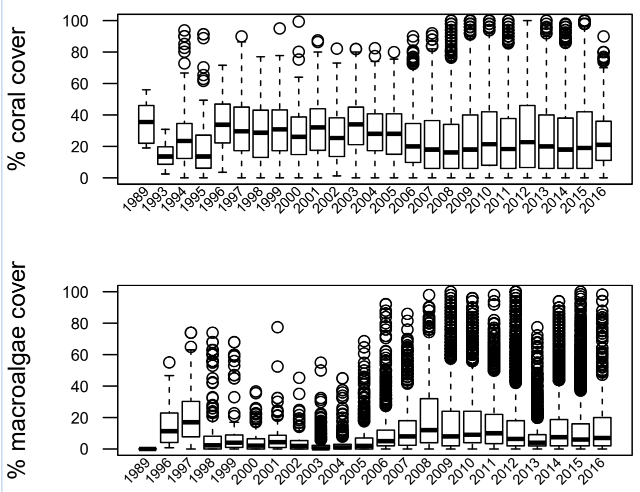


FIGURE 12
Boxplots of (top) coral and (bottom) macroalgae annual cover records from all surveys.

We then performed an analysis at the survey level by averaging the replicates for each survey. We calculated the proportion of surveys for different classes of coral cover (0 to 5%, >5 to 10%, etc.). A change in the proportion of coral reef surveys displaying high coral cover was observed over the past decades (Fig. 13). At the beginning of the study period (1989-1999 time-bin), the majority of the sampled reefs displayed percent of live coral ranging from 0 to 60%. This pattern did not change for the following 4-year time bin. From 2004, the histogram becomes positively skewed, with a substantial number of surveys with 10% or less live coral cover. In the mean time, however, a higher proportion of reefs display >75% coral cover after 2008 than before, and the mean across surveys varies only slightly among time bins (from 22.1% in 2012-2014 to 29.8% in 2000-2003).

The percent cover for coral, macroalgae, CCA, and other invertebrates were subsequently averaged across surveys per island in order

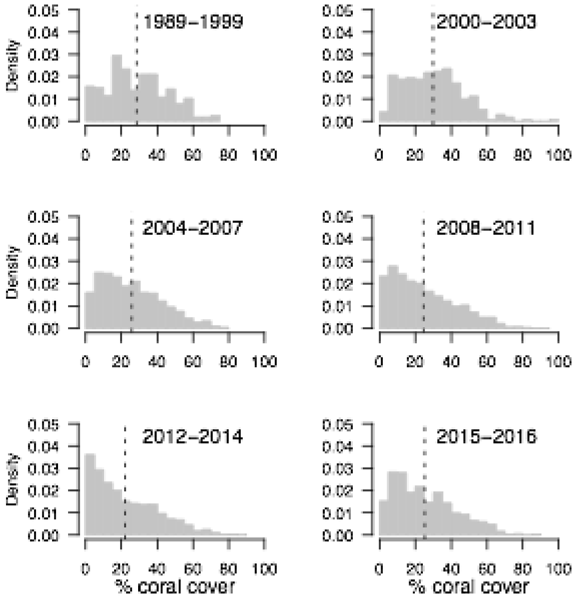


FIGURE 13
Distribution of coral cover among all surveys for successive time intervals. Dashed lines represent the average coral cover across surveys for each histogram.

to remove the bias of having highly sampled versus weakly sampled islands. The average coral cover across islands is summarised in Fig. 14 (top), and shows three patterns:

1) An inconsistent trend between 1989 and 1998 due to the low number of islands sampled (see comments on boxplot above);
2) A slight decline from 1999 onward, significant but only explaining 31% of the variance ($p=0.017$, $R^2=0.31$);
3) An average of 25.6% (SD±3.8%) coral cover with yearly averages over islands remaining close to the average over the study period.

Therefore, we can consider that coral cover has been relatively stable over the past two decades in the Pacific Island Region, with a decrease of only 3% in the last 18 years.

The trend for macroalgae averaged across islands (Fig. 14 bottom) also depicts an inconsistent trend between 1989 and 1998 (a period when only few islands and archipelagos were sampled), but a significant increase between 1998 and 2016 ($p=0.007$, $R^2=0.37$). The average macroalgae cover calculated for the study period is 10.2% (SD±5.9%), and we observe lower-than-average cover values between 1996 and 2004, and higher-than-average cover values from 2004, with a consistent increase since 2013. We note however that for each year average macroalgae cover is systematically lower than average coral cover over the entire study period.

Using statistical models (LMMs) to take into account the variation among sites and datasets, we refined the temporal trends of live scleractinian coral and macroalgae percent cover over the past decades. The smoothed modelled trend confirms an overall stability in coral cover overall, especially after 1996 when more islands were sampled (Fig. 14 top). The smoothed modelled trend for macroalgae also shows a slight increase from 2005 onward (Fig. 14 bottom).

The stable trend observed for all coral reef data holds when considering the different habitats (lagoon, back reef, fore reef: Fig. 15). The lagoon and back reef show more variability in the patterns among consecutive years, likely due to the fact that we have a lower number of islands and archipelagos sampled for these habitats when compared to the forereef, which composed most of the data.

The trends in coral and macroalgae cover appears to have been fairly consistent over the period when several archipelagos were sampled, but the paucity of data prior to 1998 and the absence of data prior to 1989 prevents estimation of whether the starting point of this temporal assessment represents an already-altered state, or if the reefs were in the same condition decades ago. Recent studies suggest that the Pacific coral cover baseline could be higher than the 25.6% average we provide in this report (Bruno 2013, Eddy et al. 2018). Extending this meta-analysis to include snapshot data prior to 1989 and for sites or islands that were not included in this report could be an additional step to get more information on the baseline coral and macroalgae cover in the Pacific Island region.

Turf algae cover did not show any significant temporal trend over the past two decades (Fig. 16 top left), as opposed to the trend for macroalgae (Fig. 14 bottom). Recording turf algae on the transects or quadrats as a category

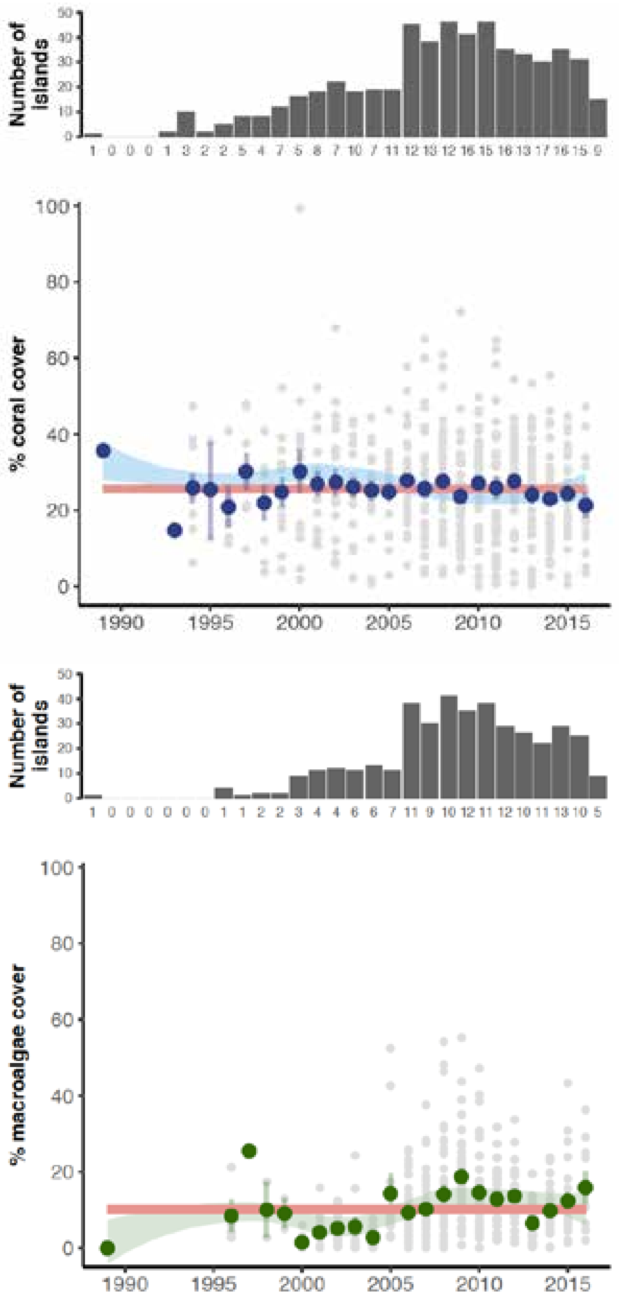


FIGURE 14
Average annual percent cover across islands (blue dots on the top panel: live hard coral; green dots on the bottom panel: macroalgae.) and standard error (blue and green segments, respectively) between 1989 and 2016. Grey dots represent the average annual percent cover for each island. The red line represents the average percent cover across the study period. The shaded blue and green area, respectively, represents the 95% confidence interval of the fit of a linear mixed-effect model including 'islands' and 'datasets' as random factors to the coral and macroalgae cover data. Black bars on the top graphs represent the number of islands monitored per year, and the number under each bar gives the number of archipelagos monitored per year.

per se (in 1997) than for macroalgae, maybe because it was previously ignored as a benthic category. Even in currently well-established monitoring programs, the turf-algae category is often classified into different categories due to its small size. As it is sometimes barely visible on benthic photos, it is therefore categorised as a non-living substrate (rock, carbonate...), and assigning turf to a particular species is difficult as turf is often a combination of several small algal species.

The crustose coralline algae (CCA) pattern shows a step increase from 2005 and a relative stability onward, with an average around 10% over the study period (Fig. 16 top right). However, since CCA were highly monitored only from 2006, the pattern we observe needs to be considered with caution. The percent cover of soft corals recorded in the benthic monitoring programs did not show any trend (Fig. 16 bottom). Even though some species of soft coral can be sensitive to changing conditions, some others can take advantage of hard coral death and become rapidly invasive (e.g. a site in Palmyra, USA), similar to macroalgae. Here, no regional soft coral dominance was observed, and the average of soft coral over the study period was very low (2.2 % SD±0.9%).

Abiotic substrate cover was variable from year to year (results not shown). Caution should be taken while interpreting this result since substrate includes a range of categories such as sand, rubble, rock, pavement, and silt, which are not always assigned in the same way across monitoring programs. This effect may persist despite the corrections we applied to each dataset, as for turf, to appropriately reassign abiotic substrate categories. Even though no trend was detected, abiotic substrate should be considered more accurately in monitoring programs as it can be a good indicator of reef responses to disturbances (e.g. dead corals after COT outbreaks, rubble after cyclone, sand after sediment deposition processes, etc.).

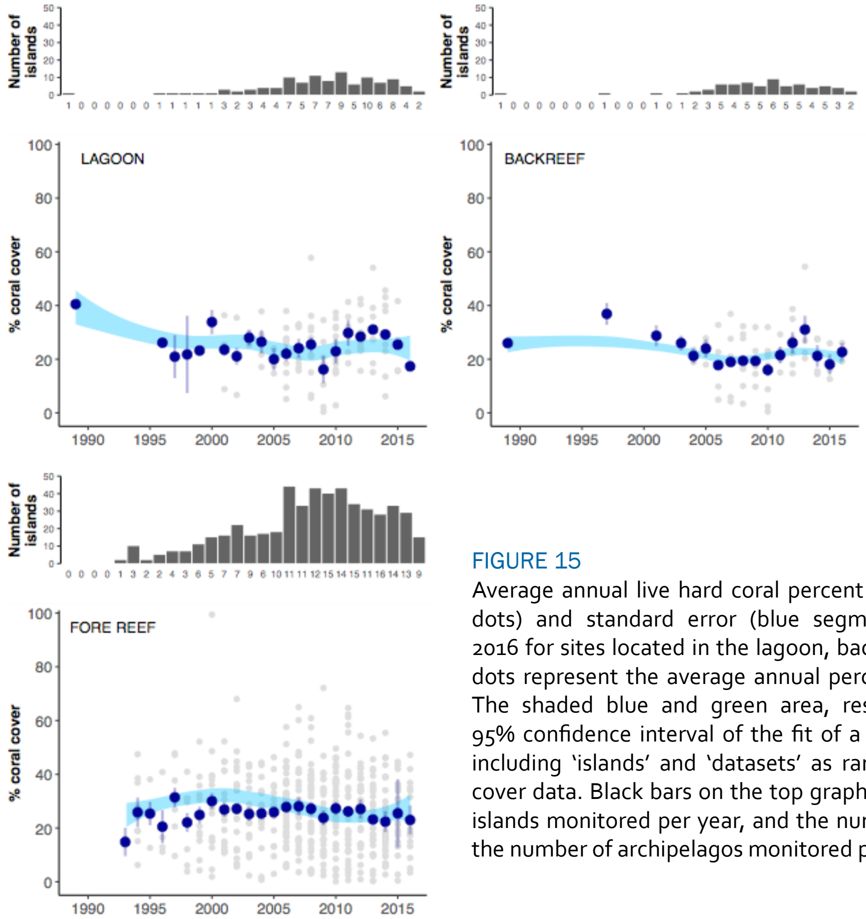


FIGURE 15

Average annual live hard coral percent cover across islands (blue dots) and standard error (blue segments) between 1989 and 2016 for sites located in the lagoon, back reef, and fore reef. Grey dots represent the average annual percent cover for each island. The shaded blue and green area, respectively, represents the 95% confidence interval of the fit of a linear mixed-effect model including 'islands' and 'datasets' as random factors to the coral cover data. Black bars on the top graphs represent the number of islands monitored per year, and the number under each bar gives the number of archipelagos monitored per year.

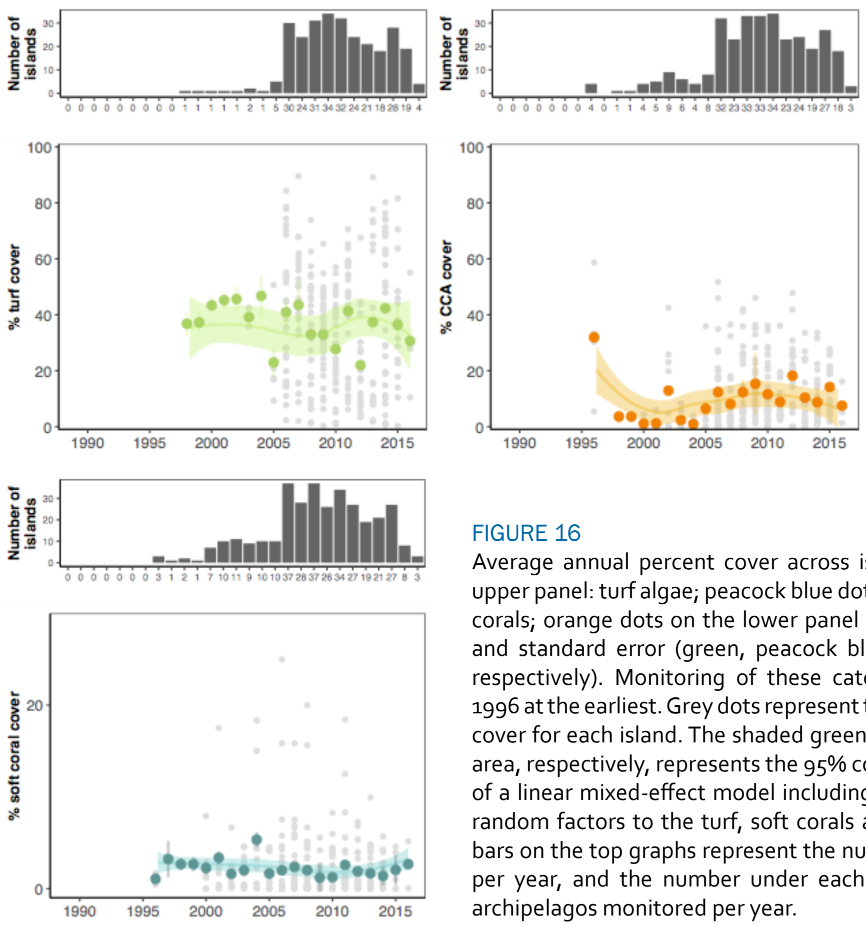


FIGURE 16

Average annual percent cover across islands (green dots on the upper panel: turf algae; peacock blue dots on the middle panel: soft corals; orange dots on the lower panel calcareous coralline algae) and standard error (green, peacock blue and orange segments, respectively). Monitoring of these categories only started from 1996 at the earliest. Grey dots represent the average annual percent cover for each island. The shaded green, peacock blue and orange area, respectively, represents the 95% confidence interval of the fit of a linear mixed-effect model including 'islands' and 'datasets' as random factors to the turf, soft corals and CCA cover data. Black bars on the top graphs represent the number of islands monitored per year, and the number under each bar gives the number of archipelagos monitored per year.

ii. Geographic variation in reef trends

There is a great variation in coral cover trends across the Pacific. This variation is illustrated in Fig. 1 (see Part I Introduction), and more examples of coral cover trends are provided in Appendix II and in the Country Reports. These variations are mainly the local environmental conditions, island geomorphology, and biogeographic patterns that drive coral reef structures. These factors taken apart, these variations can be explained by the occurrence and type of acute disturbances hitting specific locations in this vast Pacific Island region (Hughes et al. 2018, and see Timeline in the Country Reports). Furthermore, these disturbances may vary in intensity among locations (e.g. bleaching event intensity depends on the location of the warm water pool, cyclones vary in intensity along their trajectory, etc.). For instance, the 2014-2017 bleaching event weakly impacted Moorea (Society Islands, French Polynesia, Fig. 1), where most corals bleached only partially without subsequent mortality, while the same event strongly impacted some of the northern islands of the Tuamotu Archipelago (French Polynesia) (CRIOBE, personal communication). This same bleaching event also strongly impacted other regions such as Hawaii (Rodgers et al. 2017) and Samoa (Tara-Pacific, personal communication). Similarly, previous global bleaching events did not equally impact all regions of the Pacific (see Country Reports), as evidenced in Fig. 1 where the 1998 global bleaching event had no effect on Moorea's coral reefs.

Cyclones are acute disturbances that destroy the three-dimensional structure of the reefs by breaking coral heads. However, they are geographically localised, even if their occurrence, trajectory, and intensity are unpredictable. For instance, some islands in the Pacific have strongly suffered from cyclone impacts, such as Fiji in 2016 with cyclone Winston (the most intense tropical cyclone in the Southern Hemisphere on record, Mangubhai et al. 2016), and Palau, which was hit by Bopha and Haiyan over two consecutive years (Gouezo et al. 2015). Many islands in the South Pacific were hit by numerous cyclones during the 1982-1983 wet season alone. Conversely, French Polynesia has not been hit by any cyclones for several consecutive years (since 2010) (Fig. 17), while several strong cyclones formed on the western part of the Pacific (e.g. Winston in 2016). The patchiness activity of cyclones in the Pacific Island region can substantially contribute to the geographic variation in reef trends.

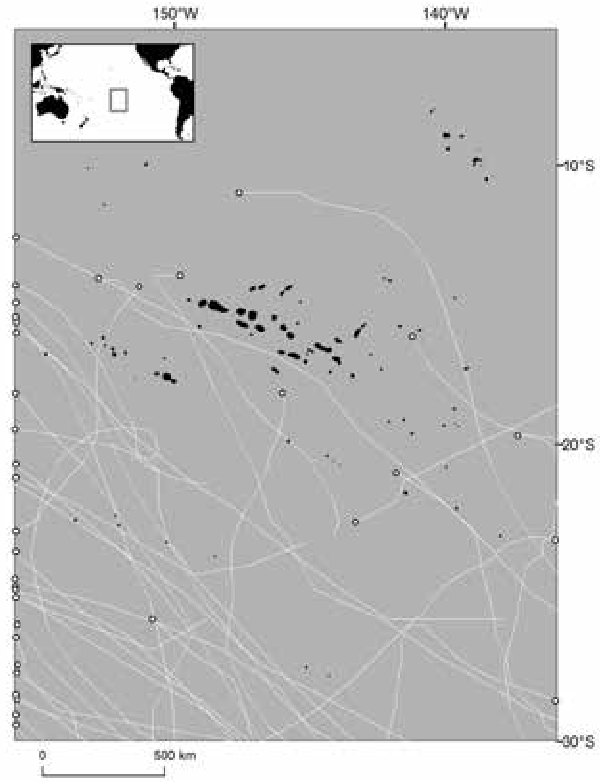


FIGURE 17
Examples of trajectories of cyclones throughout French Polynesia since 1905. Unpublished data from IBTRACS, Knapp et al. 2010.

These geographic variations in coral reef trends suggest that coral reefs of the Pacific Island region could be considered as a mosaic composed of patches of reefs with different trajectories, combining declining patterns due to disturbances and recovery patterns in the absence of disturbances. Considering this, the stable pattern observed at the scale of the Pacific (Fig. 12) is likely to cumulate different reef dynamics. This stability pattern diverges from the declining pattern observed in the Caribbean (Jackson et al. 2014) or on the Great Barrier Reef (De'ath et al. 2012).

iii. Long-term changes in coral community composition

The multivariate analyses performed on the coral community matrix of each survey and comprising of the 15 most common genera across the Pacific (i.e. *Porites, Montipora, Pocillopora, Acropora, Pavona, Leptastrea, Astreopora, Dipsastraea, Goniastrea, Synaraea, Millepora, Diploastrea, Montastraea, Psammocora, and Turbinarea spp.*) indicate how the composition of the coral community has changed throughout the past decades.

The NMDS plot shows that coral community composition has changed over the past decades in the Pacific Island region (Fig. 18). We can identify 3 groups of years with each group pooling consecutive years as follows:

- a cluster including years 1998 to 2003,
- a cluster including years 2004 to 2008, and year 2016,
- a cluster including years 2009 to 2015.

Three major changes in coral community structure therefore occurred: between 2003 and 2004 (change along the second NMDS axis), between 2008 and 2009 (change along the first NMDS axis), and between 2015 and 2016 (change along the first NMDS axis). Such changes are difficult to interpret, as they do not correspond to major regional events at the scale of the Pacific. They could for instance reflect the effect of bleaching or other disturbances on the monitored sites at specific years, or be a bias due to the lower number of sites monitored in some years (e.g. 2016 compared to 2015).

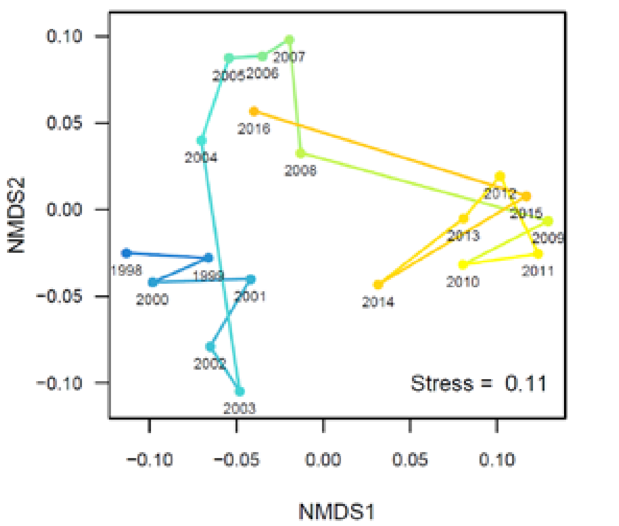


FIGURE 18
Non-metric multidimensional scaling (NMDS) plot computed on the coral community matrix of each survey and based on the 15 most common coral genera.

The principal component analysis (PCA) graph shows that the coral community (analysed at the survey level) was initially characterised by coral genera including Synaraea, Acropora, Leptastrea, Astreopora, and Montipora, whereas the current community is characterised by Porites and Goniastrea (Fig. 19).

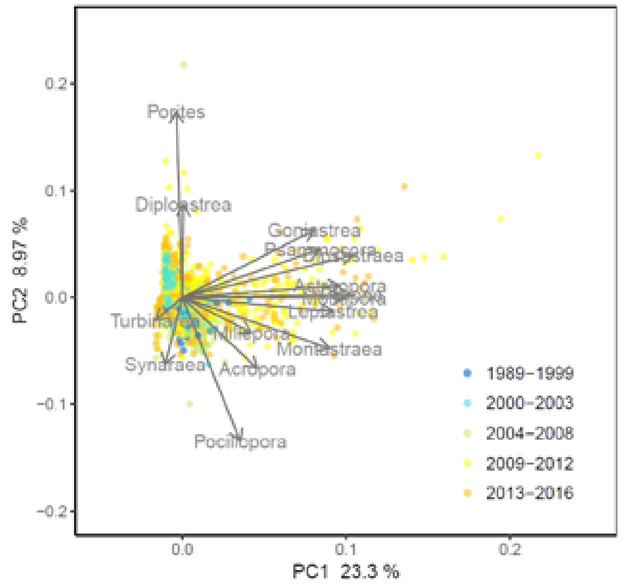


FIGURE 19
Principal component analysis of the coral community at the survey level. Colours highlight the position of the dots for different time intervals. The 15 main coral genera are represented by arrows.

These trends are confirmed by the trends observed for Pocillopora and Porites: whereas Pocillopora declined at the Pacific scale, the Porites increased (Fig. 20). The decrease in Pocillopora, however, is not consistent throughout the Pacific (for instance, it has been the major coral genera in Moorea since 2010, after the cyclone and the Acanthaster planci outbreak, but makes up only ~ 2-3 % of total coral cover in Palau). Pocillopora is known to be a weedy coral, meaning that it can reproduce and grow fast, and is considered a pioneer species in some reefs in which it recruits very quickly by colonising bare substrate (e.g. Hawaii, Moorea). However, widespread mortality of

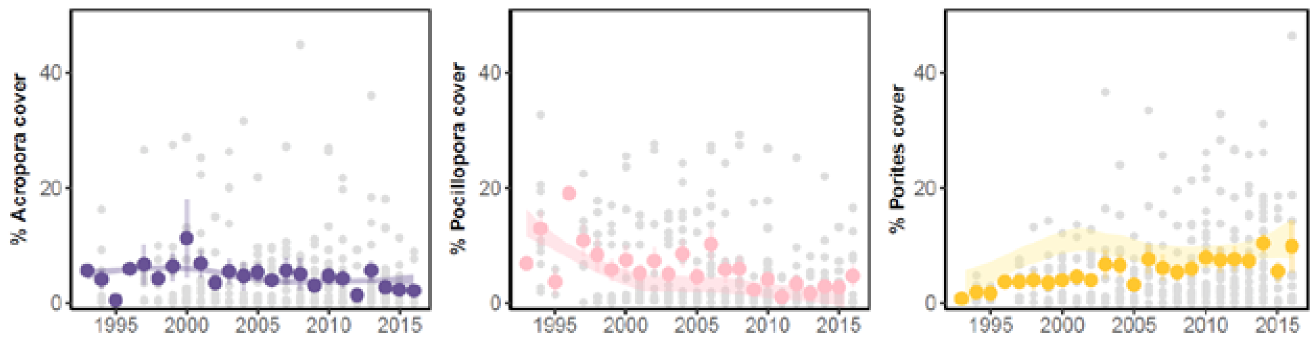


FIGURE 20
Average annual Acropora, Pocillopora, and Porites spp. percent cover across islands (purple, pink, and yellow dots, respectively) and standard error (purple, pink, and yellow segments, respectively) since 1993. Grey dots represent the average annual percent cover for each island. The shaded purple, pink, and yellow areas represent the 95% confidence interval of the fit of a linear mixed-effect model including 'islands' and 'datasets' as random factors to Acropora, Pocillopora, and Porites spp. cover data, respectively.

Pocillopora was recently observed in the Line Islands, because they are usually very sensitive to thermal stress, such as was observed during the third global mass coral bleaching event that occurred across the Pacific between 2014 and 2017 and impacted many islands in the Pacific. This sensitivity to bleaching may however depend on the species considered within genera. Acropora is another weedy coral that grows fast, and is characterised by broadcast spawning. The relative stability of Acropora cover in our region is different from the striking decrease observed in other regions, such as the Great Barrier Reef in Australia (Clark et al. 2017). Finally, stress-tolerant corals are usually slow-growing species that typically have primarily massive morphologies, large corallites and high fecundity. This is the case for Porites, which appears to be a winner coral species at the Pacific scale, surviving all disturbances and growing at the expense of other genera. The 20-year survey shows that Porites was a minor genera in terms of cover in the 1990's, but it represents nearly 50% of the average live coral cover of 25.6% after 2010.

The change in coral community structure and the change in percent cover of the main coral genera contrasts with the lack of change in average coral cover that we observe at the Pacific scale. The coral community tends to shift toward massive genera while branching genera are decreasing. This can lead to a change in the reefscape, and, more importantly, a change in the function of the reef ecosystem, with potential impacts on the other invertebrate and fish compartments.

2.b. Patterns of change for fish

i. Long-term changes in total fish biomass

Total fish community biomass was investigated using only datasets that record all diurnal, non-cryptic fish species. Therefore, fish monitoring datasets from Palau, Fiji, the Republic of the Marshall Islands, the Federated States of Micronesia, part of American Samoa, and part of New Caledonia were not included in this analysis since they only target some fish groups. As such, only a few datasets covered the period before 2004 (Fig 21). We also observed extremely high total fish biomass in one particular dataset for Kiribati. This dataset, which included surveys from 2005, 2009, and 2015, led to an overestimation of the average biomass calculated over all datasets for these specific years. This dataset was therefore not included in the meta-analysis.

For all the remaining datasets, representative of a large part of the Pacific, no significant pattern was detected in total fish biomass (Fig. 21). The average biomass tends to vary from year to year, with high values between 2005 and 2008, and lower, but more consistent, values from 2009. It should be noted that the increase in the number of surveys decreases the variance around the yearly averages over the last decade.

ii. Long-term changes in fish biomass for major groups

Several significant trends in fish biomass emerged when trophic groups were considered separately. The following four trophic groups were considered: 1) corallivores are the fish that consume coral polyps as their main diet (e.g. mostly the Chaetodons); 2) herbivores are considered as the fish that consume macroalgae, turf, and detritus which are often mixed with primary resources (e.g. parrotfish, rabbitfish, and surgeonfish); 3) planktivores are the fish that pick out tiny zooplankton from the water column (e.g. some damselfish, soldierfish) or eat larger jellies; and 4) carnivores are the fish that consume other fish (i.e. piscivores such as most groupers), benthic invertebrates (i.e. invertivores such as some wrasses), or dead carcasses (e.g. some snappers). To perform

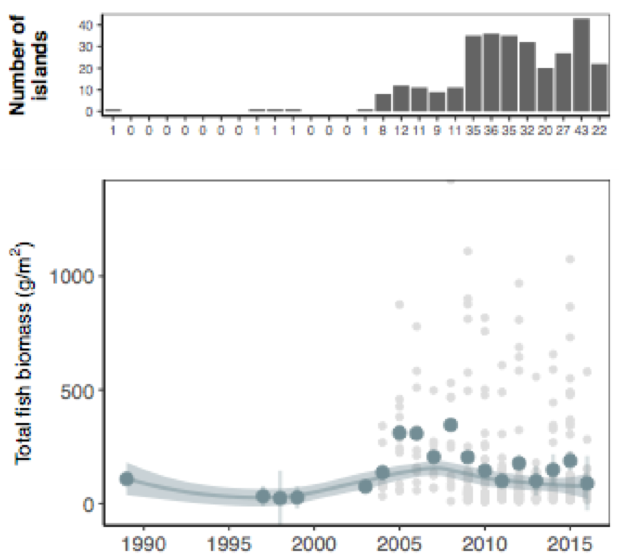


FIGURE 21
Average total fish biomass across islands (slate blue dots) and standard error (slate blue segments) between 1989 to 2016. Grey dots represent the average annual biomass for each island. The shaded slate blue area represents the 95% confidence interval of the fit of a linear mixed-effect model including 'islands' and 'datasets' as random factors to total fish biomass data. Black bars on the top graph represent the number of islands monitored per year, and the number under each bar gives the number of archipelagos monitored per year.

an analysis on these groups, all datasets were included. Indeed, even the datasets that did not record the entire fish community recorded species from these specific trophic groups and were therefore collated.

Large fish such as sharks, rays and tuna were removed from the analysis to avoid having extremely high biomass values in transects where they were counted.

Our analysis of the herbivore fish community revealed a marginally significant decrease in biomass over time from, beginning in 2004, when a substantial number of islands started to be sampled (linear model on annual averages: $p=0.054$, $R^2=0.30$; Fig. 22). The decrease in herbivorous fish biomass was mainly driven by the decline in surgeonfish biomass (Fig. 22).

Herbivores, planktivores, and corallivores significantly decreased over the last decades, whereas carnivores significantly increased (Fig. 22). The decline in corallivorous fish, for which the presence of live coral is essential, may be explained by the progressive decrease in branching corals, as these are the main habitat and food source for corallivore fish (Fig. 20). Among planktivores, planktivorous damselfish, highly dependent on live coral for their habitat, may also decline as a result of live coral decline, affecting more specifically branching corals such as *Pocillopora spp.* (Fig. 18). Other planktivores such as some species of Acanthuridae, Caesionidae, Holocentridae, and Balistidae may have declined as a result of overfishing, since many of these species are highly targeted as food sources. However, no Pacific-wide fishery information was collated in this report (e.g. fishing effort) to properly assess the effect of fishing on the fish community.

Analyses of Scarinae and Acanthuridae temporal trends were performed on all datasets which recorded these families. Among the herbivores, Acanthuridae biomass showed a strong significant decline (Fig. 22). Contrary to what was observed in the Caribbean (Jackson et al. 2014), biomass of parrotfish (Scaridae) did not show any decline but remained stable over the study period at the Pacific scale. In addition, a test on parrotfish >10 cm, mostly targeted by fishermen, did not reveal a decline over time. Some species of Acanthuridae are known to eat macroalgae. A decline in Acanthuridae could explain the observed increase in macroalgae (Fig. 12), and further decline of these fish species may favour future macroalgae increase and shift to a macroalgae-dominated state of coral reefs in the Pacific. Further analyses on these species are however required to quantify their role in changing reefscapes.

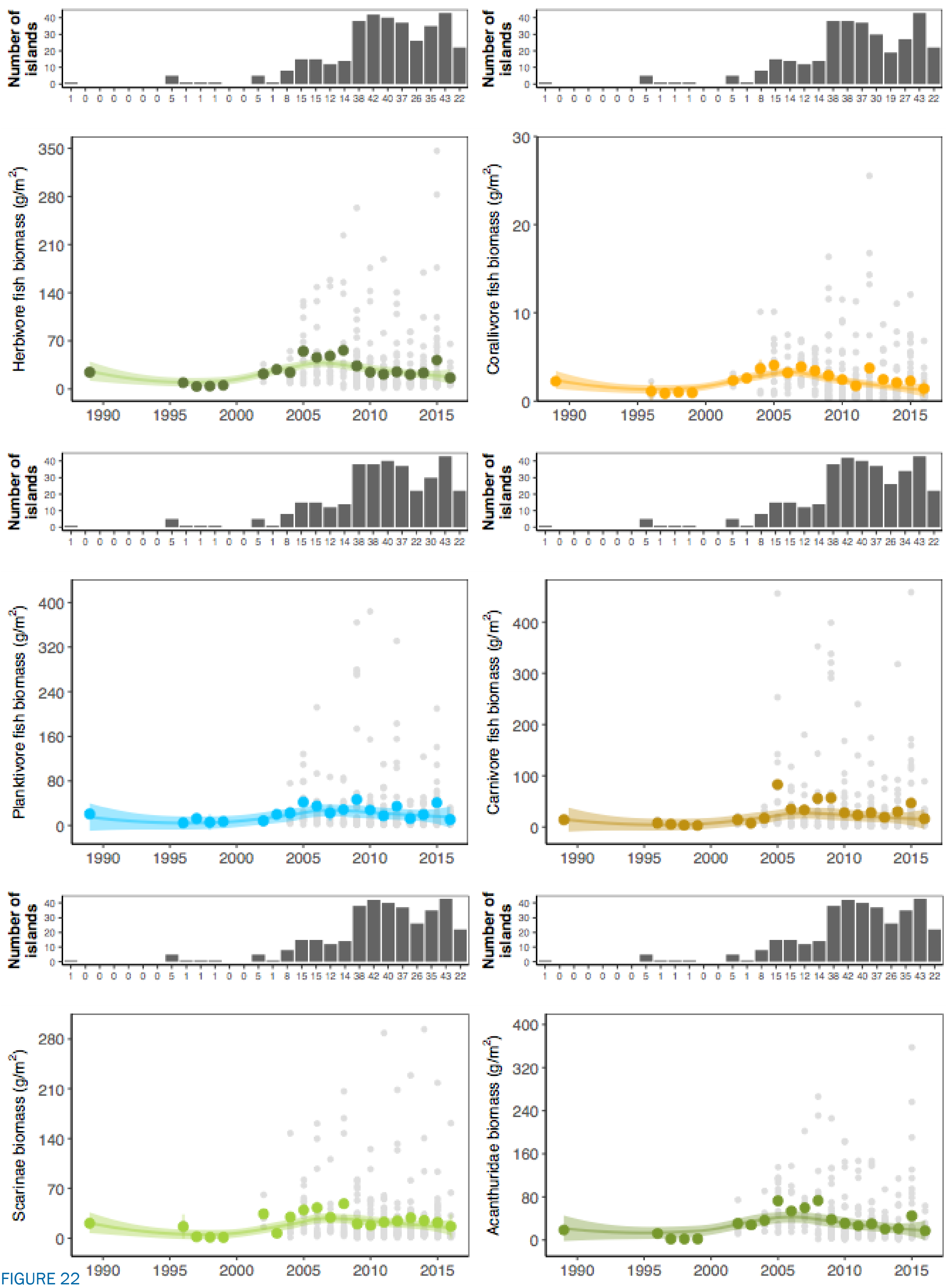


FIGURE 22

Average fish biomass across islands (coloured dots) and standard error (colored segments) from 1989 to 2016 for four trophic groups (herbivore, corallivore, planktivore, carnivore) and two families (Scarinae, Acanthuridae). Grey dots represent the average annual biomass for each island. The shaded colored areas represent the 95% confidence interval of the fit of a linear mixed-effect model including 'islands' and 'datasets' as random factors to the fish biomass data for the four trophic groups and two families separately. Black bars on the top graphs represent the number of islands monitored per year, and the number under each bar gives the number of archipelagos monitored per year.

3. ANTHROPOGENIC DRIVERS OF CORAL REEF STATUS AND TRENDS

Human actions result in environmental stressors that affect natural ecosystems (Crain et al. 2008, Hoegh-Guldberg and Bruno 2010, Crichton and Esteban 2018). They include population growth and are coupled with increases in resource consumption, pollution, and habitat degradation (Duran et al. 2018). In general, the effects of humans on the environment are proportional to population times consumption times technology (Commoner et al. 1971). The level of stress induced by these actions depends on the level of consumption, cultural traditions, and the way people exploit and pollute the environment. There are great disparities in human presence and influence among islands throughout the Pacific, and among localities within islands (Table 1).

It is often difficult to distinguish between the potential drivers of coral decline directly related to human presence (overpopulation, overfishing, coastal pollution, invasive species, etc.) and their effects on the reef (increase in macroalgae, coral bleaching, disease, etc.). Change in coral reef ecosystems can also be caused by acute disturbances such as cyclones, heat stress that leads to coral bleaching, and coral predator invasions (Obura and Mangubhai 2011, De'ath et al. 2012, Gouezo et al. 2015, Lamy et al. 2016). Today, the natural origins of these disturbances can be questioned, as they are all influenced to some extent by human activities on Earth. Heat stress that results in bleaching can be partly natural (El Niño phenomenon) and partly human-produced (global warming), since anthropogenic activities worldwide influence increases in seawater temperatures. Similarly, it has been hypothesised that cyclone intensity and frequency have increased due to climate change (Webster et al. 2005) and COTS (crown of thorn starfish) outbreaks can be intensified by local anthropogenic pollution (Birkeland 1982, Fabricius et al. 2010).

In the Pacific, these human activities impact the trophic structure of coral reef fish, which can influence ecosystem health and functioning, with differing effects among the regions (Mangubhai et al. 2014, Ruppert et al. 2018). The increase in coral diseases, although natural in coral reef ecosystems, may have resulted from the combination of several anthropogenic stressors (eutrophication, introduction of exotic pathogens, runoff containing pollutants, etc.). Currently, documentation of widespread increase in diseases for the Pacific Island region is limited. Additionally, it is hard to separate increased awareness and vigilance from actual increases.

Different environmental and anthropogenic drivers reviewed in this section provide cues on the major factors responsible for coral reef changes in the Pacific Island region. Although our analyses considered them separately here, chronic drivers may act together (e.g. population increase, pollution, fishing increase), and can add to acute disturbances. Gathering consistent data for all these drivers in an area as wide as the Pacific was a challenge and could not be performed for all variables. When data were missing, the literature was used to support our hypotheses.

3.a. Human presence

The Pacific Island Region is characterised by the high remoteness of its archipelagos and islands. Many islands are still uninhabited, or inhabited on a temporary basis (e.g. Palmyra and Johnston in the PRIA, USA). In most cases, population centres are located on the main island of a country or territory, with different levels of urbanisation (e.g. Honolulu in Hawaii with 953,207 inhabitants versus Molokai with 7,345 inhabitants in 2018). Outside of urban centres, the population is located along the coasts, mainly in the (narrow) coastal plains on volcanic islands or on atoll cays, to benefit from the access to the lagoon or the open ocean either for fishing or for recreational activities.

We collated data from Wikipedia (https://www.wikipedia.org), UN Environment

Islands (http://islands.unep.ch), and governmental websites on the last census of the number of residents per island where coral reef data was available (Table 1). Because of the lack of information at small scale, we could not assess the exact number of residents at each location where substrate or fish were sampled. For our analysis, we instead used the number of residents for the entire island, as this information was readily available from the aforementioned sources. We also collated the land area of each island in order to calculate the population density per island. Island-scale population density can be biased for islands with large urban centres (e.g. Nandi in Fiji, Papeete in Tahiti, etc.) located at one specific location and not a reflection of the average population density on the rest of the island. However, except for some extreme cases, and because some islands are relatively small and population is evenly distributed, estimating population density remains informative with respect to the level of human pressure on reef resources. Additionally, because the sole presence versus absence of humans can be a good indicator of coral reef status (Smith et al. 2016, Moritz et al. 2017), we also characterised each island by its human occupation, i.e. «inhabited» or «uninhabited».

Island size varied from 0.012 (Kingman Reef, PRIA) to 35,145 km² (New Britain, Papua New Guinea), with a mean of 833 km² and a median of 14 km2. Among the islands for which we have coral reef data, 46 were uninhabited, and 83 were inhabited. Population density in inhabited islands varied from 0.7 inhabitant/km² in Niihau (Hawaiian Islands) to 2,863 inhabitants/km² in Majuro (Republic of the Marshall Islands).

We plotted the percent coral cover and the herbivore fish biomass against the population density for all islands, and found no significant linear relationship (Fig. 23). This result is in agreement with a recent study showing that coral reef degradation in terms of coral and macroalgae cover was not correlated with human population density (Bruno and Valdivia 2016). However, other studies have documented clear relationships between reef isolation and fish abundance or trophic structure (Stallings 2009, Williams et al. 2011) even if this is still questioned (Cinner et al, 2013, Friedklander et al, 2018, Robinson et al, 2107, Sandin et al, 2008, Stamoulis et al. 2018, Williams et al, 2015).

To further understand whether human presence influences coral reef status and trends, we calculated the temporal trends in percent coral cover and herbivore fish biomass for inhabited and uninhabited islands separately (Fig. 24). Given that fish data were scarce, and even absent for uninhabited islands before 2004, we plotted the results from 2004 to 2016. Because most coral data were from inhabited islands, the coral cover trend mirrored the general trend observed on Fig. 14, with annual averages close to the trend mean of 25.6%. Coral cover in uninhabited islands was much more variable from year to year. This does not reflect the fact that coral cover changes abruptly every year, but rather reflects the absence of continuity in monitoring effort for some of the uninhabited islands difficult to access on a regular basis.

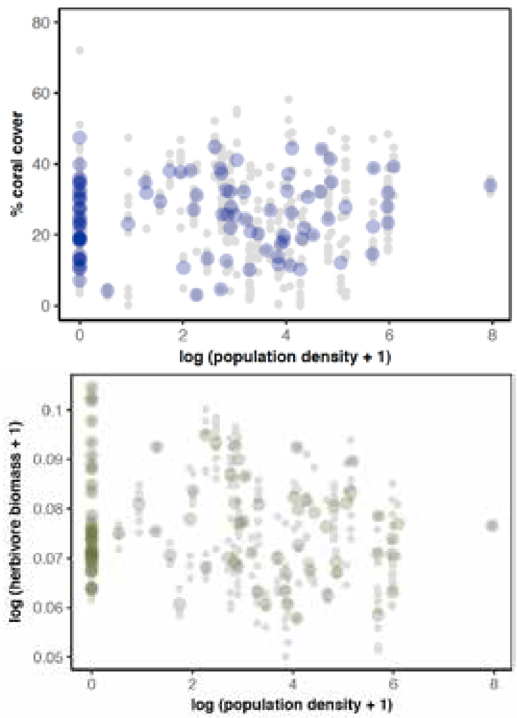


FIGURE 23

Percent coral cover and herbivore fish biomass (g/m2) according to human population density of each island (given as log(number of inhabitants per km2 +1) (see Table 1 for the island population data). Grey dots represent annual data for each island, and blue and green shaded dots represent, respectively, percent coral cover (top) and herbivore fish biomass (bottom) (expressed in log+1 for clarity) averaged across years for each island.

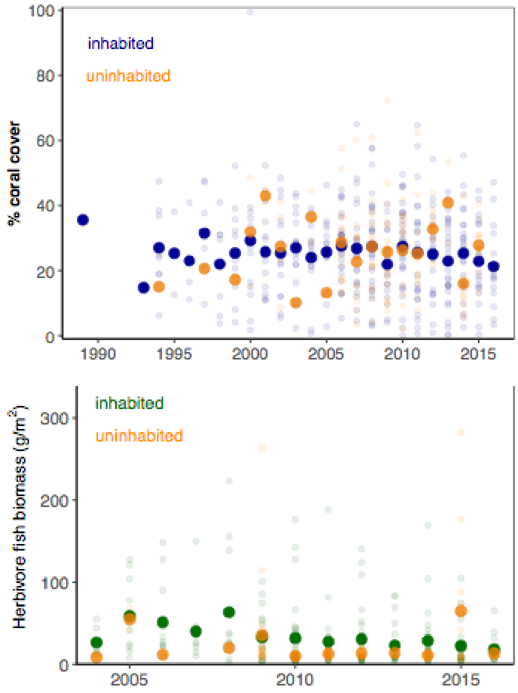


FIGURE 24

Top: average annual live hard coral percent cover across inhabited (blue) and uninhabited (orange) islands between 1989 and 2016. Shaded dots represent the average annual percent cover for each island. Bottom: average annual fish biomass across inhabited (green) and uninhabited (orange) islands between 2004 and 2016. Shaded dots represent the average annual fish biomass for each island.

Average herbivore fish biomass over the study period was not significantly different between inhabited and uninhabited islands (inhabited: 34.0 SE±4.0 g.m-2, uninhabited: 23.1 SE±6.5 g.m-2; t-test: $p=0.33$). However, the herbivore fish biomass of inhabited islands significantly declined between 2004 and 2016 (linear model on annual averages: $p=0.013$, $R^2=0.44$), whereas no significant trend was observed for uninhabited islands ($p>0.05$). The declining trend in herbivorous fish biomass observed only in the inhabited islands suggests that these species are subject to significant fishing pressure, mainly by local populations. Indeed, in the Pacific, the herbivorous fish species are a fisheries target. Strong variations in the average from year to year were however observed, as for coral, between 2004 and 2009, but were less marked from 2010 to 2016.

Some of the largest monitoring programs (e.g. NOAA CRAMP and Polynesia Mana) sample uninhabited islands infrequently (about every 2 to 4 years), which prevented a proper assessment of the average temporal trends from year to year. This clearly suggests that monitoring efforts should be increased in these islands, despite their remoteness and the financial and technical capacity that the monitoring process requires. The monitoring of remote uninhabited islands is critically important as information gleaned from these relatively pristine ecosystems can serve as a baseline from which to compare healthy (untouched from local stressors) versus degraded reefs. Given these logistical and financial issues, we advocate that partnerships should be built between the Pacific countries and territories to raise funds dedicated to more efficient long-term monitoring.

3.b. Tourism in the Pacific Island region

The number of tourists was collected from different sources (Table 1). However, it was only possible to get the number of tourists for each island or territory. It was especially problematic for territories since the number of tourists in the Pacific territories does not reflect the number of tourists recorded in the home country (e.g. USA). The number of tourists varies greatly among countries, but also among islands within countries, and accounts for different percentages of imports of goods and services in the countries and territories (World Bank 2017). For instance, in Palau, tourism is the second most important source of revenue after tuna fisheries; in French Polynesia, it is the first economic sector. In general, tourism is a very important source of income in most of the Pacific countries with airports and hotel infrastructures.

Tourism in the Pacific Island region is mainly focused on activities such as discovery of pristine areas, learning of cultural heritage, and leisure in guesthouses and luxury resorts. A large number of cruise boats sail the Pacific (Fig 25). In some countries, tourism has been blooming recently with upsurge in Chinese visitors who are attracted by the aesthetic and cultural assets of the islands (World Bank 2017). Recent reports emphasise the expected increase of tourism in the Pacific islands.

FIGURE 25
Typical cruise boat crossing the Pacific and carrying up to 5000 tourists (© Douglas Fenner).

It is suggested that by 2040 tourism will provide a crucial economic backbone for many of the countries in the Pacific Island area, because the development of tourism will create opportunities for jobs and increased incomes (World Bank 2017). Predictive analyses revealed more specifically that for Vanuatu, Samoa, and Palau tourism would be the main driver of economic growth, while fisheries and labour mobility could support higher growth for Tuvalu, Kiribati, and the Federated States of Micronesia; Fiji, Samoa and Tonga growth could be boosted by multiple opportunities including tourism, labour mobility, and opportunities related to information and communication technologies (World Bank 2017).

However, to preemptively address the threats that typically go hand-in-hand with an increase in tourism activities (e.g. increases in coastal development and pollution, etc.), some countries, such as Palau, are thinking about implementing studies to determine the «sustainable» number of tourists per year based on ecosystem carrying capacity. To make the vast Pacific Island region more attractive, tourism development will require improved air and sea connectivity, well-targeted infrastructure enhancements, development of new tourism sites, and better water and sanitation, all of which are currently limited even on developed islands (World Bank 2017). To achieve this, it is important that efforts to develop tourism are clearly prioritised through a dialogue between governments, tourism sector stakeholders, and potential investors. In this context, regional cooperation is essential despite the remoteness of some archipelagos. If sustainably developed, tourism presents a great opportunity to preserve both the environment and the cultural heritage of the Pacific Islands.

3.c. Fishing in the Pacific Island region

The nutrition, welfare, culture, employment, and recreation of islanders are essentially based on the living resources located between the shoreline and the outer reefs. Therefore, appropriately managing reef resources is fundamental to sustain food security, current lifestyles, and opportunities for future development (Johnson et al. 2017). Artisanal coastal fishing in particular is of fundamental importance in the Pacific Island region as it provides the most important source of protein to islanders. Tuna fishing is also an important activity but is located offshore and is therefore not considered in this report. Finally, an increase in demand from Asian markets for items such as the beche de mer, shark-fins, etc., is placing increased pressure on the fisheries of the Pacific and may threaten these resources.

The increase in population and diversification of fishing practices has led to the depletion of fish stocks for many inhabited islands (Stallings 2009, Williams et al. 2011). Despite the variety of fishing practices and target fish preferences among the Pacific Island region, selective fishing has led to the depletion of specific fish stocks (e.g. surgeonfish, Fig. 20, and sharks, Rotjan et al. 2014) and to the reduction in individual fish size (DeMartini et al. 2008) and size spectra of the fish community (Dulvy et al. 2004, Robinson et al. 2016, Zgliczynski and Sandin 2017). It is now evident that overfishing is sometimes correlated with the decline or collapse of reef ecosystems (McClanahan et al. 2008, Jackson et al. 2014, Rogers et al. 2018). This collapse is characterised by a decrease in coral cover and recruitment, and the increase in macroalgae cover and the prevalence of coral diseases (Jackson et al. 2014). The decrease in coral cover may in turn affect fish species related to corals for food or habitat, and may potentially induce a variety of trophic cascades, which may alter the ecosystem functioning (Rogers at al. 2018).

In the Pacific Island region, the ecological consequence of fishing appears to be a decrease in the number of herbivorous fish species, especially from the Acanthuridae family and around uninhabited islands, as documented on Fig. 22 and Fig 26. Parrotfish do not seem to be declining at the Pacific scale, contrary to what was observed on Caribbean reefs (Jackson et al. 2014). These fish species may contribute to the resilience of coral reefs (Martin et al. 2017), which might explain why no shift to a macroalgae-dominated state was observed in our meta-analysis. However, the continuous weak decline in coral cover along with the increase in macroalgae is a warning signal of the threat put on coral reefs in the Pacific Islands region. Experiments and observations have demonstrated that the removal of grazers can result in striking increases in macroalgae (Hughes et al. 2007, Adam et al, 2015, Burkepile and Hay, 2008, 2010, Kelly et al, 2017) that compete with corals for space. Decrease in targeted fish from other trophic groups also has an impact on the overall food web (trophic cascades) and functioning of the reef (Mumby et al. 2006, Dulvy et al. 2004), but to different levels according to the gear used, the species exploited, the initial condition of the reef, and the interactions with the other anthropogenic disturbances (Dulvy et al. 2004). Continuous fishing pressure on herbivores around inhabited islands may contribute to the collapse of coral reef ecosystems in the Pacific if not sustainably managed.

One of the ways to curb the influence of overfishing is to implement protection on a portion of a reef. Indeed, protection from fishing would allow the reefs to recover faster after disturbances than heavily fished reefs (MacNeil et al. 2015). In the Pacific, traditional fishing closure (called 'rahui' for instance by the Polynesians, a system of temporal closure of fishery of some species or groups of reef organisms used in New Zealand, the Cook Islands, or French Polynesia, among other

FIGURE 26
Herbivorous fish species targeted by local fisheries
(© Lauric Thiault)

countries) used to be implemented in many islands but was abandoned during colonialism, influencing local traditions (Bambridge 2016). In some islands, modern management is however inspired by these traditional conservation practices, which have sustained local, sometimes large, human populations during many generations, and are still implemented in some locations (e.g. Tahiti). Indeed, some communities recognise the need to revitalise more traditional management systems of this kind. Another example in Hawaii shows community-based initiatives that are integrated with government-level marine resource management on a common joint conservation effort on coral reef ecosystem state at regional scale (Frieldander et al, 2013).

Besides these traditional management practices, the modern management system of the Marine Protected Areas (MPAs) is extensively implemented in the Pacific and includes a range of designations (e.g. PGEM Moorea in French Polynesia, PRIA in the USA territories, etc.). At the time of writing (2017), there were about 921 marine protected areas in the Pacific, encompassing 8,960 km2 of coral reefs, or about 13% of the total coral reef area of the Pacific. However, only about 20% of these MPAs were considered enforced or effectively managed.

Because of the concern regarding reef health and in an effort to protect and preserve the remaining intact coral reefs, a number of major conservation initiatives have been undertaken in the Pacific region over the past ten years. This includes several large-scale protected areas also listed as World Heritage sites, such as the Papahānaumokuākea Marine National Monument in the North West Hawaiian Islands and the lagoons of New Caledonia. In Kiribati, the Phoenix Islands Protected Area (PIPA) is one of the largest no-take MPAs in the world and is the largest marine conservation effort of its kind by a Least Developed Country as well as the largest and deepest UNESCO World Heritage Site (Rotjan et al. 2014). The Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security includes the Pacific's Solomon Islands and Papua New Guinea. The Micronesia Challenge, launched by the Northern Mariana Islands, Guam, Palau, the Federated States of Micronesia and the Marshall Islands, is a commitment to effectively conserve 30% of coastal waters and 20% of the land area by 2020. As a party to the United Nations Convention on Biological Diversity (CBD), Fiji has committed to making progress against the CBD Strategic Plan Aichi Targets, including Target 11 to achieve protection of 17% of terrestrial and 10% of marine areas by 2020, and has made a further commitment to protect 30% of its seas by 2020.

The efficiency of these MPAs in some locations has been assessed. In Palau, Friedlander et al. (2017) showed that in the Protected Areas Network (PAN), comprising numerous MPAs that vary in age, size, level of management, and habitat, no-take MPAs had on average nearly twice the biomass of resource fish (i.e. commercially and culturally important) compared to nearby unprotected areas, while biomass of non-resource fish showed no differences between no-take areas and areas open to fishing. In Micronesia, results from a statistical study suggested that the MPAs have limited efficacy when grouped together across the region, but that localised benefits exist and are expected to increase over time (Houk et al. 2015).

Efficient MPAs not only aid in conserving high fish biomass, but also provide important conservation and tourism benefits to the Pacific countries and territories, and may also provide fisheries benefits by protecting spawning aggregation sites and by providing adult fish through spillover. Unfortunately, protecting the reefs does not necessarily prevent poaching, especially if controls are not enforced (Thiault 2014, Gill et al. 2017, Moritz et al. 2017). A recent global study showed that MPAs with adequate staff capacity had ecological effects 2.9 times greater than MPAs with inadequate capacity (Gill et al. 2017). A recent report showed that the PIPA, which is almost entirely no-take (Rotjan et al. 2014), is effective in deterring illegal fishing (McCauley et al. 2016). Additionally, bottom-up control of MPAs by local people has proven to be efficient (Ferreira et al. 2015, Chirico et al. 2017), which suggests that merging top-down and bottom-up approaches in MPA planning can be a good compromise to benefit both the ecosystem and the human communities (Gaymer et al. 2014). Both human and financial capacity are therefore essential to get optimal conservation outcomes, which is unfortunately in many cases difficult to reach due to the remoteness and great size of some MPAs in the vast Pacific Island region, and to the limited financial resources of some developing countries to implement proper controls.

3.d. Pollution and coastal development

Dredging

The development of major cities drove the demand for sand as a material for construction. Large and small sand-mining operations were established. Large-scale operations are carried out by contractors using machinery that can remove significant quantities of sand in a short amount of time (Fig 27). Small-scale sand mining also occurs by individuals and small contracting companies for small construction projects, while sediments coming out of the rivers can also be targeted. The sand is usually taken from the beach or from the lagoonal sand patches. In many islands, coral is also targeted and used to build roads and buildings.


FIGURE 27
Dredging activities in a lagoon. (© Bernard Salvat)

Shoreline hardening

Building hard defences such as seawalls, embankments, jetties, or breakwaters often address coastal erosion issues. Despite that these structures are usually perceived as the best solution, they can cause further erosion problems for shorelines adjacent to them if not appropriately designed (Gombos et al. 2014). Coastal engineers are normally required to develop appropriate seawalls and embankments to ensure protection from all hazards and avoid interference with natural processes using analyses of the coastal hydrodynamics, but this is not always the case. Thus, shoreline hardening structures are often not effective over the long term, and many examples demonstrate the profound environmental changes that occurred on natural features after the shoreline constructions modified the natural flow and wave patterns, deepening the area in front of the structure and eroding adjacent areas (Wong 2003, Gombos et al. 2014). Among these changes we observe a loss of biodiversity and organism abundance (Gittman et al. 2016), progressive loss of beaches (Mimura and Nunn 1998, Wong 2003), burying of corals in the lagoon (Maragos 1993, Gombos et al. 2014), mangrove ecosystem modification (Heatherington and Bishop 2012), etc. Additionally, these structures require a high level of funding to build and maintain over time. Therefore, instead of using these short-term, often damaging, shoreline protections at large scale, sets of measures should be determined at the local-scale with the local population, to provide long-term protection while maintaining ecosystem services provided by the coastal area (Gombos et al. 2014).

Harbours and airports.

Harbours and airports are essential for islands as they are the entry points for all goods, and these goods are essential to sustain local communities. Their development has nevertheless caused deep changes on the area where they are implemented. These changes include altered landscapes, major coral reef embankments, construction of jetties, increase in water temperature due to restricted water circulation, increase in diseases and in ciguatera prevalence, increase in turbidity, etc. Harbours and airports are most of the time associated with high population density as they are usually located in or around cities. Given their indispensable presence on each island, the only way to avoid or minimise their adverse effects on the coral reef ecosystem is to adopt sound planning, impact assessments, and monitoring and management practices. Improvements in the design, siting, and construction at early stage of coastal projects should also be made (PIANC 2010).

Runoff : Pollution and sediment

Shallow near-shore and lagoonal coral reef habitats are the first areas to be impacted by land-based sources of pollutants and disturbances. These disturbances result mainly from terrestrial runoff carrying pollution and sediment due to construction projects, agriculture, and grey water release (Fig. 28). Short-term, localised stressors (e.g. on the fringing reef) can result in latent changes in other parts of the reef (e.g. on the back reef), such as changes in coastal species abundance and diversity, changes in coastal water quality (increase in nutrients, chemicals, and turbidity and a decrease in oxygen), changes in natural community structure, and changes associated with exotic species invasion (Sullivan-Sealey et al. 2017). An increase in nutrients favours algal growth (which are in direct competition with corals) and phytoplankton blooms, turbidity decreases light availability for corals, sediments smother coral polyps, and chemicals (e.g. pesticides) and bacteria can weaken corals, alter their reproduction, and promote an increase in disease prevalence (Anthony and


FIGURE 28
Terrestrial runoff in a lagoon of a high island. French Polynesia (© CRIOBE).

Connolly 2004, Fabricius 2005, Pollock et al. 2014). Detection of pathogens, disease ecology, advances in microbial ecology (genetic probes), and bleaching and pollutant studies (e.g. on pesticides, fungicides, pharmaceuticals) have progressively helped identify chronic stressors. Unfortunately, these studies are not systematically implemented at all locations where pollution is present, and disentangling their effects from natural or broad-scale anthropogenic effects remains a challenge. Therefore, studies of long-term environmental change coupled with analysis of long-term biological data are essential to understand the nature of change and chronic local degradation of complex coral reef systems. Additionally, these studies should be implemented across the shoreline to better grasp the gradient of pollution impacts from the coast to the open ocean.

Waste and marine debris

Waste materials of all sorts threaten coral reef ecosystems. Debris found on coral reefs can come both from the open ocean or the portion of land nearby. A large part of marine debris found is derelict fishing gear (trawl netting, buoys, fishing traps, etc.), but items such as tires, containers, household appliances, and everyday objects can be found in the marine environment and degrade the coral reef habitat and/or the organisms using this habitat. Examples are numerous: ghost fishing occurs when lost gear traps and kills marine animals; waste material from land exploitation can impact the reef over several kilometres (Haywood et al. 2016); and plastic waste increases disease prevalence for corals (Lamb et al. 2018).

While increasing efforts have been implemented to remove marine debris (Donohue et al. 2001), a better solution is to reduce the overall amount of waste in the ocean by implementing measures such as proper waste disposal, and through the reuse and recycling of objects (Lamb et al. 2018).

3.e. Ocean warming

Pacific Island nations are among the world's most physically and economically vulnerable to global climate change and extreme weather events such as floods, earthquakes and tropical cyclones. Among the most documented effects of global change, ocean warming often comes first. It causes a rise in sea level of around 3 mm per year, due to the melting of glaciers and ice sheets, an increase in water temperatures causing more frequent coral bleaching events, and an increase in the frequency and intensity of cyclones.

Sea level rise

Sea level rise threatens low islands in the Pacific, although not homogeneous at the Pacific scale (Mimura 1999). The common threats to these islands include inundation, coastal flooding, and exacerbated beach erosion, saltwater intrusion into rivers, changes in sediment deposition patterns, and impacts on the infrastructures and on coastal communities. In the Solomon Islands, five remote reef islands have already disappeared due to sea-level rise (around 7-10 mm per year since 1993 in this archipelago) and coastal erosion. Low-lying nations in the Central Pacific such as Kiribati, Tuvalu, and the Marshall Islands, comprising mainly coral atolls that lie only a few metres above sea level, are particularly vulnerable to sea level rise (Ford 2012, Obura et al. 2016). The implications of the threat of sea level rise and their severity for ecosystems and human society differ with respect to geographic and social conditions, and the response to sea level rise and climate change in the Pacific area focuses on adaptation rather than mitigation (i.e. reduction of greenhouse gas emissions, Mimura 1999). For instance, the Kiribati government has promoted, over the past years, "migration with dignity," urging residents to consider moving abroad with employable skills, and bought 6,000 acres in Fiji as a potential refuge. But local communities are reluctant to leave their land and prefer to try to adapt. For instance, in Tokelau a community of about 350 residents enclosed their entire islet in five-metre high concrete walls. However, man-made changes to the shoreline can have adverse ecological impacts (Maragos 1993) and can even exacerbate coastal erosion (Xue 2001). Islands in areas where sea-level rise is similar to the global average can, however, keep pace with this, and sometimes even expand (Ford 2012, Kench et al. 2018).

Sea surface temperature rise

The global increase in water temperature is another phenomenon that is particularly harmful for coral reefs. Coral polyps host endosymbiotic photosynthetic dinoflagellates (Symbiodinium) that provide sugar (i.e. energy) to their coral host. They are therefore essential for coral growth and survival. Increase in sea temperatures causes a stress to the polyp that, as a response, expels its symbionts. The coral is then weakened and may die, unless the temperature decreases to normal levels and the symbionts re-enter the polyps. The ejection of symbionts from the coral leads to a loss of colours in the coral tissues, called bleaching. Bleaching and coral death are caused by an extended increase in sea surface temperature above a physiological threshold that depends on the location and the coral genus or species. It is well-established that some coral genera are less sensitive to bleaching than others (Guest at al. 2012). Porites, for instance, is more resistant to bleaching as it usually bleaches in spots, without impacting the entire colony, in contrast to e.g. Pocillopora where entire colonies are typically impacted by increased temperatures.

Mass bleaching on coral reefs was first recorded in early 1980 in the Caribbean and in the Pacific starting with Panama, the Galapagos Islands, French Polynesia, the Great Barrier Reef, and Asia-Pacific (e.g. Thailand).

Since the monitoring of temperature anomalies and sea surface temperatures began, three global coral bleaching events have been reported. The first event, triggered by El Niño in 1998, killed 16% of the corals around the world. The second major global bleaching event struck in 2010, triggered again by a strong El Niño. Recently, in October 2015, the US NOAA announced the third global bleaching event (2014-2017) that has been the longest, most widespread, and most damaging event on record.

Other major but localised bleaching events occurred for instance in 1991 in French Polynesia, in 1994 in American Samoa, and 2000-2002 in Vanuatu (see Timeline in the Country Reports). Heron et al. (2016) defined warming trends and bleaching stress for the Pacific and states that the frequency of bleaching-level thermal stress increased three-fold between 1985-1991 and 2006-2012.

Monitoring and sampling actions for bleaching events are undertaken throughout the Pacific. For example, a collaborative effort between the French overseas territories has been launched to define a common strategy for environmental monitoring of coral bleaching episodes within these territories in the future (Nicet et al. 2018).

NOAA Coral Reef Watch monitors thermal stress by providing the coral bleaching Hotspot, a type of thermal anomaly calculated as the difference between the observed temperature at a grid point and the highest of the 12 climatological SST monthly averages at the grid point (https://coralreefwatch.noaa.gov/satellite/hotspot.php). Sea-surface temperature (SST) is also routinely measured as Degree Heating Weeks (DHW), expressed as degree C-weeks. This measure combines the intensity and duration of thermal stress (i.e. the number of weeks during which SST exceeds 1°C above the local climatological thermal maximum) into one single number. Based on research at Coral Reef Watch, significant coral bleaching is expected when the thermal stress reaches four DHW, especially in more sensitive species (Kayanne 2017). However, the symbionts vary in their resistance to elevated temperatures, and the bleaching response of corals in a given location can be particularly complex.

We used DHW records (see Methods) to assess the relationship between coral cover loss and sustained high water temperatures. We only considered cases where a decline in percent coral cover was observed between consecutive sampling dates. We observed that the decline in coral percent cover increased with the number of DHW for the entire dataset ($R^2=0.03$, $p<0.001$). We then calculated the average and standard deviation of absolute change in coral cover across surveys for classes of 5 DHW (1-5, >5-10, >10-15, >15-20, >20-25, >25; Fig. 29), and observed an increasing change in coral cover (i.e. strong coral cover decline between two consecutive samplings) as DHW increased.

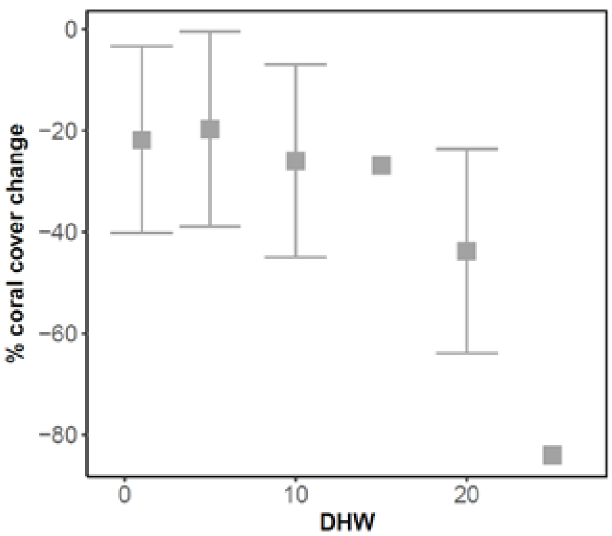


FIGURE 29
Percent of absolute coral cover change according to different degree heating week (DHW) classes. Vertical bars are standard deviation. Absence of vertical bars indicated that only one survey was included in the DHW class.

These results, in agreement with Kayanne (2017), suggest that increasing warming temperatures causing regular, localised or regional bleaching may lead to strong declines in coral cover. This is alarming as the predictions point to an increasing global warming trend that can induce an increase in the intensity and frequency of bleaching events. Sheppard was first to predict when increases in frequency of bleaching would cause sustained loss of corals (Sheppard 2003). Other studies aiming at predicting the impacts of recurrent bleaching on coral reefs were implemented, and showed that some refuge areas may exist in the Pacific Island region (Fig 30). A recent modelling study using RCP 4.5 emission scenario, that have been approved at the 2015 Paris Climate Change Conference (COP21), showed that coral reefs will have difficulties to adapt and acclimatize prior to bleaching events occurring annually, and that 75% of the coral reefs are expected to experience annual bleaching before 2070 (van Hooidonk et al, 2016).

Hopefully, it is predicted that corals may adapt to increases in temperatures. This adaptation could be genus-specific and dependent on past bleaching history in specific locations (Guest et al. 2012). Promising results also indicate that acclimatisation achieves the same heat tolerance in less than 2 years that we would expect from strong natural selection over many generations for such long-lived organisms (Palumbi et al. 2014). Therefore, short-term acclimatisation and long-term adaptive acquisition of climate resistance suggest that coral may overcome climate change. However, since these processes might be species-specific, we expect a change in the coral reefscape, as illustrated in our results (Fig. 18) where a resistant coral genus becomes more abundant in the Pacific Island region. The current coral communities are therefore composed of «losers» and «winners» with regards to climate change, and their abundance or proportion in specific locations may provide insights into the future of coral reefs.

Cyclones

The intertropical belt where coral reefs are predominantely located is also the region where most cyclones occur. Although they are brief disturbances, they have long-lasting impacts on coral reef physical features and functioning (Harmelin-Vivien 1994, Gouezo et al. 2015, Lamy et al. 2015, Lamy et al. 2016). Cyclones are mechanically destructive to coral reefs especially because they damage the

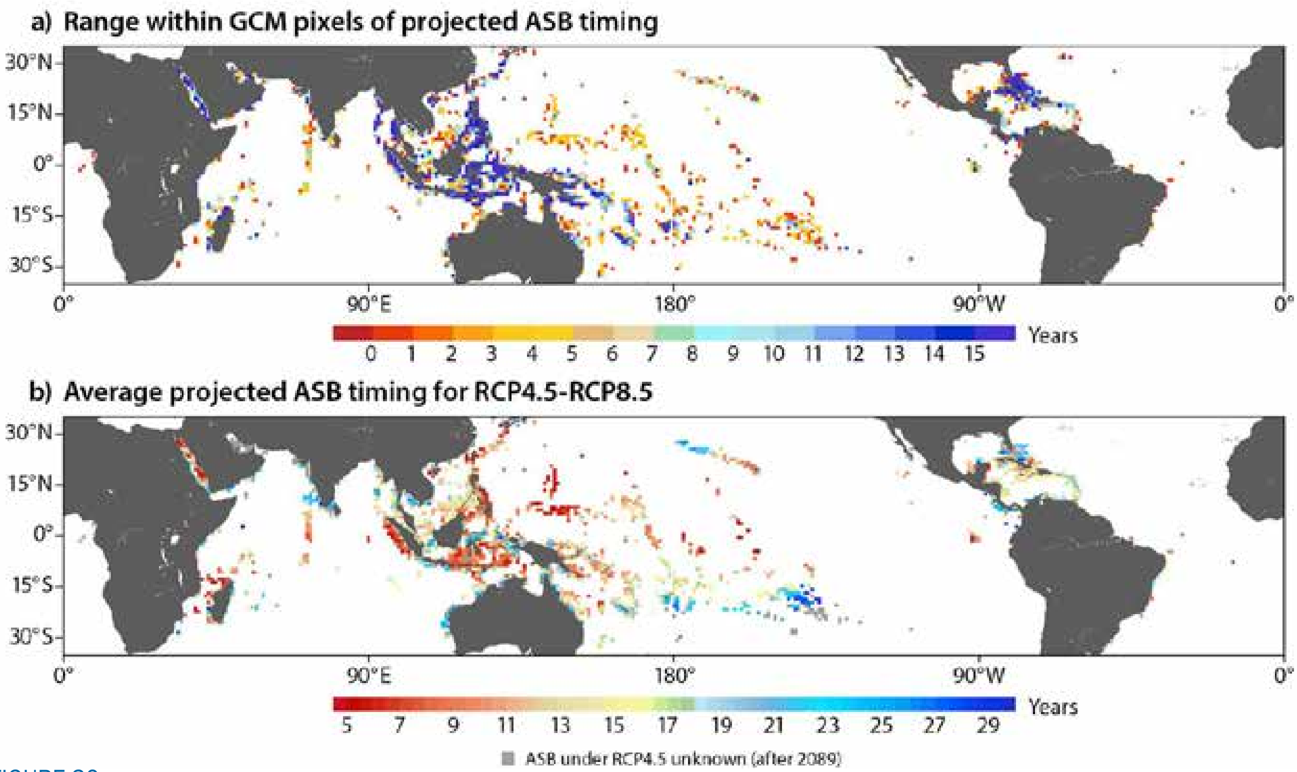


FIGURE 30

Range for statistically downscaled projections of annual severe bleaching (ASB) timing (years) at 4 km resolution within GCM pixels under RCP8.5 (a), and the average difference within GCM pixels between RCP4.5 and RCP8.5 in projected ASB timing (b). This figure was created with NCL (NCAR Command Language Version 6.3.0, http://www.ncl.ucar.edu/) (van Hooidonk R et al. 2016)

3-dimensional structure of coral constructions, and can alter these structures down to a depth of 30 m (Mangubhai 2016). Even though some coral rubble may still recover (if polyps remain alive), the loss of the 3-dimensional structure at the reef scale is problematic for the other organisms that depend on corals as a habitat (e.g. damselfish, Cheal et al. 2017, Gonzalez-Rivero et al. 2017). Coral death after a cyclone is also detrimental to the organisms feeding on their polyps (e.g. chaetodons). Cyclones and storms also induce changes in sedimentation processes, increase turbidity, lower salinity, and temporarily modify the sea level. All of these kinds of damage affect not only the corals but also the primary production, fish, and invertebrates (Gouezo et al. 2015).

Data on main cyclone pathways in the Pacific is available from different sources (e.g. National Hurricane Center at the National Oceanic and Atmospheric Administration, the Japan Meteorological Agency, etc.). Since 1989, we counted 821 hurricanes in the Pacific Ocean (category 1 to 5). Among these, notable cyclones are Winston in Fiji in 2016 (the most intense tropical cyclone in the Southern Hemisphere on record, Mangubhai 2016), Bopha and Haiyan, both category 5, that hit Palau in two consecutive years in 2012 and 2013 (Gouezo et al. 2015), cyclone Oli in French Polynesia in 2010, the five cyclones (Menna, Nancy, Olaf, Percy and Rae) that hit the Southern Cook Islands from February to March 2005, and the sixteen cyclones that hit the South Pacific tropical islands during the 1982-1983 wet season.

Despite the fact that the impacts of cyclones on reefs can persist for years or even decades, corals are well adapted to recover from these storms since they have coexisted for most of the life of the planet (see Fig. 1 for particularly fast recovery in Moorea, French Polynesia). Additionally, the effects and consequences of cyclones on coral reefs depend largely on their pathway, intensity, and frequency. However, a recent study on the GBR showed that cyclones are likely to become more intense with global climate change, leaving insufficient time for coral reefs to recover between disturbances (Cheal et al. 2017). Similarly to bleaching, massive corals such as Porites are more resistant to cyclones, and may eventually be the winners of the coral reef community, especially since their percent cover is regularly increasing at the Pacific scale (Fig. 18).

3.f. The role of *Acanthaster planci* outbreaks

Acanthaster planci, or crown-of-thorns starfish (COTS), is an echinoderm that feeds on reef-building coral polyps. When COTS become invasive, commonly referred to as an outbreak, these animals can cause extensive coral decline across large expanses of reef (Fig. 31). During these outbreaks, *A. planci* density can reach several individuals per square metre (Keesing and Lucas 1992), can consume up to 6 square metres of live coral per year per individual (Madl 1998), and have different feeding preferences across coral genera (Kayal et al. 2011). Adults can reach about 35 cm in diameter, with some individuals reaching up to 80 cm. *A. planci* larvae feed on phytoplankton before settling on the reef. *A. planci* are usually attracted by coral-rich reefs rather than by coral-poor reefs (Clements and Hay 2017), because they are probably attracted by the chemical cues of the reef (Johnson and Sutton 1994). Juvenile starfish feed nocturnally and remain cryptic during the day, contrary to adult starfish, which are mostly mobile around dawn and dusk. Main predators of *A. planci* are *Charonia tritonis*, *Arothron hispidus*, *Balistoides viridescens*, and *Cheilinus undulatus*, and their important role in regulating the abundance of *A. planci* has been modelled (Ratianingsih et al. 2017). Unfortunately, the abundance of these key species has decreased in some locations in the Pacific due to local consumption by humans (Rhodes et al. 2017). Moreover, increased phytoplankton food resulting from eutrophication (e.g. from agricultural runoff) is believed to enhance *A. planci* larval survival (Brodie et al. 2017), while warmer temperature can also enhance larval development (Uthicke et al. 2015). However, *A. planci* outbreaks are not exclusively associated with locations where humans are present, as evidenced by several examples around the world (e.g. Chagos Archipelago: Roche et al. 2015). A recent study showed that A. pl*anci* larvae could sustain low nutrient levels, thus suggesting that the initiation of an outbreak does not necessarily require eutrophic conditions (Wolfe et al. 2017).

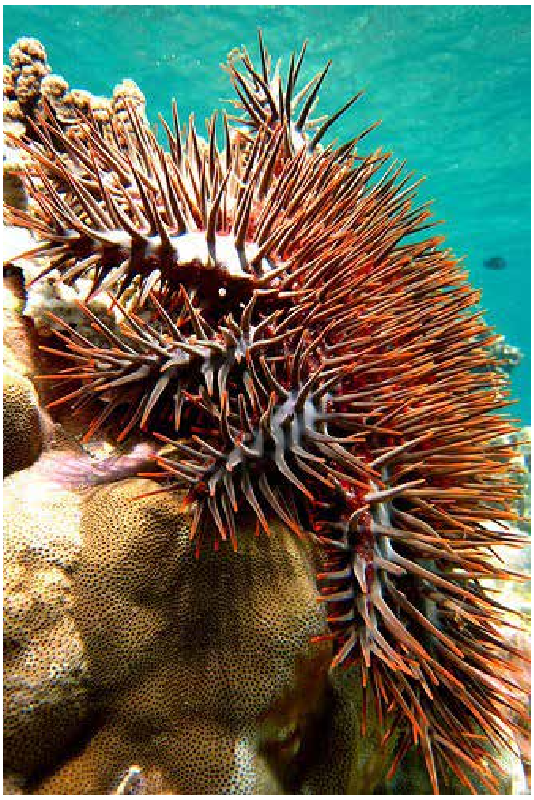


FIGURE 31
Acanthaster planci (© Thomas Vignaud)

Several cases of *A. planci* outbreaks, widespread across time and scale, were described throughout the Pacific. In 1978, a severe outbreak occurred in Tutuila (American Samoa), with up to 90% of corals killed in some areas (Birkeland, 1982). Considerable amounts of seastars were removed (486.933) but this did not prevent the outbreak from spreading. In 2004, *A. planci* around Majuro in the Marshall Islands decimated Acropora spp., with 90% mortality. In 2009, major outbreaks started in Pohnpei (eastern FSM) and moved westward to Chuuk and Yap over the next year. In Vanuatu from 2006 to 2008, *A. planci* had significant impacts on some reefs in the Shefa Province (Efate, Emau, Nguna, Pele, Moso, Lelepa and Mele islands). Between 2006 and 2009, outbreaks occurred in French Polynesia, especially in Moorea, and led to a coral decrease down to nearly 0% at some locations. (Fig. 1)

A. planci outbreaks can lead to the destruction of centuries-old coral colonies within days, and reefs within weeks to months. However, it is likely that they are part of the natural evolution of the reef since historical reports and paleontological studies provide evidence of the presence of COTS. In this case, they may act as cleaners of the reef, creating open space for new recruits of more adapted corals and associated organisms (fish and other invertebrates) to settle. This is evident in Moorea where *A. planci* outbreaks seem to occur every ca. 30 years (see Fig. 1 and Country Report for French Polynesia), and where good recovery has occurred after disturbance. However, further work is still required to better understand ecological processes driving the reef dynamics. Although *A. planci* outbreaks are probably part of the long-term dynamics of corals reefs, the balance between the natural occurrence of these disturbances and their frequency within the context of global change remains fragile.

4. SYNTHESIS

The present analysis is the first of its kind for the Pacific Islands region, gathering nearly 20,000 surveys across most of the island nations. This analysis showed little change over the last two decades for the major indicators and metrics used to monitor reef health; coral percent cover remained relatively stable, i.e. close to 25% (Fig. 32). The estimated annual percent of coral cover was also systematically above the estimated annual percent of macroalgae cover, an observation that differs from several previous alarming observations showing a shift from coral dominance to algal dominance.

However, attention should be drawn to the weak but significant decline in coral cover from 1999 to the present at the scale of the Pacific Islands region. Interestingly, a change in dominant coral taxa was observed (Fig. 33), as well as a decrease in biomass of herbivorous fish, especially on inhabited islands, and highly variable macroalgal cover within the survey period. These results differ from what has been observed in the Caribbean, in the Western Indian Ocean, and on the Great Barrier Reef (Fig. 34). The Pacific includes about 25% of the world's corals, and our report accounts for a very large area compared to previous studies. The vast size of the Pacific, the biogeographically-driven variations that exist along latitudinal gradients in the northern and southern hemispheres, the west-ern-eastern gradients in species diversity, and the diversity of the islands sam-pled may buffer local variations. This overview may thus downsize the local im-pacts of disturbances, while large scale changes are more likely due to global climate change, which may affect the turnover of the coral communities rather than induce a decrease in coral cover. The comparison of the present study with previous

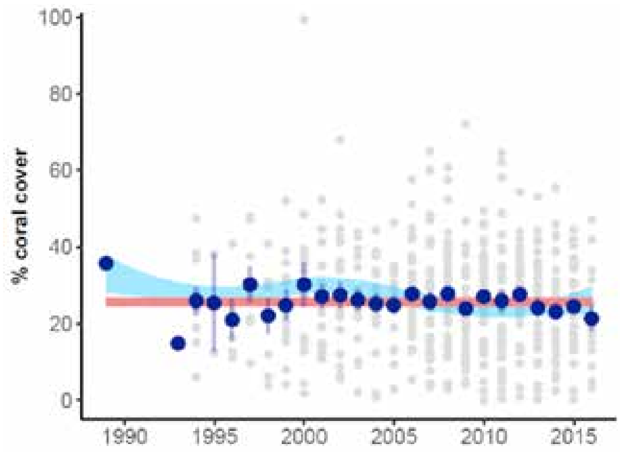


FIGURE 32
Change over time of the average coral cover in the Pacific region for the last 2 decades. See Data, Methodology, and Analysis for details.

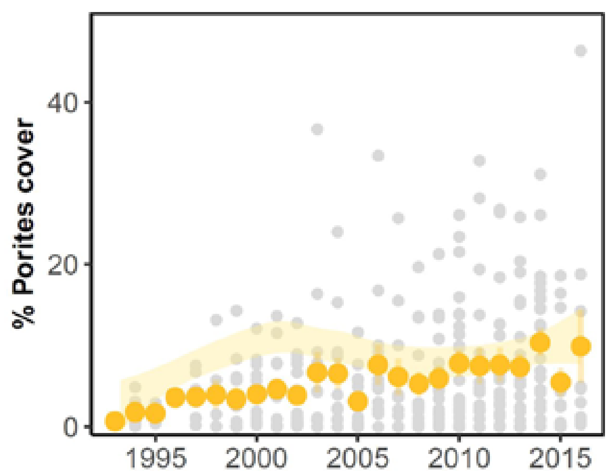


FIGURE 33
Change over time of the average cover of Porites spp. in the Pacific region for the last two decades. See Data, Methodology, and Analysis for details.

similar studies also indicates that decline in coral reefs can present different patterns according to the regions considered. In the Caribbean, one region presented a real decline while another one, less inhabited, was more stable. Overall, there is a minor tendency of decline of coral reefs that stand out from significant decline recently emphasised in other regions. However, what is more important is the clear change in the coral reef assemblage, and this is something that must be considered in future reef dynamics. This change is critical, as it will impact some essential functions of coral reefs starting with calcification and net accretion of reef putting into question the future role of coral reefs in shoreline protection. This in turn has further implications for fishing (through changed habitat structure and therefore also fish community structure), tourism and on the coral reef as a biodiversity reservoir. Understanding the future biodiversity shifts on coral reefs and the changes in their functioning and service provision is a challenge that merits further attention.

The change in coral reef assemblage has also been recently emphasised by Hughes et al. (2018) who showed a decrease in fast-growing staghorn and tabular corals which has transformed the three-dimensional structure of the reef and will certainly result in associated consequences for the ecological functioning of the reef (Fig. 35). The changing coral reef community structure may be a sign of large-scale environmental changes that favour the maintenance and proliferation of stronger corals, while the decrease in herbivore fish biomass may be a sign of local human impacts (i.e. fishing). Together these patterns suggest that, even at the Pacific considered less impacted than other regions in the world, reefscapes are changing in terms of composition and functions

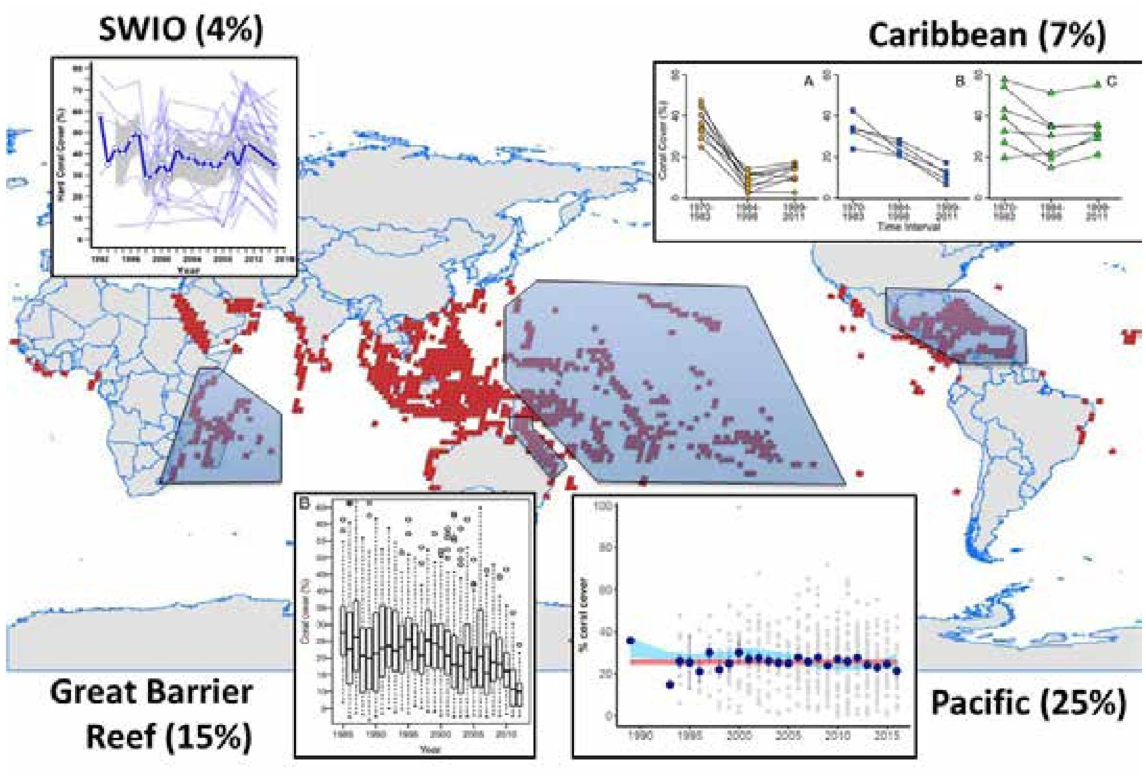


FIGURE 34

Synthesis of the results obtained in recent studies for the Great Barrier Reef (De'ath et al, 2012), the Caribbean (Jackson et al, 2014) and the South Western Indian Ocean (SWIO, Obura et al. 2017), which are compared to the Pacific Island region (present report). Percentages indicate the proportion of reefs in a region relative to reefs in the whole world.

. Quantifying how much the present functions of coral reefs will be affected, and how many services to humans will be altered, are real challenges that local communities have to face.

Despite the general Pacific-wide patterns, it is important to note that, at individual locations, the reefs are regularly under the influence of occasional acute disturbances, with sometimes strong reduction in coral cover. Many locations however recovered well (see Country Reports). Such disturbances were notuniform across the Pacific Island region. This explains why the impact of each of the mass bleaching events that affected corals in other regions in the world does not show up as a signal in region-wide averages, (Fig. 24) with losses in coral cover in a specific area being compensated by gains in another area. The local, island-specific dynamics suggest that local-scale management actions can help to mitigate the inevitable effects of global change at least in the near future. Coral reefs in the Pacific are highly dynamic and recovery is likely to occur rapidly following future disturbances. Given the changes highlighted in coral reefs at the Pacific scale and the high variability of the reef dynamics at local scale, local management actions should be strengthened and adapted to each case to help sustain reef ecosystems.

FIGURE 35
An example of coral reef over-dominated by *Porites spp.* Clipperton Island (© Dave McAloney - National Geographic - Pristine Seas, Clipperton Expedition 2016)

5. RECOMMENDATIONS FOR MANAGEMENT

This compilation and analysis of coral reef time series data in the Pacific provides the basis for a number of conclusions and recommendations regarding coral reef management and policy, how monitoring is conducted in order to enhance its usability as well as research applications of the dataset that was compiled.

Data on coral reef status and trends is a valuable resource. It can support environmental planning and management decisions at multiple levels. It can contribute to and underpin ecological research, enhancing our understanding of coral reefs, their biota and their ecosystem services. It also provides a basis for informing society of the fate of an ecosystem on which people, livelihoods and economies depend. Because of this, coral reef status and trend data and reporting can directly and concretely contribute to measuring progress towards established environmental and societal goals, including the 2030 Development Agenda and specifically the Sustainable Development Goal 14. Altogether, we identified 10 recommendations in different areas as described below.

5.a. Management and policy responses

It is well known that coral reef change is driven by local as well as global pressures, and that maintaining coral reef health in the long-term requires addressing both of these. In the broadest sense, this regional analysis has found little changes in the coral reef percent cover, and no evidence of region-wide decline, but a change in the in the coral community structure and herbivore fish biomass. Importantly, at the regional scale, major events of acute stress (such as bleaching episodes and crown of thorns starfish outbreaks) have to date not led to region-wide declines in coral cover. Local factors are thus important in controlling observed reef trends.

By emphasising a reduction of local anthropogenic pressures, Pacific Islands have a very significant influence over coral reef health and ecosystem service provision. Pacific nations have already taken steps to manage reefs, but the size of the region and extent of its reefs, combined with comparatively modest human population, have also likely contributed to less reef decline than has been observed, for example, in the Caribbean. Bearing in mind current regional development as well as global climate change trends, strengthened efforts are needed to keep reefs healthy into the future. Based on this, we recommend to:

1. Identify, prioritise and implement actions that reduce local, chronic pressures on coral reefs arising from land use, land use change and coastal development.

Stress reduction efforts need to address nutrient, sediment and other pollution that is derived from land, including agriculture, farming, coastal development and associated wastewater. Specific measures should be identified, prioritised and implemented based on their importance in bolstering reef recovery. This will also require specific considerations of coral reefs in broader, integrated development and management planning processes at the national level.

2. Bring use of coral reefs to sustainable levels by strengthening implementation of fisheries legislation, regulation, and enforcement with a particular focus on halting the decline in herbivorous fish, and by further expanding marine area-based management.

Most Pacific nations have relatively well-developed fisheries policy frameworks and regulations including gear and species-specific restrictions, but are often lacking in implementation, compliance and enforcement. It is therefore recommended that fisheries management efforts are strengthened to enhance compliance with existing regulations, and that regulations relating to herbivorous fish are further strengthened where relevant. The importance of herbivorous fish in maintaining healthy coral reefs is not a subject of debate and therefore these important species should be more broadly protected and/or managed across all coral reefs. Herbivore fishery management should be a priority.

Further expanding the use of marine managed areas will enhance coral reef resilience, biodiversity conservation, and fisheries productivity as well as recreational/tourism opportunities, thereby also contributing to blue economy development.

5.b. Strengthening coral reef monitoring and reporting

Coral reef monitoring in the Pacific has evolved significantly, especially over the last decade. Coral reefs in most Pacific island nations and territories have been covered by at least some ecological surveys, and regular monitoring programs now operate in most of them. However, a number of gaps and challenges remain that reduce the utility of monitoring for regional and national level reporting, reduce the extent to which monitoring data can be or is used for policy and management decisions, as well as limits its use in informing society of environmental change or supporting research.
Coral reef monitoring is in general stronger in terms of coverage, variables, and frequency or regularity of measurement in developed countries and where there is international conservation or development support. Monitoring programs have been established in most Pacific Small Island Developing States (SIDS) at some point, but continuity is challenging, e.g. where monitoring is dependent on external project funding.

The situation in the Pacific is, in other words, similar to what was documented in the Caribbean by the GCRMN, where monitoring was found to be "scattered, disorganised and largely ineffective". Key recommendations in addressing the specific gaps and challenges related to coral reef monitoring and reporting in the Pacific include the following:

3. Ensure coherence and data compatibility in coral reef monitoring across the Pacific region, through the development and adoption of common monitoring indicators and data formats.

This may be pursued through GCRMN, and may entail establishment of common minimum standards, tiered to accommodate different levels of monitoring (e.g. drawing on experiences from GCRMN's work in the Caribbean). Intergovernmental adoption or endorsement of the recommended standard at the regional level will facilitate broad uptake and use among national monitoring programs as well as among other initiatives, organisations and projects.

Specific consideration should be given to common data and metadata formats, common variables/indicators for coral reef monitoring, common methodological requirements, key physical parameter, and investigate opportunities offered by new or increasingly cheap technology, such as increased use of digital imagery as well as enhanced use of microsensors where possible.

4. Strengthen data management as well as access to data and data products, through the development of a regional data repository.

A regional data platform that is developed based on clearly defined principles for data contribution, access and sharing, and hosted and maintained by competent regional institutions, will strengthen coral reef monitoring and reporting and their impact, by:

- Providing data management services to monitoring programmes that do not have sufficient capacity to operate fully fledged data systems and storage;
- Enhancing access to coral reef data, as well as a range of data products, for environmental management and other decision making, reporting in the context of regionally or globally established targets, research, and awareness raising;

• Enabling the further development of data and reporting products, including enhanced periodic reporting on coral reef status and trends in the region, and contributions towards global syntheses.

5. Fill key geographic gaps in coral reef monitoring, with a focus on areas where monitoring is absent or highly intermittent.

This may be pursued by relevant ongoing monitoring programs, as well as through establishment of new programs where required, which is likely to require additional support in terms of targeted technical assistance, capacity building, and funding. It is recognised that many locations are unlikely to be regularly surveyed through long-term monitoring programs, bearing in mind the size of the Pacific, the remoteness of some islands, and the extent of the coral reef area. Because of this, data from surveys that do not form part of a monitoring program (e.g. those conducted through various research, development or other projects) constitutes an important resource for long-term coral reef monitoring and reporting in the Pacific.

6. Support regional networking to strengthen monitoring and reporting, including exchange of expertise and capacity building, by (re-) establishing a regional GCRMN committee.

The process for preparing this report has re-energised regional communication and collaboration in relation to coral reef monitoring. Recommendations provided herein, especially in relation to monitoring, require follow-up, and many countries and territories will benefit from continued exchange of experiences and expertise, training, peer-to-peer learning, etc. Establishment of a regional network or committee (e.g. similar to the GCRMN Committee in the Caribbean) is recommended, hosted and convened by a competent regional institution.

7. Provide continuing support, including financial support, for both long-term coral reef monitoring and reporting, as well as the ability to rapidly respond and assess unexpected events.

The analysis illustrates the importance of continuous coral reef monitoring in tracking of ecosystem status and trends, and in enabling analysis of the longer-term implications of perturbations such as bleaching. Commitment to strengthening long-term monitoring across the region, including building capacity for it, is therefore needed. In addition, provide urgency grants, that allow monitoring agencies and scientists to readily mobilise (and deviate from their long-term monitoring cycles) to respond and assess unexpected and transient events affecting coral reefs, such as the 2011 Crown-of-thorns outbreak in American Samoa, or the 2014-2017 coral bleaching event.

5.c. Further research

8. Pursue further and more in-depth analyses of the dataset, including in relation to pressures/drivers of reef change, and develop collaborative research projects for this purpose.

The dataset compiled lends itself to further analyses, beyond what was possible to do within the scope of this report. Such analyses may delve further into identifying appropriate pressure metrics and datasets, in order to gain a better understanding of the processes that control reef change in the Pacific and further sharpen recommendations for management. Such research may be pursued through a working group.

9. Support greater understanding of bleaching sensitivity and impacts on Pacific coral reefs, by enhancing observation of bleaching mortality and recovery.

Coral bleaching events in the Pacific have caused significant local impacts on coral cover, (see Country Reports), but region-wide coral reef decline driven by bleaching was not found in this study when analysing the large-scale trends. For the purposes of reef management planning, the speed of recovery from a bleaching event is more important than the immediate impact in terms of the amount of coral bleached. In other words, good regular monitoring has greater management application than bleaching observation. However, in view of projections of future temperature stress expected to induce bleaching, it is important to enhance understanding of how and whether temperature tolerance of Pacific corals may change, and how this may impact reef communities in the longer term.

5.d. Dissemination of findings

10. Raise awareness about report findings, conclusions and recommendations, in the context of the International Year of the Reef 2018.

This analysis provides new findings on coral reef status and trends as well as a number of recommendations relevant to specific target audiences, including the general public, national policy makers, coral reef management practitioners, entities engaged in monitoring as well as researchers. Dissemination utilising a broad range of media is therefore important.

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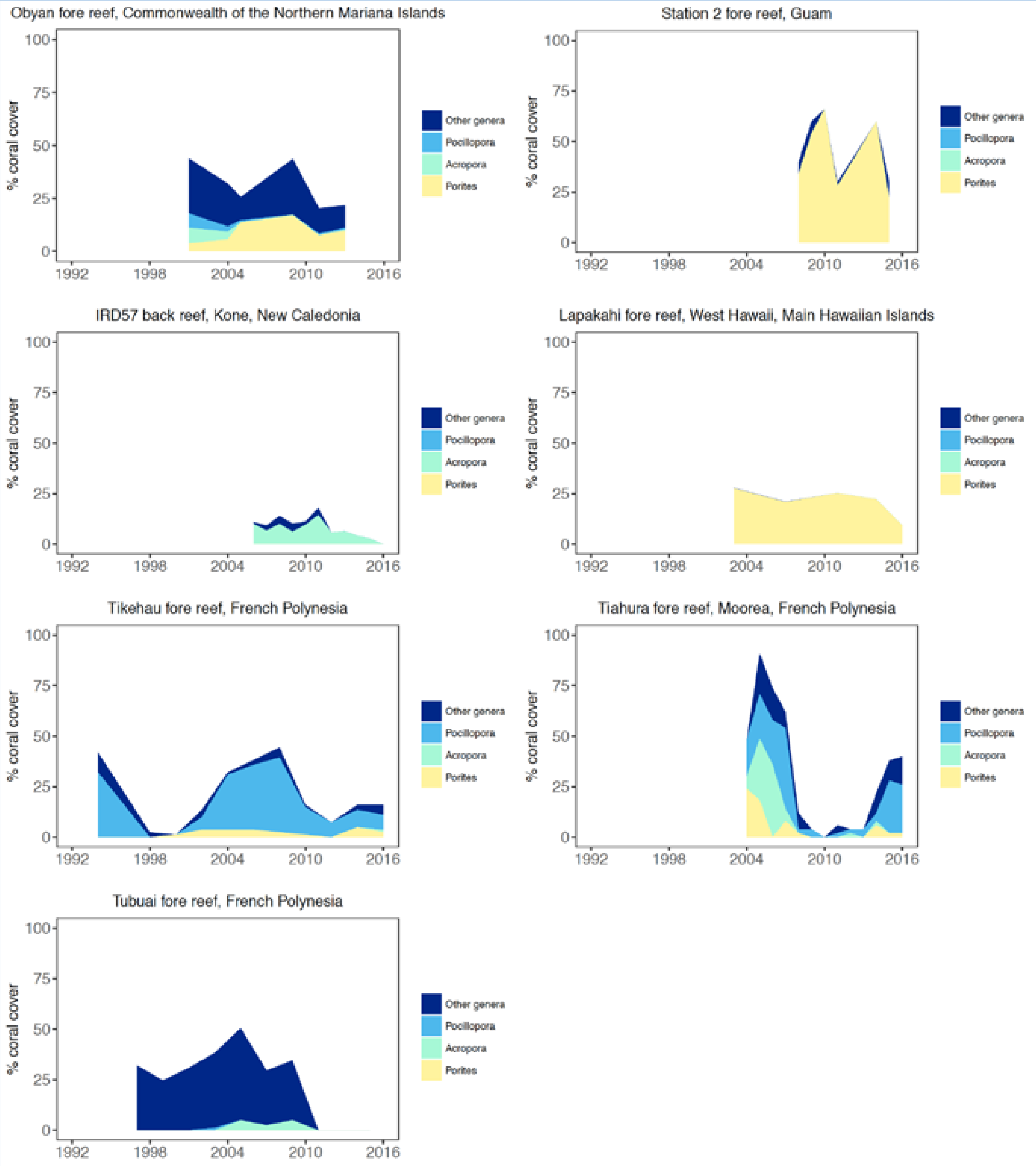
7. APPENDICES

I. Database structure

Field	Field options
Dataset ID	
Survey ID	
Replicate ID	
Sum Level	Raw; Summarised with error; Summarised without error
Data Level	Species; Genus; Family; Functional
Year	
Site Name	
Station Name	
Replicate Code	
Region	
Country	
Island	
Latitude	
Longitude	
Depth	
Bottom Type	Hard; Soft; Hard-Soft
Site Type	Permanent; Non-Permanent
Sampling Design	Random; Random Stratified; Selective; Haphazard
Sampling Method	Belt Transect; Linear Point Intercept Transect; Photo-Quadrats; Quadrats; Species Point Count
Transect Length	
Transect Width	
Quadrat Area	
Number of Quadrats per Transect	
Method Area	
Number of Points Sampled	
Transect Intervals	
Reef Zone	Lagoon; Back reef; Fore reef; Onshore
Reef Slope	Flat; Gentle; Steep; Wall
Management	No-take MPA; Restricted-take MPA; No Management

II. Timelines of coral cover and composition at reef sites for major time series



PART II. REPORTS FOR INDIVIDUAL COUNTRIES AND TERRITORIES

1. INTRODUCTION

The part II of this report provides more details to understand the status and trends of coral reefs for each individual countries and territories. In this section, the following information is presented:

1. Geographic Information: This section includes maritime, reef and land areas, coastal length, number of islands, distance to nearest continent, island type and age, population, number of uninhabited islands, climate, major wind regimes, total MPAs (or MMAs), and GDP per capita.

2. Overview: Global information about the country or territory and their dependence on coral reefs.

3. Timeline of major events: A selective list of local events (natural and anthropogenic) affecting coral reefs and local management, and major conservation efforts. Information about these events were found in the grey literature and gathered from individuals' co-authors in each country and territory.

4. Map(s) of individual surveys for substrate: The maps indicate the location of survey for substrate data only (coral, macroalgae, and other categories – see Part I), based on geographical coordinates of individual surveys (see definition in Part I). Point size on the maps is proportional to the number of times the site was sampled. A colour is assigned to each point according to its original datasets. Some datasets could not be represented on the maps due to missing coordinates.

5. Table of data sources: Summary tables listing the data contributors with dataset arbitrary reference number, time period, year count for this specific country, as well as the biological compartment(s) concerned by the dataset.

6. Results and trends: This section includes graphs of average percent in coral and macroalgae cover at the country-scale and at the island-scale when possible. Similarly, the graphs of average total, herbivore, carnivore, planktivore and corallivore biomass or abundance are presented (see Part I for definition of these trophic groups). Analyses were implemented by dataset separately. Results are for depths 0-21 meters (all habitats, see Part I for definition) and are averaged by dataset and location. LOESS smoothing, a weighted linear regression that incorporates adjacent values into the fit, were applied to the data when relevant.
   The number the graphs in each country report depends on the geographic extent of each country and the amount of data available (e.g. fish biomass is not available for all the countries and territories, and graphs of abundance are not represented when biomass is available).

7. General Literature: Basic references, scientific articles or general literature on coral reefs, gathered from co-authors in each country and territory.

2. COUNTRIES, STATES, AND TERRITORIES

American Samoa
Commonwealth of the Northern Mariana Islands
Cook Islands
Federated States of Micronesia
Republic of Fiji
French Polynesia
Guam
Main and Northwestern Hawaiian Islands
Republic of Kiribati
Republic of the Marshall Islands
New Caledonia
Pacific Remote Island Area
Republic of Palau
Papua-New Guinea
Pitcairn Islands
(Western) Samoa
The Kingdom of Tonga
Republic of Vanuatu
Wallis & Futuna

American Samoa

Collaborators: Charles Birkeland, Tim Clarke, Douglas Fenner, Marie Ferguson, Alison Green, Adel Heenan, Kelly Kozar, Alice Lawrence, Sheila McKenna, Mareike Sudek and Bernardo Vargas-Angel

Geographic information	
Maritime area: 390 000 km^2	**Reef area: 220 km^2**
Land area: 200 km^2	**Coastal length: 116 km**
Number of islands: 7	**Distance to nearest continent: 3 972 km (Australia), 2 768 km (New Zealand)**
Island type: volcanic and low-lying atoll	**Island age: 150.000 years to 1.5 million years (high islands), 65 million years for atolls**
Population: 55 000	**Number of uninhabited islands: 2**
Climate: tropical	**Major wind regime: Southeast trade winds**
Total MPAs: 17	**GDP's/CAP: $9 421**

Overview

American Samoa, situated in the central tropical South Pacific, consists of a group of 5 volcanic islands and 2 atolls. It is a territory of the USA and thus falls under US federal law and administration; the local government consists of an elected governor, senate and a house of representatives. Tutuila, the largest island (138 km2), is the centre of government and business.

About 2705 marine species have been recorded from reefs around American Samoa with 276 species of hard coral, 945 fishes, 170 crustaceans, and 700 molluscs.

Timeline of major events

1920's	Coral reefs on the south shore of the inner Pago Pago Harbour were destroyed by the construction of a naval base
1938	Outbreak of *Acanthaster planci* documented in Flanigan and Lamberts
1940's	Construction of airport runways and Navy buildings on top of reef flat; excavation of reef flat areas in the harbour, Faga'alu, and Alofau to obtain material to add to village land
1948	COTS outbreak
1950's	Excavation of the inner reef at the village of Aua for road construction
1954	Construction of first tuna cannery in inner Pago Pago Harbour and the start of industrial pollution
1963	Construction of the second cannery in inner Pago Pago Harbour
1966	Cyclone (major disaster)
1973	Rose Atoll National Wildlife Refuge
1974	Record drought, followed by especially heavy rains and mudslides
1978	Severe COTS outbreaks in Tutuila with high proportion of corals killed, up to 90% in some areas (outbreaks of considerably more than the 486,933 Acan-thaster planci that were removed by the bounty system).
1981	Cyclone Esau
1985	Fagatele Bay National Marine Sanctuary established
1986	Department of Marine & Wildlife Resources established
1987	Cyclone Tusi (hit Manua Islands heavily impacted)
1990	Cyclone Ofa (hit Tutuila hard, grounded 9 ships on the reefs in Pago Pago Harbour)
1991	Cyclone Val, major impact to coral reefs
1992	Industrial wastewater pipe extended from canneries to outer harbour and greatly reduced pollution in the harbour. *Acropora hyacinthus* returned
1994	Major bleaching event
1998	Extreme low ties
2000	Governor directs ASG establish 20% of territory's coral reefs as no-take Marine Protected Areas
2001	Scuba spear fishing banned
2002	Widespread warm-water bleaching of corals in territory
2003	Major bleaching event; coral disease ("white syndrome") common; shark finning (taking fins only) banned in territorial waters
2004	Cyclone Heta, moderate damage to coral reefs; Local Action Strategy sets a target for establishing an MPA network that covers 20% of the territory's coral reef ecosystems
2005	Cyclone Olaf, category 5 cyclone slammed directly into Manu'a; extreme low tides (every year has low tides that kills corals that have grown too high on reef flats)
2006	Cyclone Tam; extreme low tides
2009	A tsunami causing severe damage to some coastal areas of the southern parts of the Territory, spotty coral damage at specific sites (Leone, Ama-nave, Poloa, Vatia, Tula, Fagatele Bay); Rose Atoll National Monument established
2011	Cyclone Wilma, passed over Tutuila just having reached category 1; COTS outbreaks
2012	Cyclone Evan
2013	COTS outbreaks, NPS eradication efforts around 28,000 COTS
2015	Moderate bleaching event with low mortality (mortality in a few places on reef flats)
2016	Cyclone Ula
2017	Bleaching event

Maps of individual surveys of substrate

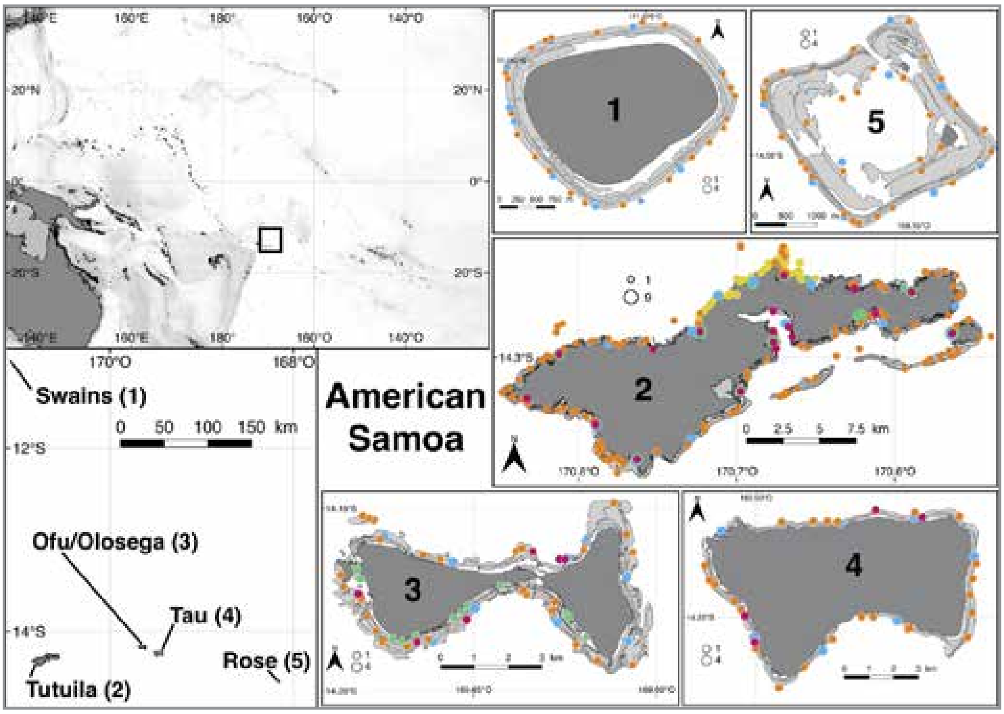


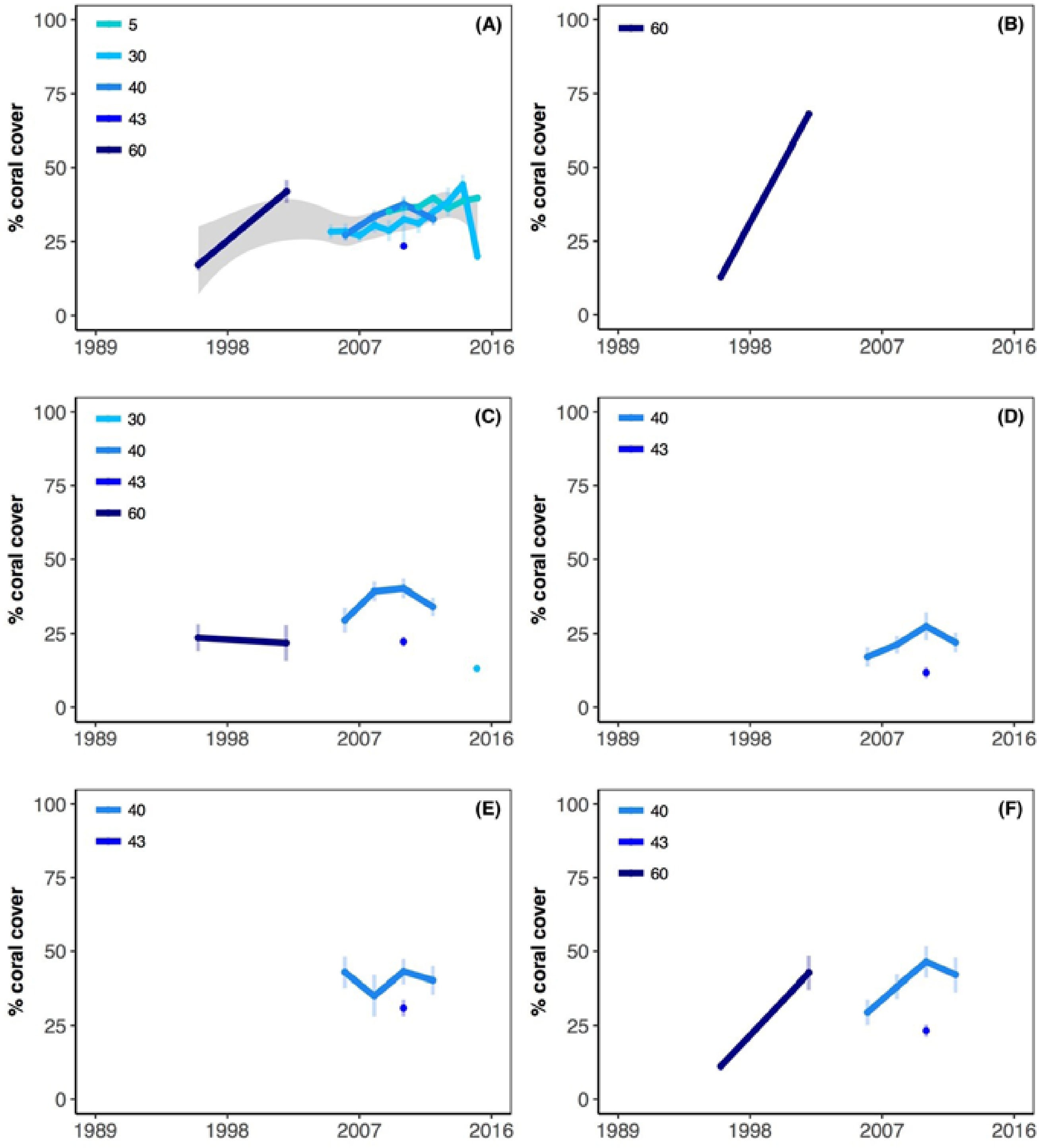
FIGURE 1
Map of the American Samoa. Each colour represents a different dataset (orange: dataset n°43, blue: dataset n°40, green: dataset n°30, pink: dataset n°60, yellow: dataset n°5). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from American Samoa used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
5	PACN – National Park Service – U.S. Department of the Interior	2006 – 2015	7	X	X	
6	PACN – National Park Service – U.S. Department of the Interior	2006 - 2015	6			X
30	ASCRMP	2005 - 2015	11	X	X	
40	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2005 – 2012	4	X	X	
43	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2011 - 2014	1	X	X	
49	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2007 - 2015	4			X
57	ASCRMP	1996 - 2015	13			X
60	ASCRMP	1996 - 2002	2	X	X	

Trends



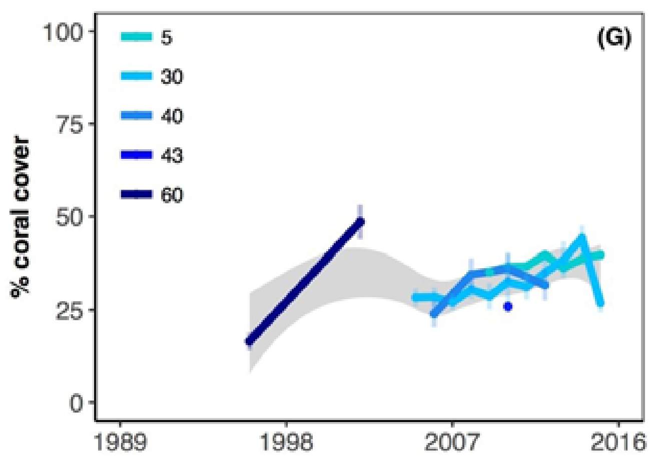


FIGURE 2.1
Average percent of live hard coral cover in American Samoa: (A) Contribution of each dataset, all islands combined; (B) Aunuu; (C) Ofu/Olosega; (D) Rose; (E) Swains; (F) Tau; (G) Tutuila. The grey area represents the average loess trend in coral cover when several datasets are combined.

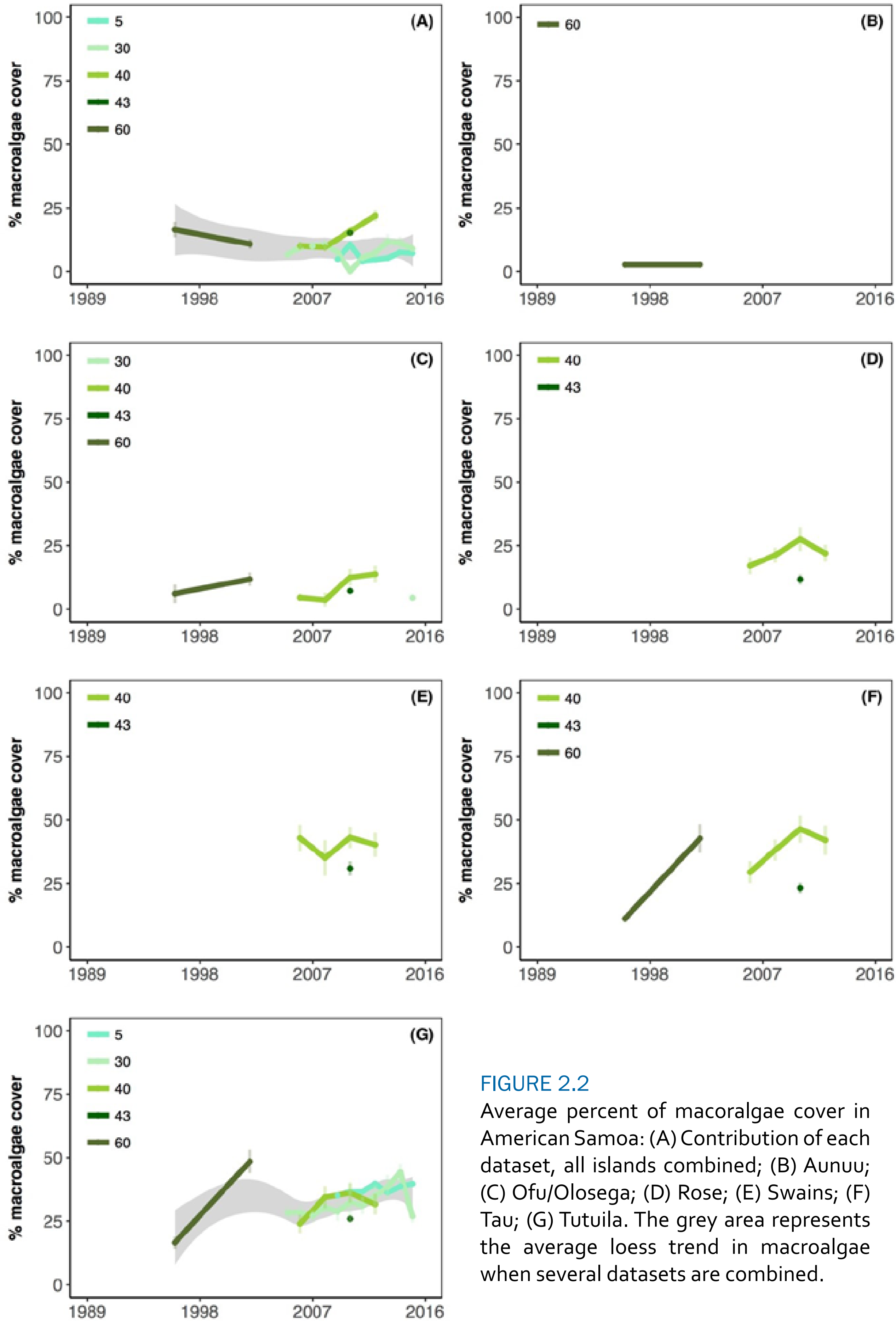
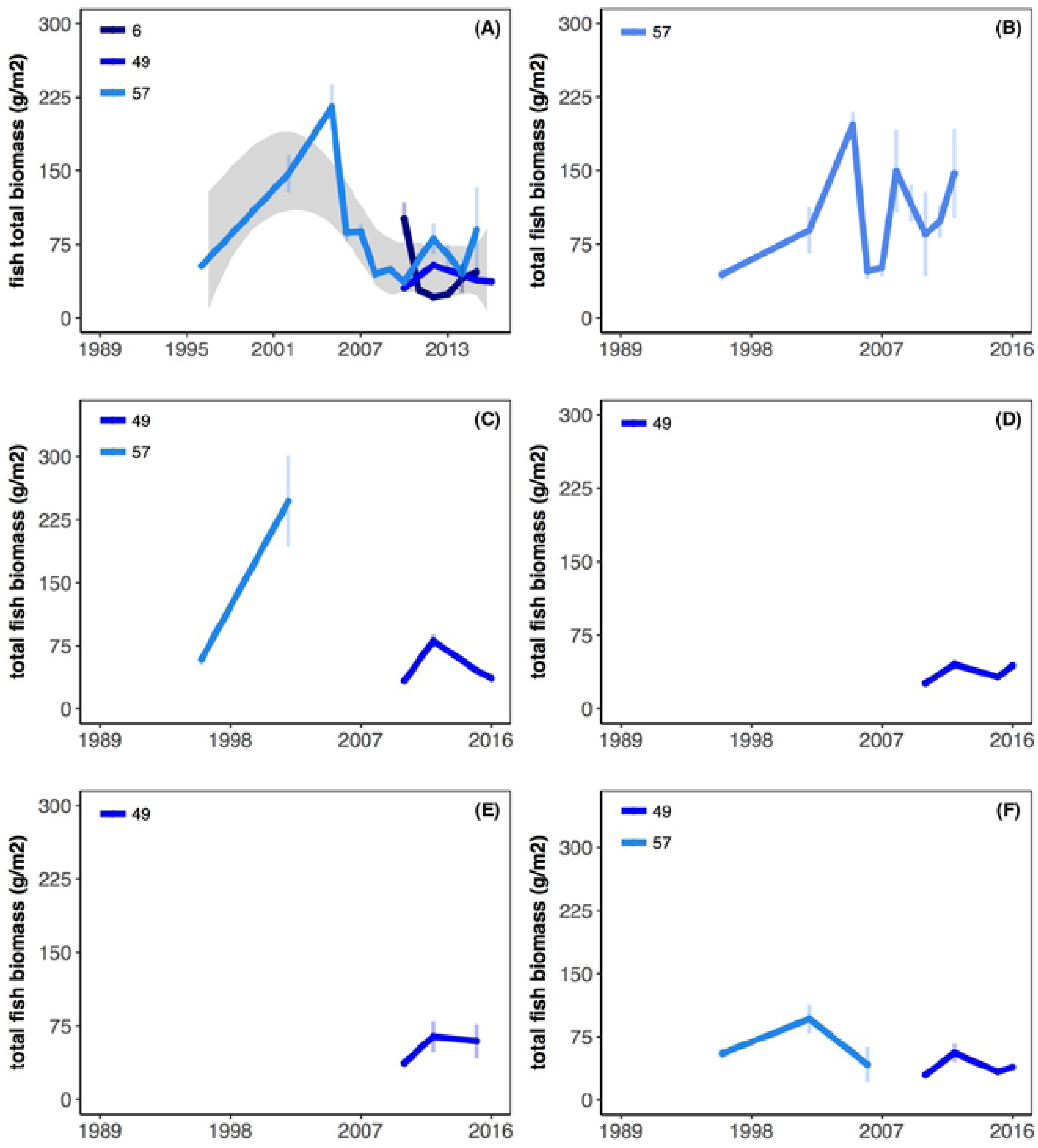


FIGURE 2.2
Average percent of macoralgae cover in American Samoa: (A) Contribution of each dataset, all islands combined; (B) Aunuu; (C) Ofu/Olosega; (D) Rose; (E) Swains; (F) Tau; (G) Tutuila. The grey area represents the average loess trend in macroalgae when several datasets are combined.



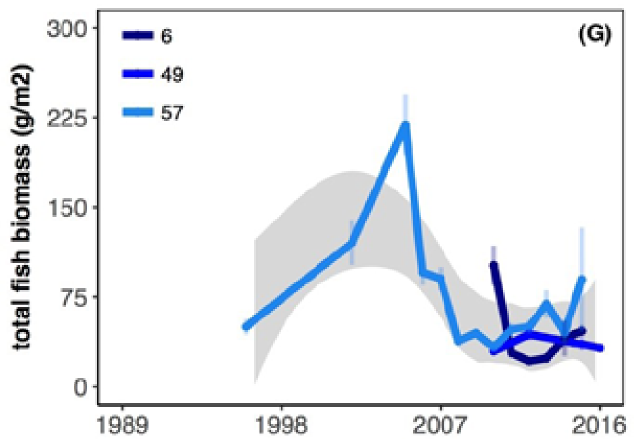


FIGURE 2.3

Average percent of total fish biomass in American Samoa: (A) Contribution of each dataset, all islands combined; (B) Aunuu; (C) Ofu/Olosega; (D) Rose; (E) Swains; (F) Tau; (G) Tutuila. The grey area represents the average loess trend in total fish biomass when several datasets are combined.

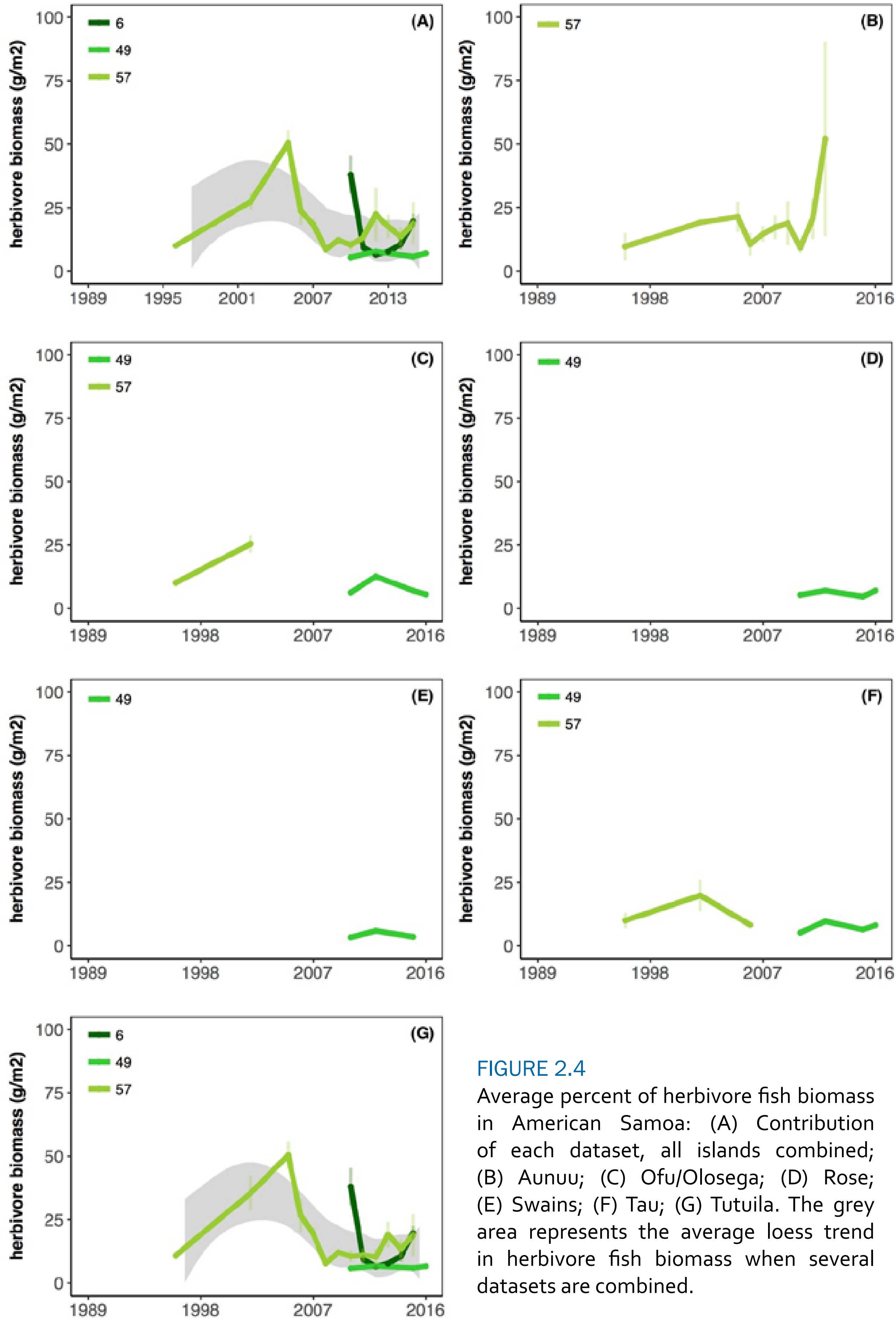
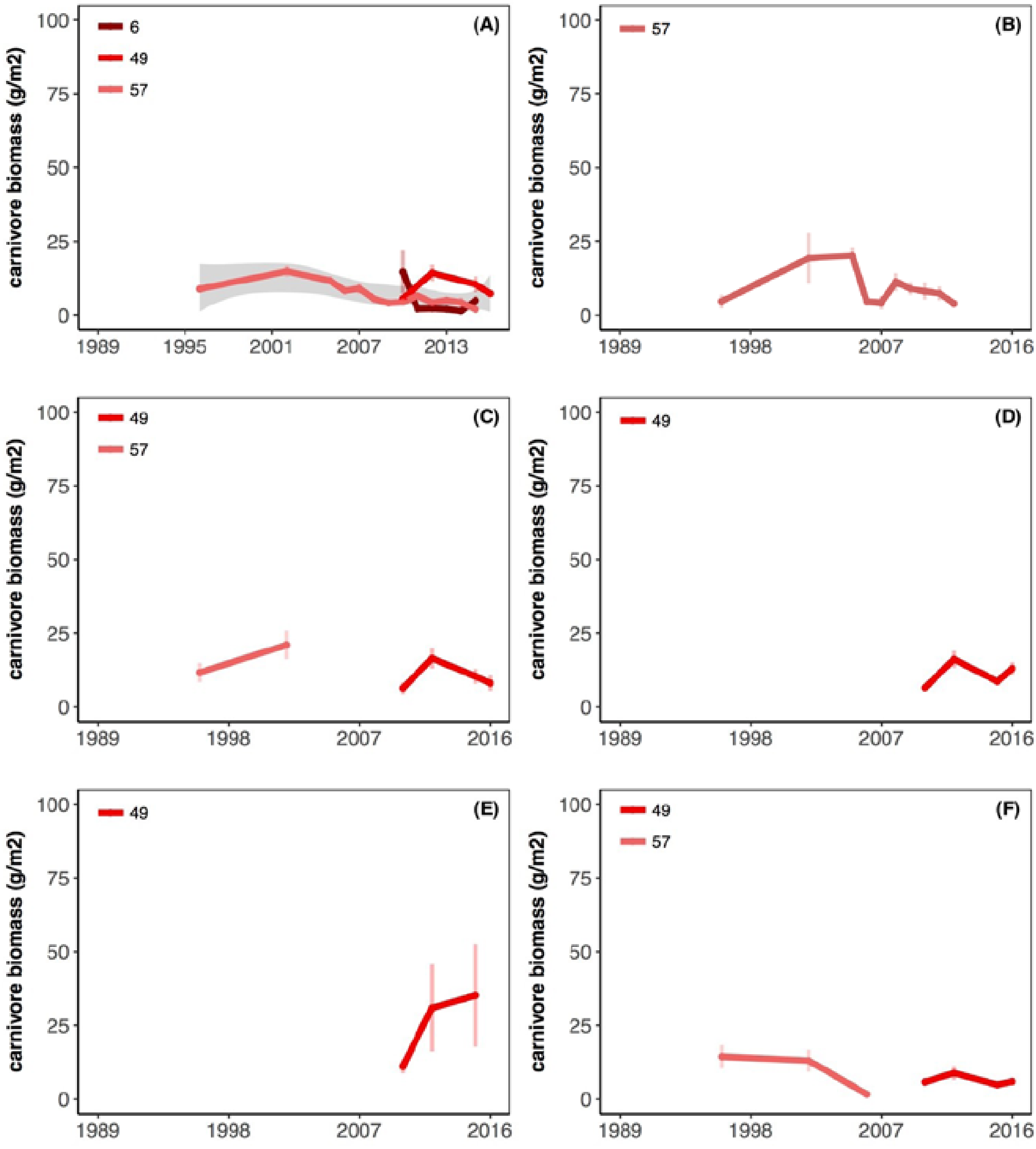


FIGURE 2.4

Average percent of herbivore fish biomass in American Samoa: (A) Contribution of each dataset, all islands combined; (B) Aunuu; (C) Ofu/Olosega; (D) Rose; (E) Swains; (F) Tau; (G) Tutuila. The grey area represents the average loess trend in herbivore fish biomass when several datasets are combined.



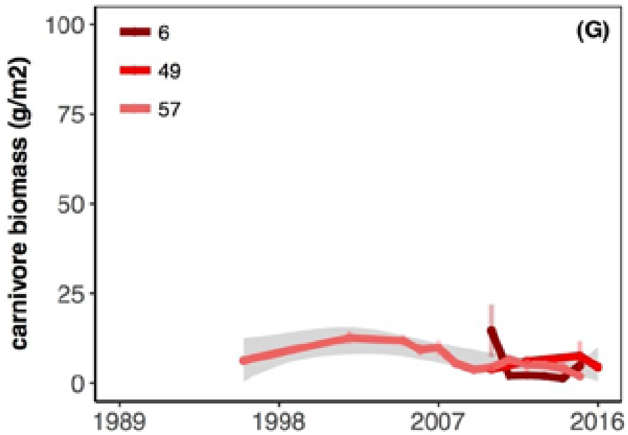
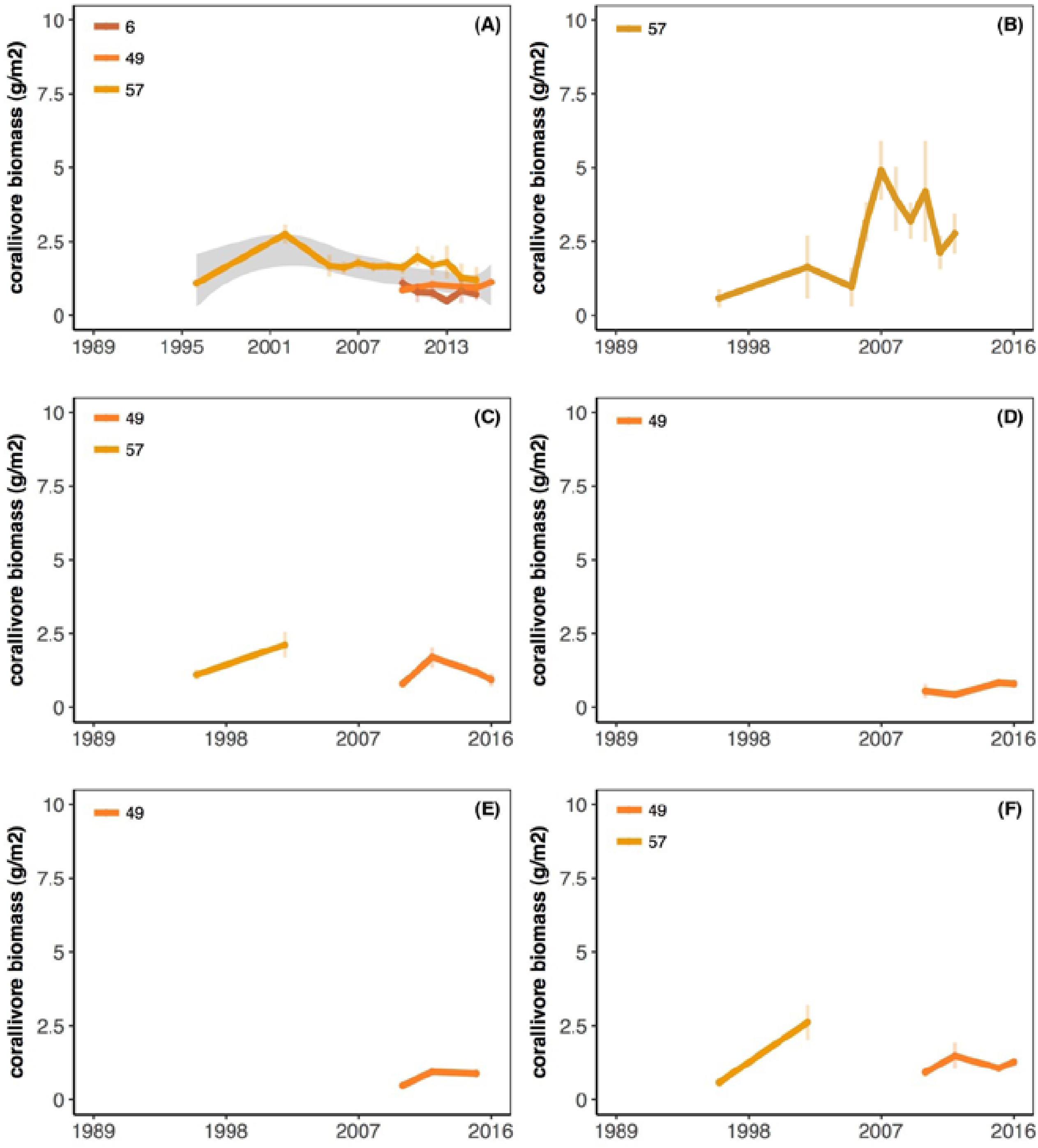


FIGURE 2.5
Average percent of carnivore fish biomass in American Samoa: (A) Contribution of each dataset, all islands combined; (B) Aunuu; (C) Ofu/Olosega; (D) Rose; (E) Swains; (F) Tau; (G) Tutuila. The grey area represents the average loess trend in carnivore fish biomass when several datasets are combined.



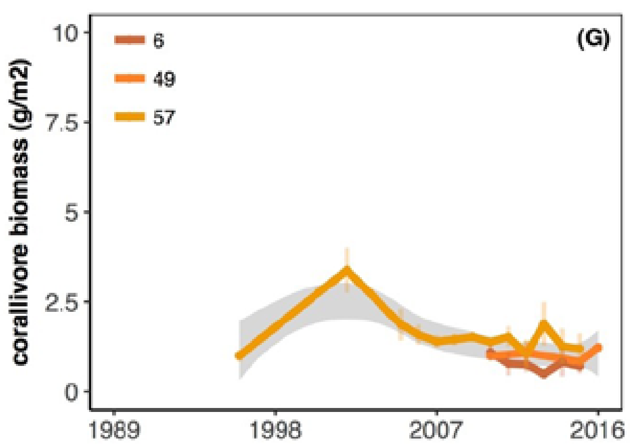


FIGURE 2.6
Average percent of corallivore fish biomass in American Samoa: (A) Contribution of each dataset, all islands combined; (B) Aunuu; (C) Ofu/Olosega; (D) Rose; (E) Swains; (F) Tau; (G) Tutuila. The grey area represents the average loess trend in corallivore fish biomass when several datasets are combined.

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Commonwealth of the Northern Mariana Islands

Collaborators: David Benavente, Rodney Camacho, Marie Ferguson, Adel Heenan, Peter Houk, John Iguel, Lyza Johnston, Steven Johnson, Denise Perez, John Stamer, Bernardo Vargas-Angel and Ivor Williams

Geographic information

Maritime area: 1 823 000 km²	Reef area: 102 km²
Land area: 475 km²	Coastal length: 1 482 km
Number of islands: 14	Distance to nearest continent: 2 500 km of Asia
Island type: volcanic, coralline limestone	Island age: 5 million to 38 million years
Population: 55 070	Number of uninhabited islands: 4
Climate: tropical marine	Major wind regime: Northeast trade winds
Total MPAs: 8	GDP's/CAP: $13 300

Overview

Since 1976, the Commonwealth of the Northern Mariana Islands (CNMI) has been a self-governed commonwealth in political union with the United States (USA), meaning it has a locally elected governor and legislature, but US federal laws apply throughout the commonwealth. The Northern Mariana Islands consists in 22 islands and islets. In 14 islands, most of the population is urban and is concentrated at the southern end of the archipelago, on the main islands of Saipan, Rota and Tinian. Geologically, the islands can be divided into two groups: a southern and a northern island arc region with the southern islands are uplifted limestone, whereas the northern are volcanic.

The CNMI's economy relies on the tourism sector, which employs more than a quarter of the CNMI's inhabitants (e.g. reef tourism on Saipan is valued at $42.3 million per year).

Timeline of major events

1981	Volcanic eruption on Pagan damaged adjacent coral reefs
1986	Typhoon Kim on Saipan and Tinian
1994	Bleaching event; Sasanhaya Bay Fish Reserve (SBFR) established on Rota (Rota Local Law No. 9-2)
1995	Bleaching event
1996	Laolao Bay Sea Cucumber Sanctuary and Lighthouse Reef Trochus Sanctuary established
1997	Bleaching event
1998	Ten year "moratorium on the harvesting of seaweed, sea grass, and sea cucumber in the Commonwealth waters" (CNMI Public Law No. 11-63)
2000	The Managaha Marine Conservation Area (MMCA) on Saipan; the LaoLao Bay Sea Cucumber Sanctuary and the Lighthouse Reef Trochus Sanctuary in Saipan were adopted into the CNMI Administrative Code
2001	Bleaching event; Bird Island Sanctuary and Forbidden Island Sanctuary are established in Saipan
2002	Typhoon Pongsona on Rota, Tinian and Saipan
2003	Volcanic eruption on Anatahan covered surrounding reefs with a layer of ash; bleaching event; restrictions on the use of gill nets, drag nets and surround nets; Crown of Thorns Starfish outbreak
2006	Micronesia Challenge Initiated
2007	Tinian Marine Reserve designated as a no-take marine sanctuary
2010	The CNMI Coral Reef Initiative listed 4 management priorities for coral reef
2014	Bleaching event
2015	Typhoon Soudelor on Saipan
2016	Tinian Marine Reserve loses sanctuary status; Fish kill event on Saipan
2017	Bleaching event

Maps of individual surveys of substrate

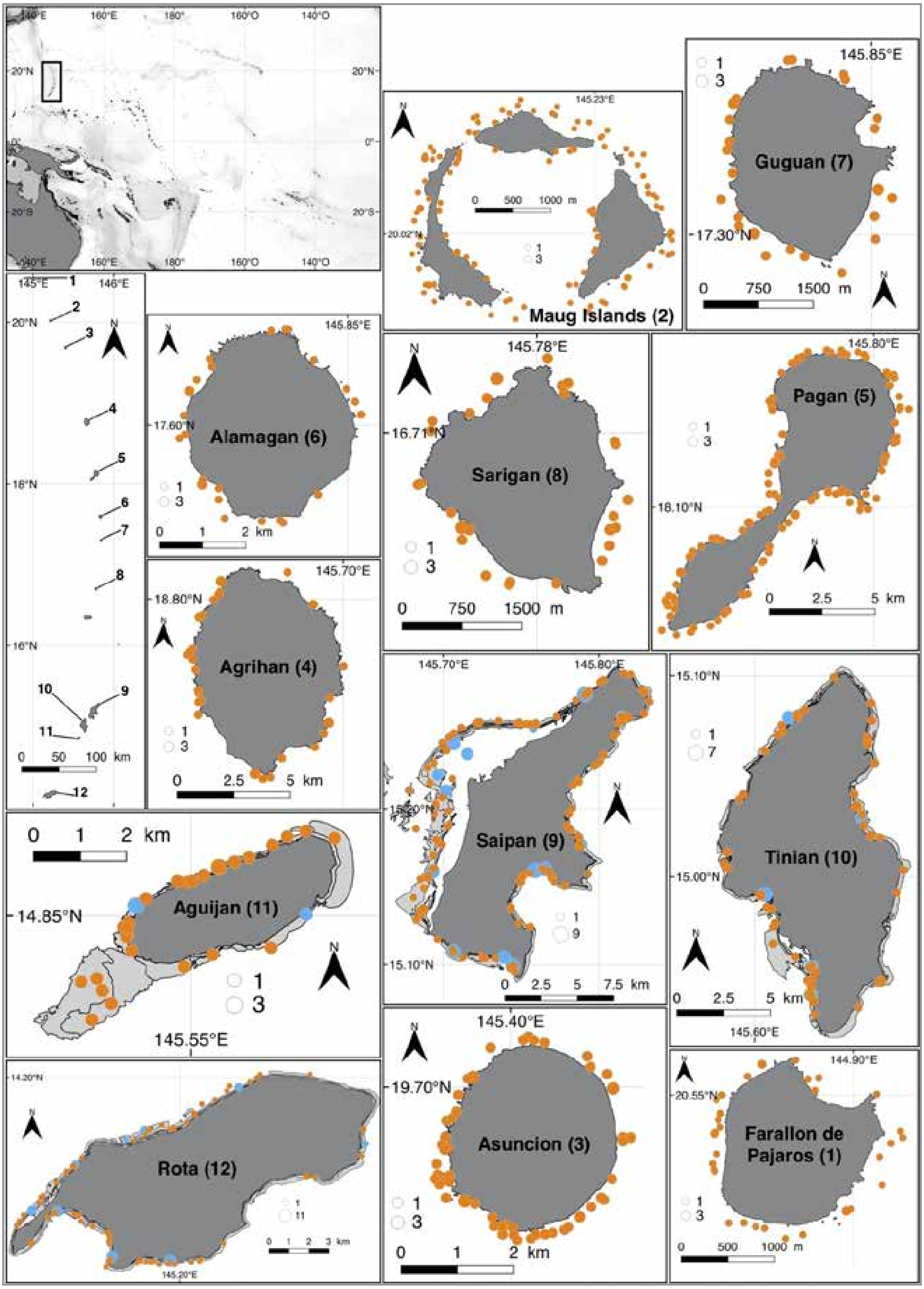


FIGURE 1

Map of the Commonwealth of the Northern Mariana Islands. Each color represents a different dataset (orange: dataset n°43, blue: dataset n°28). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from the Commonwealth of the Northern Mariana Islands used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
28	CNMI Bureau of Environmental and Coastal Quality, Division of Coastal Resources Management, CNMI	2000 - 2014	14	X	X	
29	CNMI Bureau of Environmental and Coastal Quality, Division of Coastal Resources Management, CNMI	2011 - 2014	3			X
40	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2005 – 2012	4	X	X	
43	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2011 - 2014	2	X	X	
49	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2007 - 2015	3			X

Trends

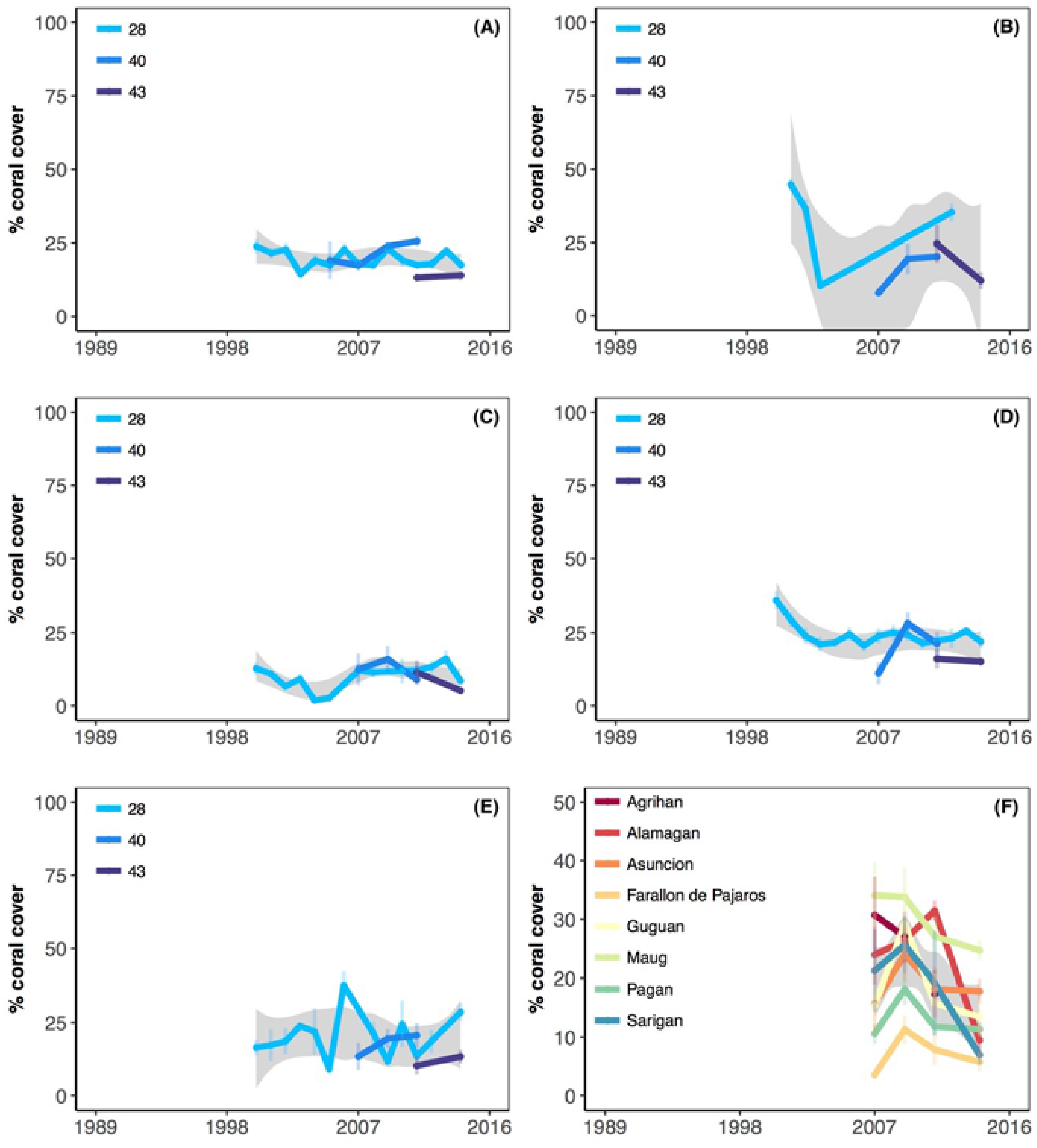


FIGURE 2.1

Average percent of live hard coral cover in the CNMI: (A) Contribution of each dataset, all islands com-bined; (B) Aguijan; (C) Rota; (D) Saipan; (E) Tinian; (F) for the Northern Mariana Islands. The grey area represents the average loess trend in coral cover when several datasets and islands are combined.

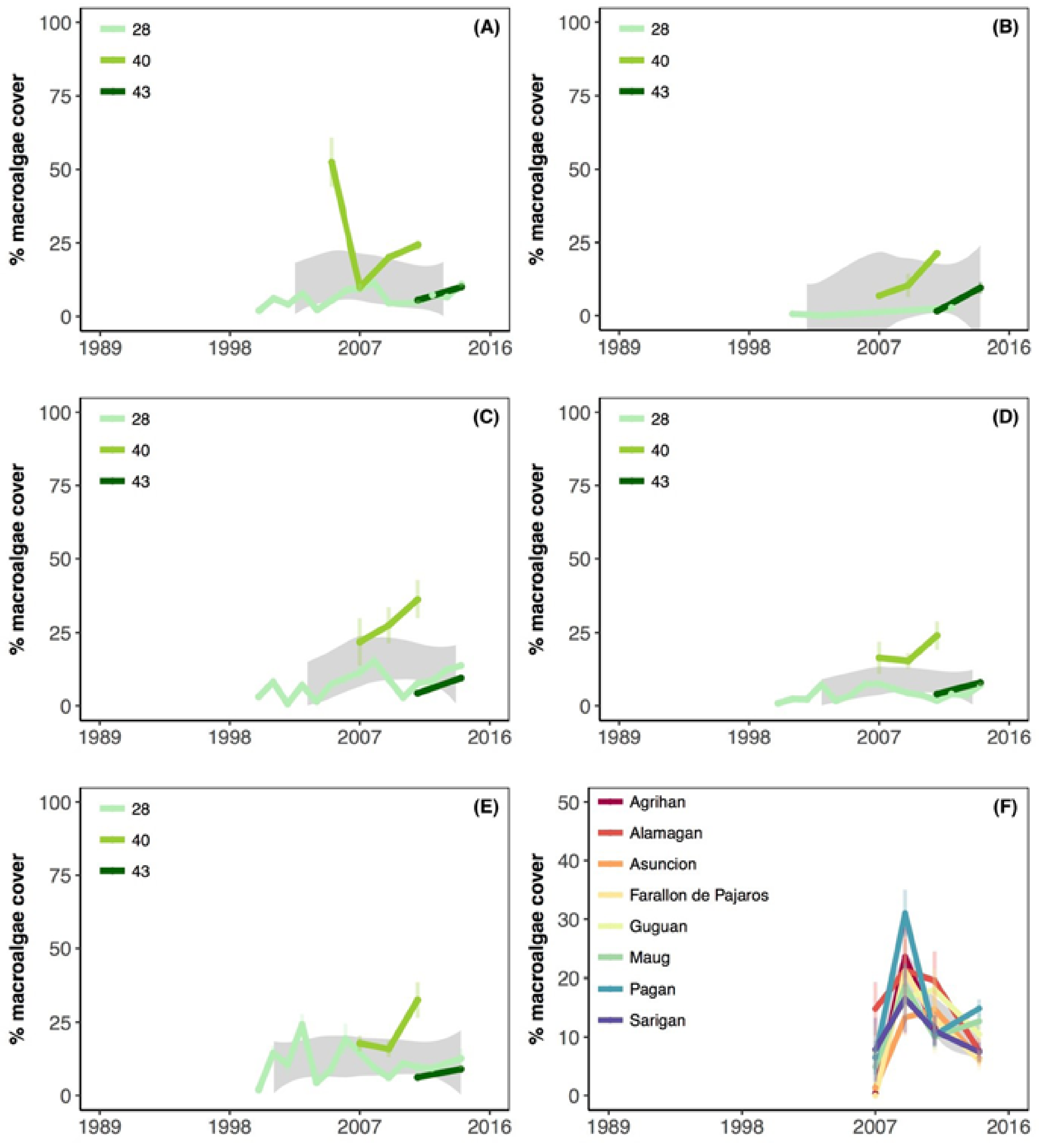
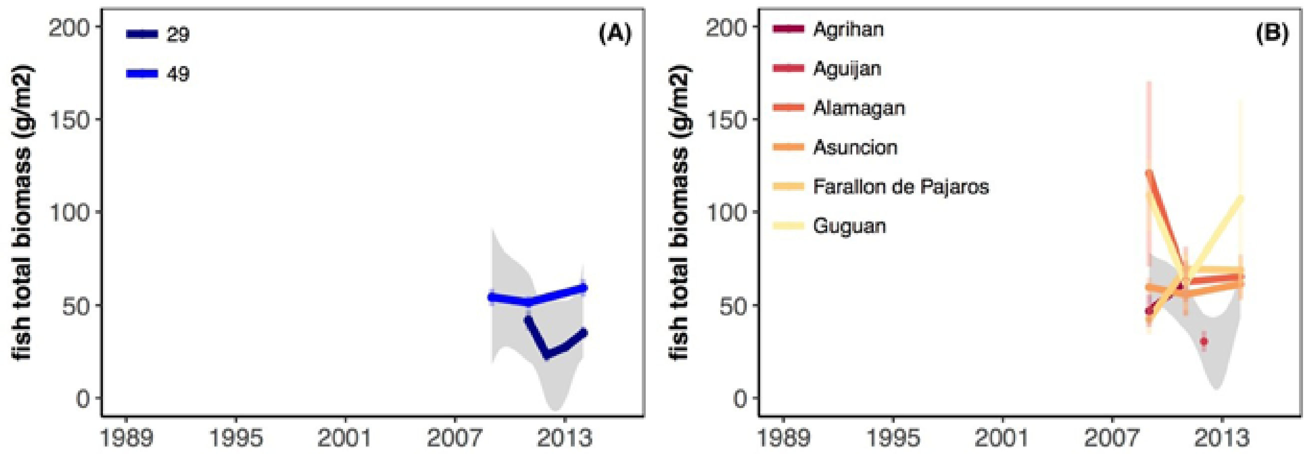


FIGURE 2.2
Average percent cover of macroalgae in the CNMI: (A) Contribution of each dataset, all islands combined; (B) Aguijan; (C) Rota; (D) Saipan; (E) Tinian; (F) for the Northern Mariana Islands. The grey area represents the average loess trend in macroalgae cover when several datasets and islands are combined.



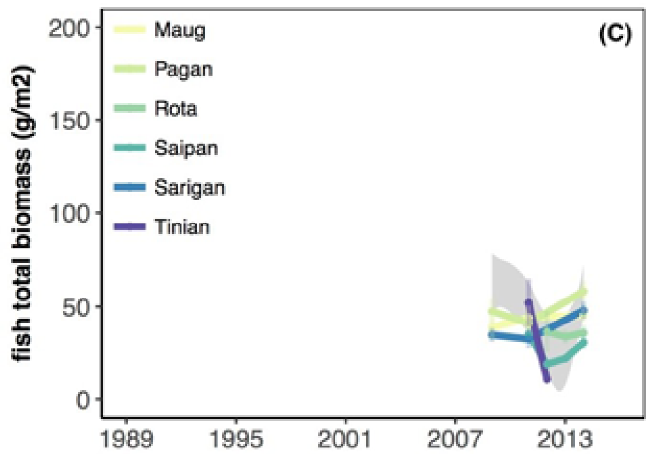
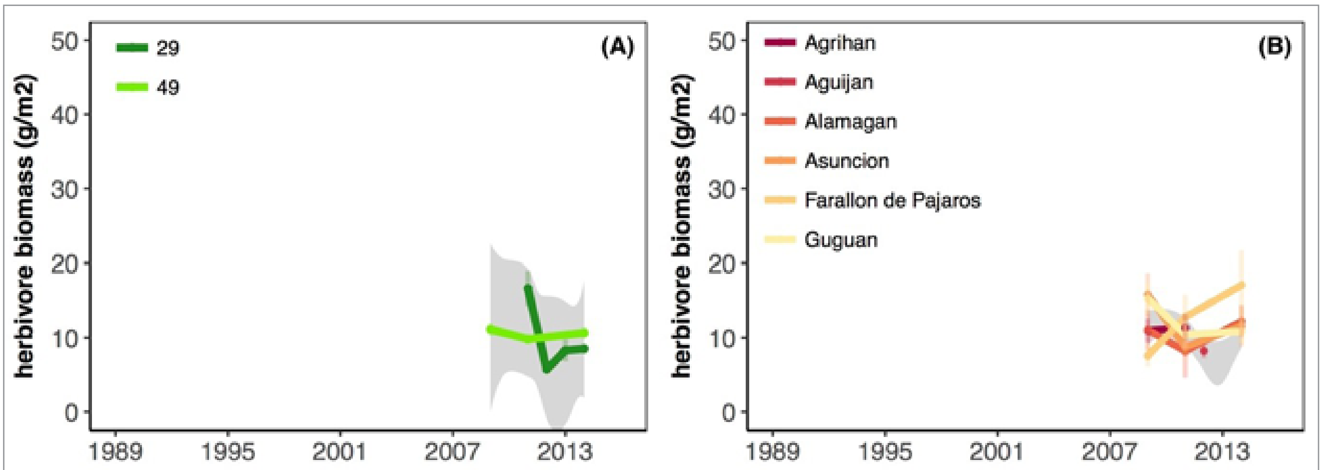


FIGURE 2.3
Average total fish biomass in the CNMI: (A) Contribution of each dataset, all islands combined; (B) Agrihan, Aguijan, Alamagan, Asuncion, Farallon de Pajaros, Guguan; (C) Maug, Pagan, Rota, Saipan, Sarigan, Tinian. The grey area represents the average loess trend in total fish biomass when several datasets and islands are combined.



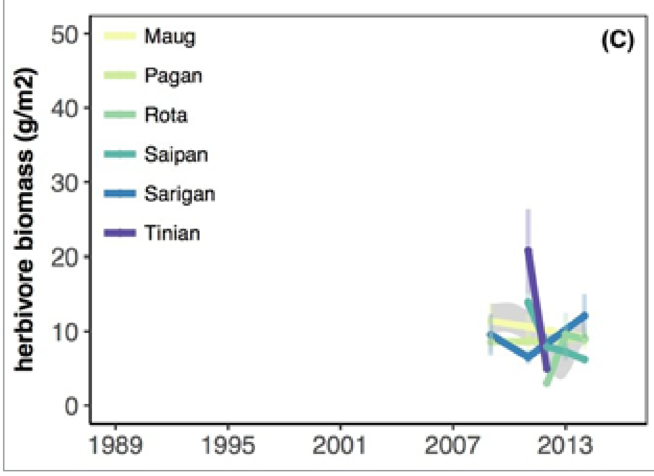
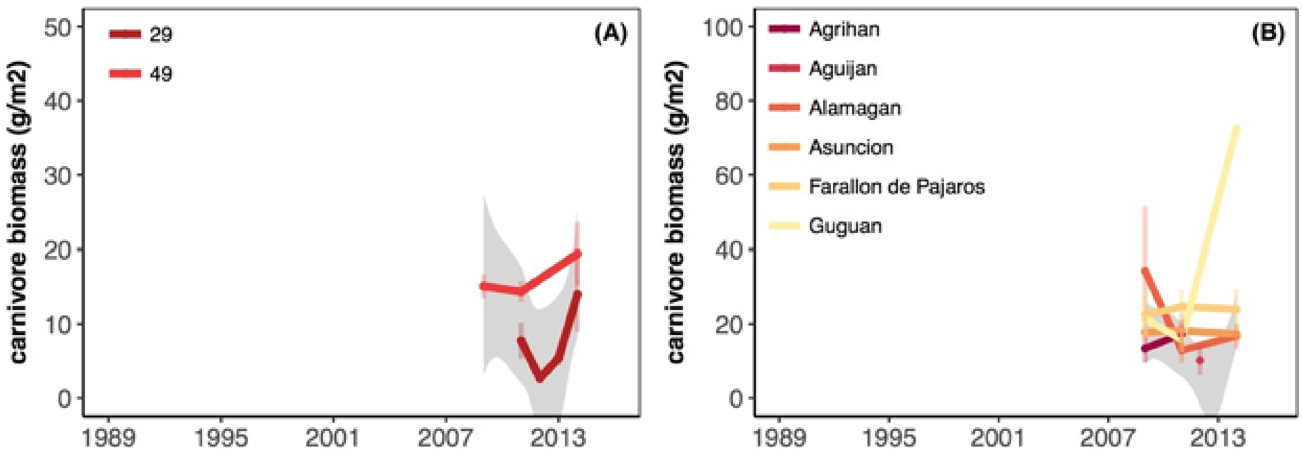


FIGURE 2.4
Average herbivore fish biomass in the CNMI: (A) Contribution of each dataset, all islands combined; (B) Agrihan, Aguijan, Alamagan, Asuncion, Farallon de Pajaros, Guguan; (C) Maug, Pagan, Rota, Saipan, Sarigan, Tinian. The grey area represents the average loess trend in herbivore fish biomass when several datasets and islands are com-bined.



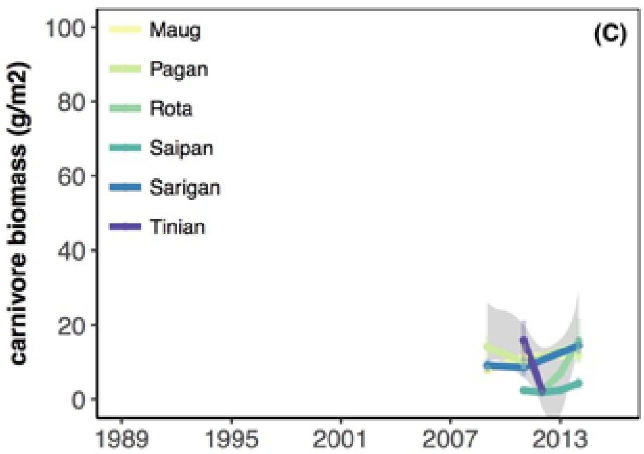
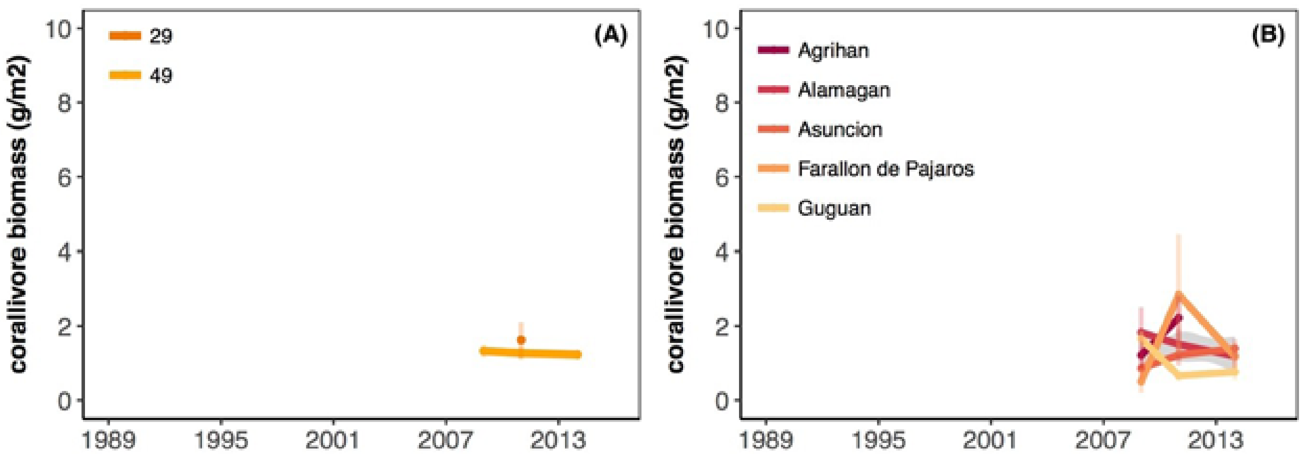


FIGURE 2.5
Average carnivore fish biomass in the CNMI: (A) Contribution of each dataset, all islands combined; (B) Agrihan, Aguijan, Alamagan, Asuncion, Farallon de Pajaros, Guguan; (C) Maug, Pagan, Rota, Saipan, Sarigan, Tinian. The grey area represents the average loess trend in carnivore fish biomass when several datasets and is-lands are combined.



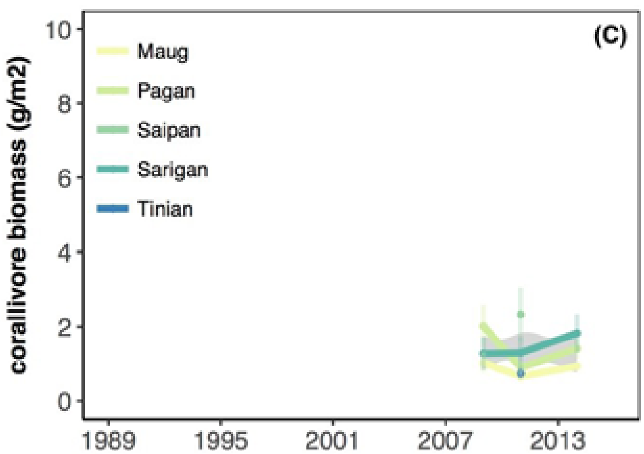


FIGURE 2.6
Average corallivore fish biomass in the CNMI: (A) Contribution of each dataset, all islands combined; (B) Agrihan, Aguijan, Alamagan, Asuncion, Farallon de Pajaros, Guguan; (C) Maug, Pagan, Rota, Saipan, Sarigan, Tinian. The grey area represents the average loess trend in corallivore fish biomass when several datasets and islands are combined.

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Cook Islands

Collaborators: Hilary Ayrton, Yannick Chancerelle, Ngere George,
Ben Ponia, Serge Planes and Gilles Siu

Geographic information

Maritime area: 1 830 000 km²	Reef area: 220 km²
Land area: 237 km²	Coastal length: 120 km
Number of islands: 15	Distance to nearest continent: 5 000 km of Australia
Island type: volcanic and atoll	Island age: 7 million to 60 million years
Population: 21 000	Number of uninhabited islands: 3
Climate: tropical	Major wind regime: Southeast trade winds
Total MPAs: 24	GDP's/CAP: $15 000

Overview

The Cook Islands are a nation with a free association with New Zealand. Foreign and defence affairs of the Cook Islands are the responsibility of New Zealand, and Cook islanders are citizens of New Zealand. The Cook Islands are divided into two distinct geographic groups: a northern group of 5 atolls, and a southern group of 9 islands which includes the main volcanic high island of Rarotonga, the center of government and commerce, and comprises 28% of the total land area of the Cook Islands. Tourism (centered on Rarotonga and Aitutaki) and perliculture (centered principally on Manihiki) are the main economic activities in the Cook Islands. Marine life is composed of about 600 species of fish, 178 species of hard corals and more than 1500 species of invertebrates.

Timeline of major events

1991	Bleaching event
1994	Bleaching event
1995-1996	COTS outbreaks
1997	Cyclone Martin in Manihiki (Northern Group) with high intensity
1998	The Aronga Mana of Rarotonga and Aitutaki established 5 Locally Managed Marine Areas called ra'ui
2001	COTS outbreaks
2005	Cyclone Menna, Nancy, Olaf, Percy, Rae (five cyclones hit the Southern Cook Islands from Febrary to March 2005)
2010	Cyclone Pat in Aitutaki
2013-2014	High COTS outbreaks
2015-2016	High bleaching event on all Northern Group atolls (Penrhyn, Pukapuka, Nassau, Manihiki, Rakahanga)

Maps of individual surveys of substrate

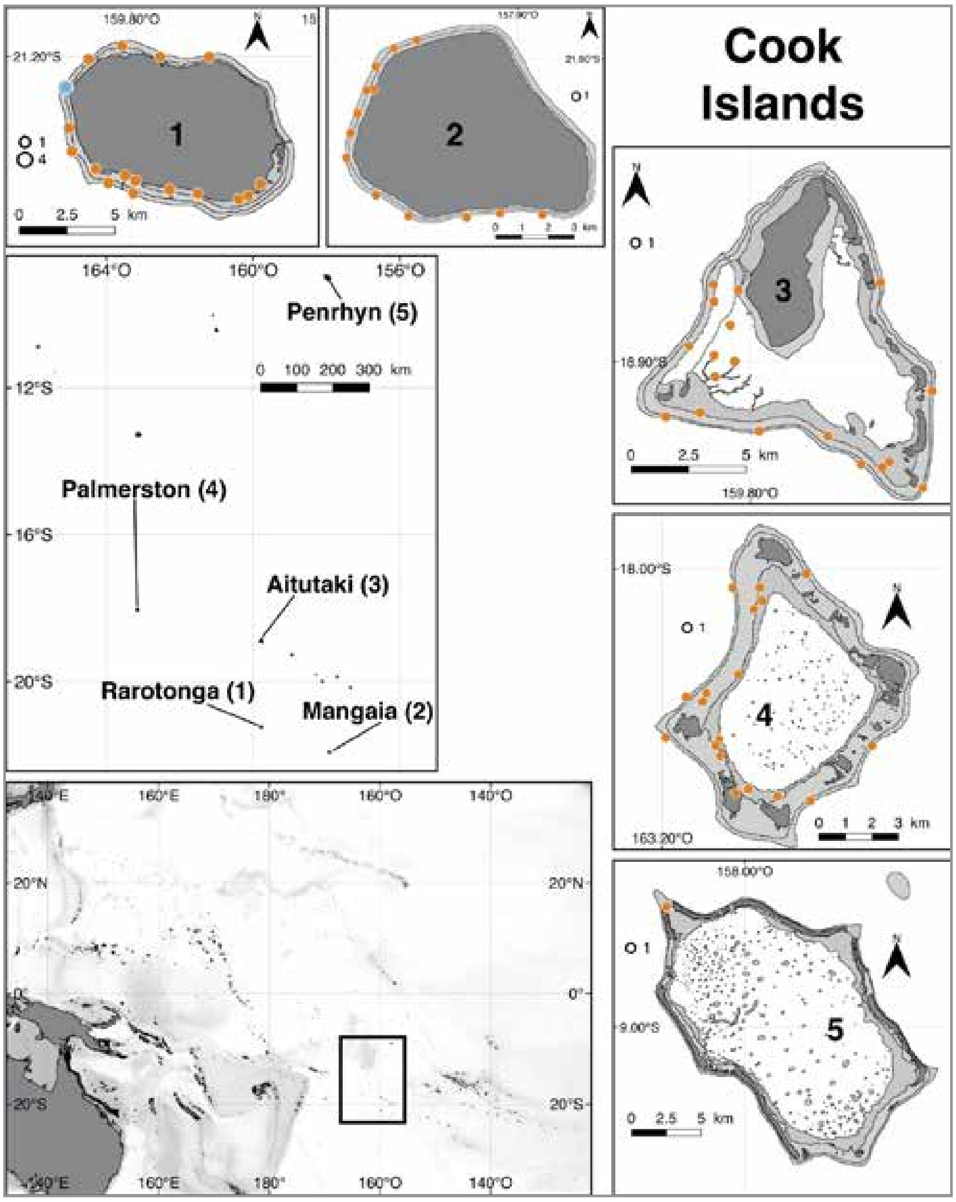

FIGURE 1

Map of the Cook Islands. Each colour represents a different dataset (orange: dataset n°62, blue: dataset n°44). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from the Cook Islands used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
44	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	1993 - 2016	4	X		
45	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	2004 - 2016	4			X
62	Ministry of Marine Resources – Cook Islands	2007 - 2015	1	X	X	
66	Ministry of Marine Resources – Cook Islands	1997 - 2000	1			X

Trends

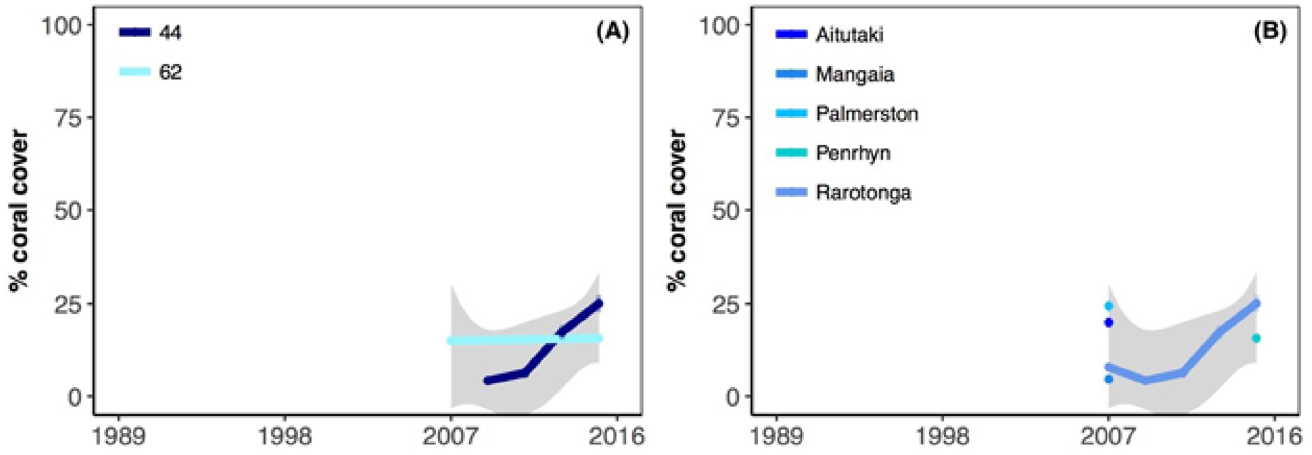

FIGURE 2.1
Average percent of live hard coral cover in the Cook Islands: (A) Contribution of each dataset, all islands combined; (B) Average percent of live hard coral cover in Aitutaki, Mangaia, Palmerston, Penrhyn and Rarotonga. The grey area represents the average loess trend in coral cover for all islands combined.

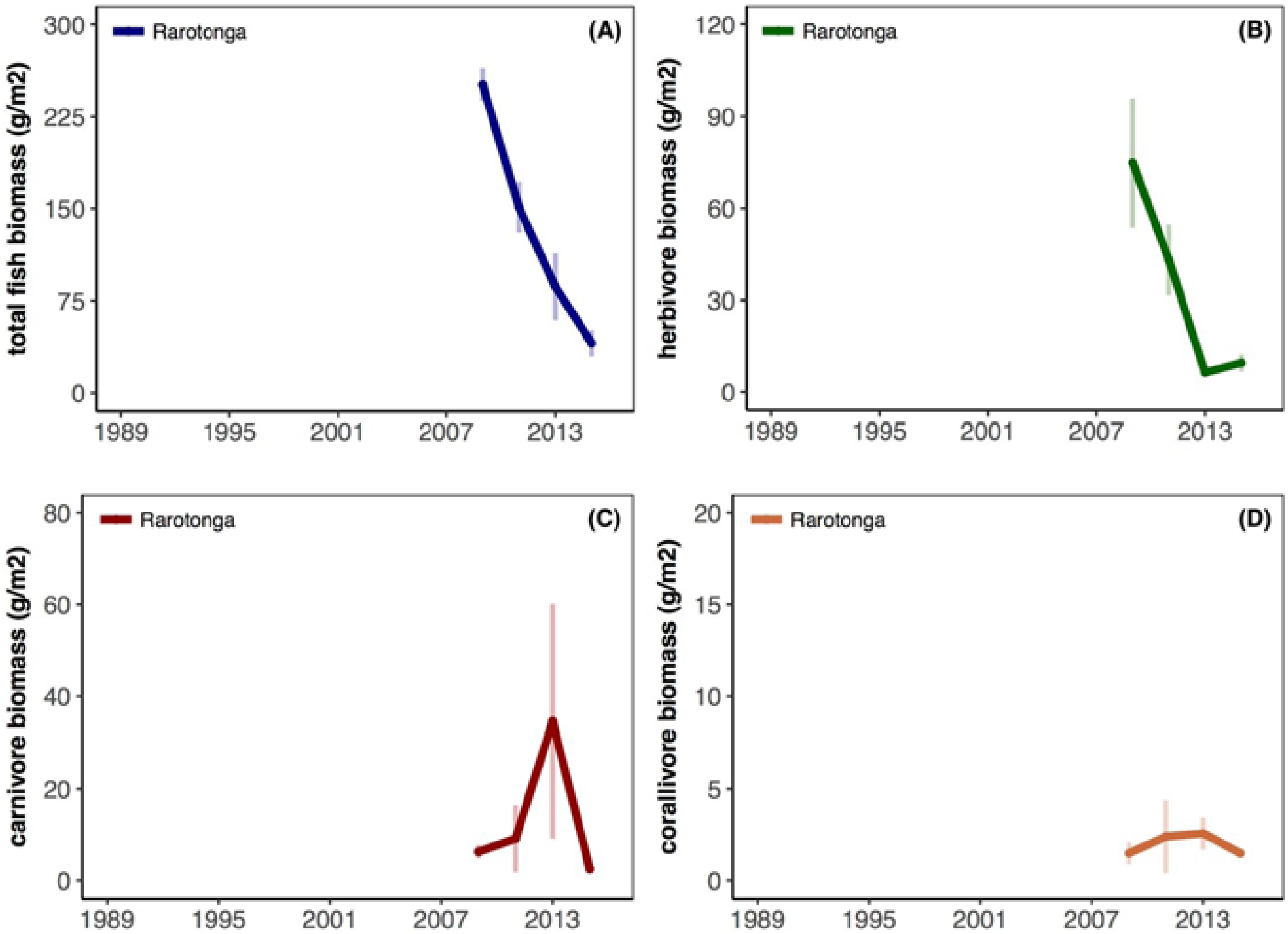

FIGURE 2.2
Average fish biomass in the Cook Islands (A) Total; (B) Herbivore; (C) Carnivore; (D) Corallivore.

General Literature

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Federated States of Micronesia

Collaborators: Jessica DeBlieck, Curtis Graham, Michael Gidibmaa, Peter Houk, Eugene Joseph, Kesdy Ladore, Selino Maxin, Marston Luckymis, Jesse Lukan, Joe Nam, Osamu Nedlic, Steven Palik, Lorenzo Stephen, Chimres Teresio and Anthony Yalon

Geographic information

Maritime area: 2 980 000 km²	**Reef area: 14 517 km²**
Land area: 702 km²	**Coastal length: 6112 km**
Number of islands: 607	**Distance to nearest continent: 2500 to Asia**
Island type: volcanic, atoll	**Island age: Chuuk (14.8 to 4.3 Ma), Pohnpei (8.7 to 0.92 Ma), Kosrae (2 to 1 Ma)**
Population: 104 460	**Number of uninhabited islands: > 542**
Climate: tropical	**Major wind regime: Northeast trade winds**
Total MPAs: > 47	**GDP's/CAP: $2 300**

Overview

Since 1986, the Federated States of Micronesia (FSM) has been an independent state that maintains close ties with the United States of America under the Compact of Free Association (COFA) which provides joint access, services and defense arrangements. The FSM is divided into 4 states: Yap, Chuuk, Pohnpei, and Kosrae. Each group has its own unique language, culture, local government, and traditional systems for managing natural resources, and population are largely reliant coral reefs and marine resources. The economic activity consists primarily of subsistence farming and fishing. Tourism, essentially based in Chuuk, is not a major economic activity in the FSM.

Timeline of major events

1994	COTS outbreaks essentially in western Kosrae
2004	Bleaching event; Typhoon Sudal passed by Chuuk and directly hit Yap
2006	The FSM is a signatory to the Micronesia Challenge which commits the FSM to effectively conserving 30% of marine resources and 20% of terrestrial resources by 2020
2009	Major COTS outbreak starts Pohnpei, eastern FSM, and moves westward to Chuuk and Yap across the next year. Reefs in Yap show interesting trend where MPA's were less impacted by COTS then fished reefs
2013	Moderate bleaching event in Kosrae, FSM, but the rest of FSM moderately impacted

Maps of individual surveys of substrate

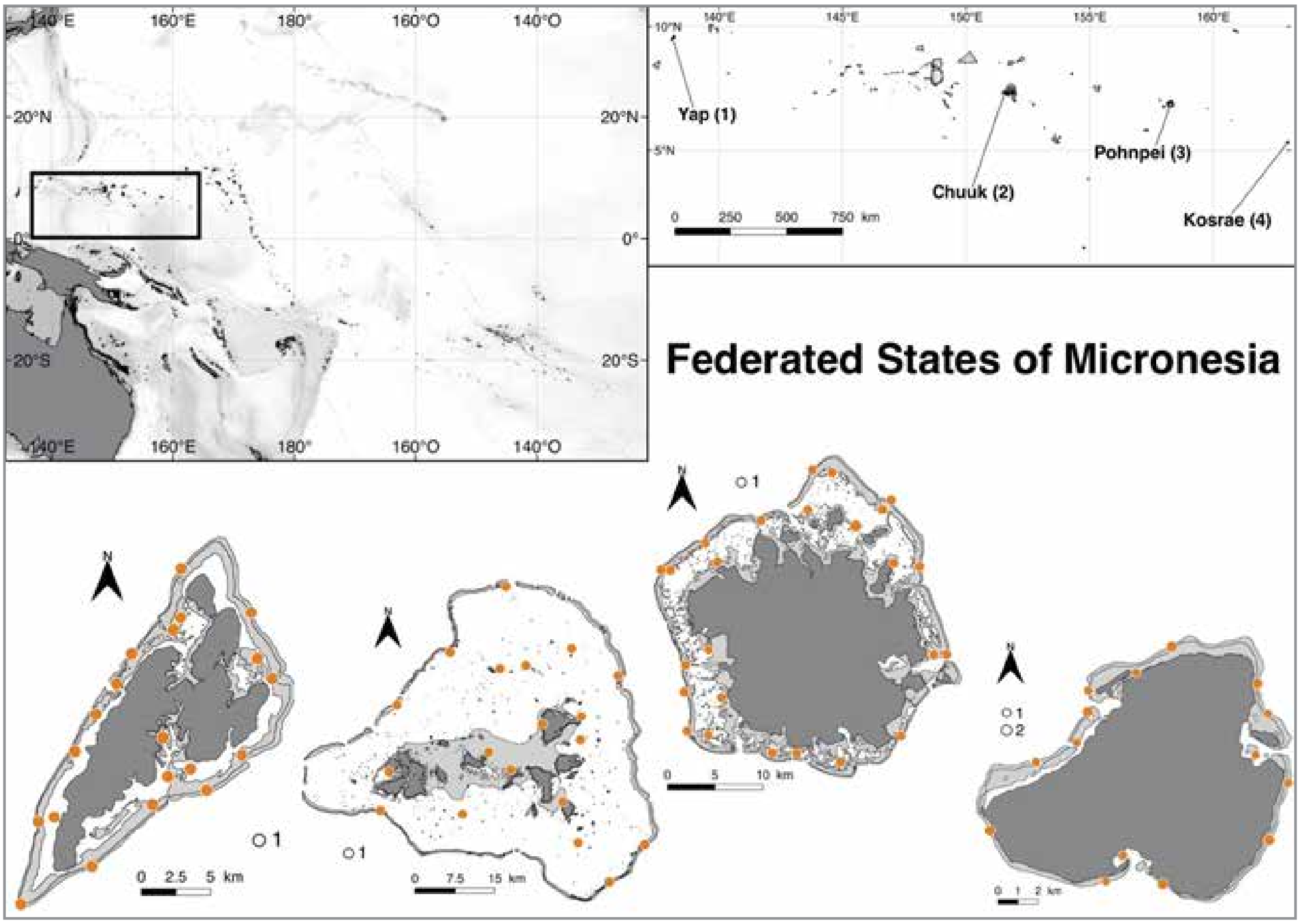

FIGURE 1
Map of the Federated States of Micronesia. Each colour represents a different dataset (orange: dataset n°18). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from the Federated States of Micronesia used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
18	Micronesia Challenge – University of Guam	2009 - 2014	3	X	X	
19	Micronesia Challenge – University of Guam	2011 - 2014	2			X

Trends

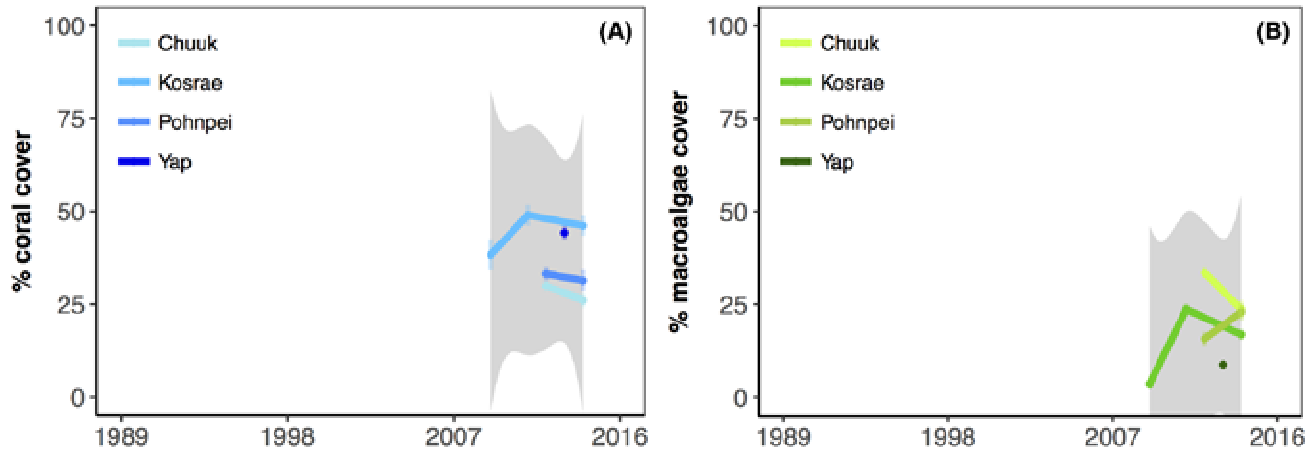

FIGURE 2.1
Average percent of (A) live hard coral cover and (B) macroalgae cover for Chuuck, Kosrae, Pohnpei and Yap in the Federated States of Micronesia. The grey area represents the average loess trend in coral cover for all datasets of this country.

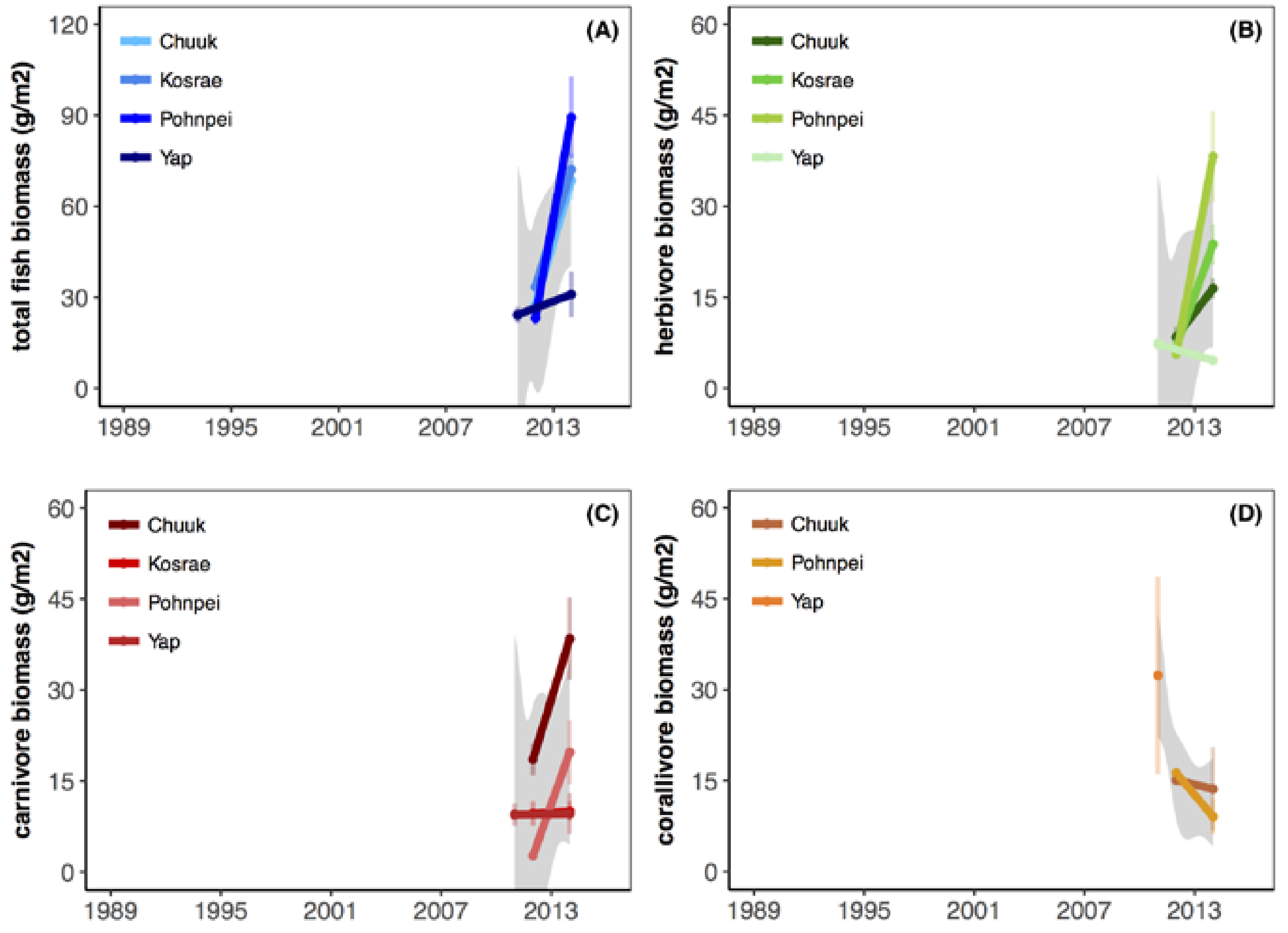

FIGURE 2.2
Average fish biomass for Chuuck, Kosrae, Pohnpei and Yap in the Federated States of Micronesia: (A) Total; (B) Herbivore; (C) Carnivore; (D) Corallivore. The grey area represents the average loess trend in fish biomass for all datasets of this country.

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Republic of Fiji

Collaborators: Bruce Carlson, Edward Lovell, Antoine De Ramon N'Yeurt, Helen Sykes

Geographic information	
Maritime area: 1 055 000 km²	Reef area: 6 704 km²
Land area: 18 270 km²	Coastal length: 1 129 km
Number of islands: 332 islands and 522 islets	Distance to nearest continent: 2 700 km of Australia
Island type: volcanic, coral, limestone	Island age (oldest/newest): volcanic activity starting around 150 million years ago
Population: 909 389	Number of uninhabited islands: 106
Climate: Tropical marine	Major wind regime: Moderate southeast trade winds
Total MPAs: over 500 (466 LMMAs, 50+ Tourism MPAs)	GDP/CAP: USD $5 411

Overview

Fiji became independant from the United Kingdom on 10th October 1970 and declared itself a Republic on 7th October 1987.

Over half the population is rural with many communities relying on small-scale commercial and subsistence fishing. About 75% of the dietary protein is sourced from the ocean.

Tourism is the major source of foreign income, with most tourist activity concentrated on the beaches and reefs of the coast of the main islands and smaller adjacent islands.

Reef biodiversity is high, with at least 422 taxa of marine algae, 342 species of hard corals, 253 species of marine molluscs and 1075 recorded reef-associated fish species. Fiji also has mangrove forests and seagrass beds, with 8 species of mangrove and 6 species of seagrass.

Timeline of major events

1997	Start of formal marine protection: first Fiji Locally Managed Marine Areas (FLMMA) sites, and Namena Marine Reserve
2000	Large-scale bleaching event followed by coralline lethal orange disease (CLOD), and crown of thorns star (COTS) outbreak
2001	Cyclone Paula (category 4)
2002	Bleaching event
2004	Cyclone Ivy (category 4)
2005-2006	COTS outbreaks, minor localised bleaching event
2007	White syndrome disease first recorded
2008	FLMMA reaches 150 sites
2009	Catastrophic flooding at Nadi; freshwater affected shallow offshore reefs
2011	Start of Vatu-i-Ra Conservation Park
2012	FLMMA reaches 400 sites
2014-2016	Minor localised bleaching events in shallow waters (<5m deep)
2016	Cyclone Winston (category 5)
2016	Establishment of the Oceania Regional Acanthaster Network (OREANET) to monitor COTs distribution and outbreaks in Fiji

Maps of individual surveys of substrate

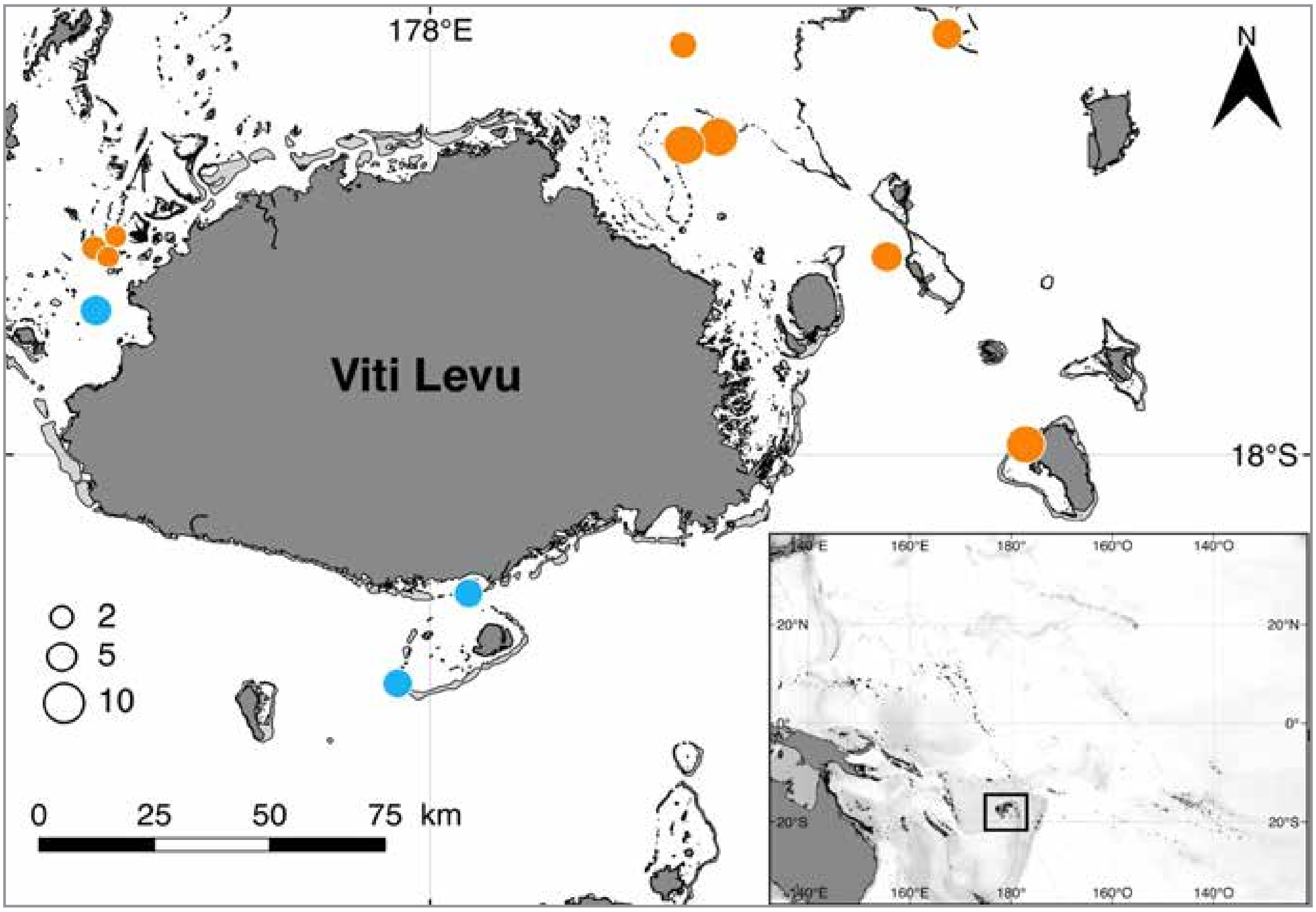

FIGURE 1
Map of the FIji. Each colour represents a different dataset (orange: dataset n°52; blue: dataset n°20). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from Fiji used in the report. Dataset represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
20	Bruce Carlson – Georgia Aquarium, USA	2000 - 2010	5	X	X	
52	FCRMN – Marine Ecology, Suva, Fiji	2000 - 2013	14	X	X	
53	FCRMN – Marine Ecology, Suva, Fiji	2002 - 2013	12			X

Trends

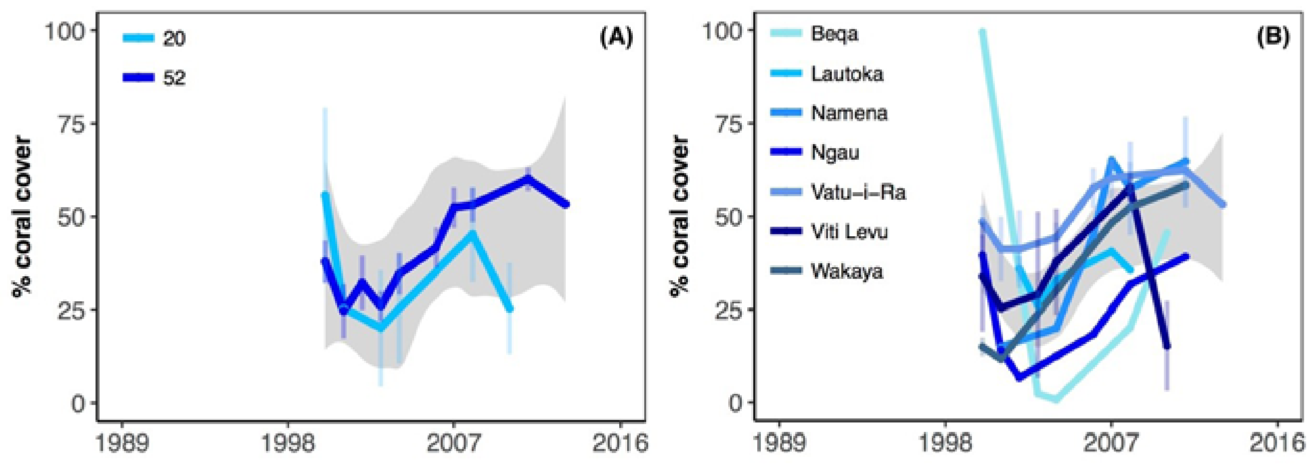

FIGURE 2.1
Average percent cover of live hard coral in Fiji: (A) Contribution of each dataset, all islands combined; (B) For Beqa, Lautoka, Namena, Ngau, Vatu-i-ra, Viti Levu, Wakaya. The grey area represents the average loess trend when all datasets or all islands are combined

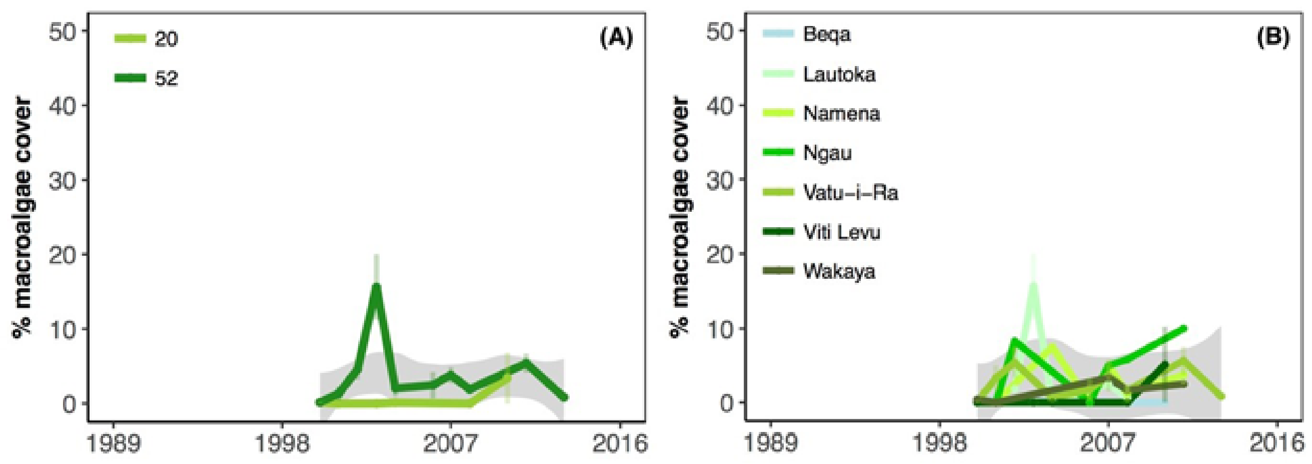

FIGURE 2.2
Average percent cover of macroalgae in Fiji: (A) Contribution of each dataset, all islands combined; (B) For Beqa, Lautoka, Namena, Ngau, Vatu-i-ra, Viti Levu, Wakaya. The grey area represents the average loess trend when all datasets or all islands are combined

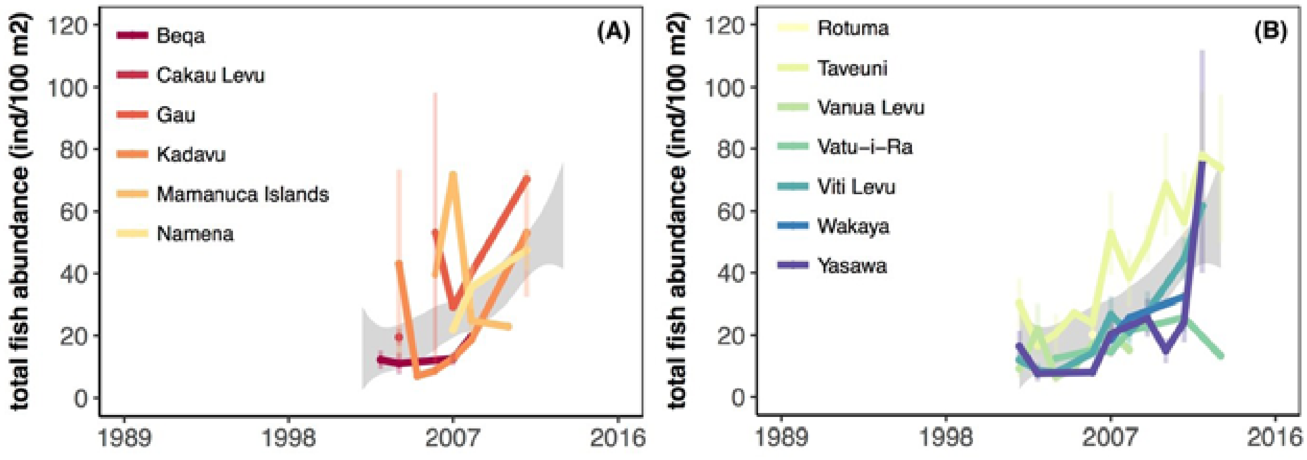

FIGURE 2.3
Total fish abundance in Fiji: (A) Beqa, Cakau Levu, Gau, Kadavu, Mamanuca Islands, Namena; (B) Rituma, Taveuni, Vanua Levu, Vatu-i-ra, Viti Levu, Wakaya, Yasawa. The grey area represents the average loess trend when all datasets or all islands are combined

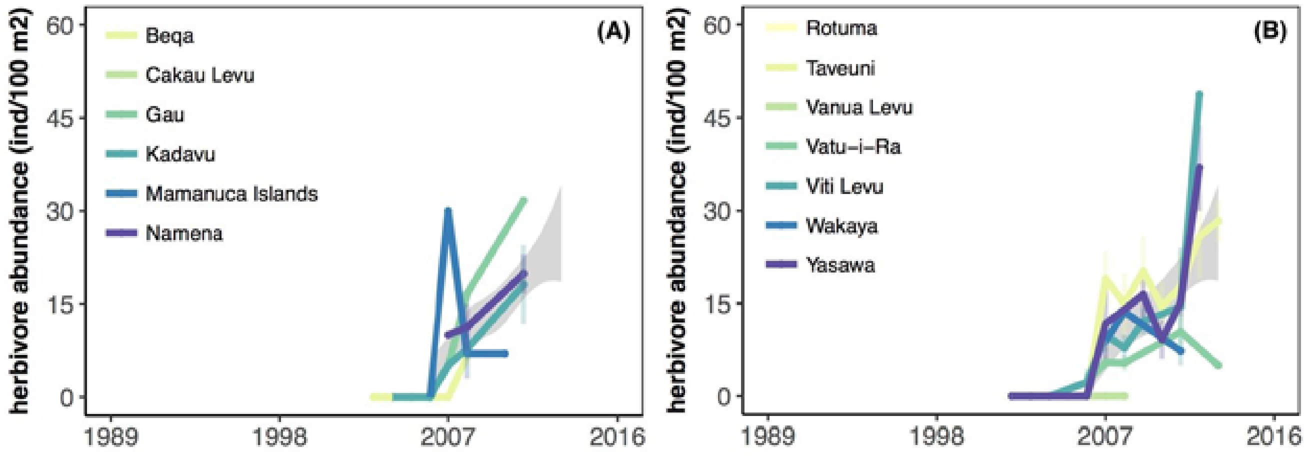

FIGURE 2.4
Herbivore fish abundance in Fiji: (A) Beqa, Cakau Levu, Gau, Kadavu, Mamanuca Islands, Namena; (B) Rituma, Taveuni, Vanua Levu, Vatu-i-ra, Viti Levu, Wakaya, Yasawa. The grey area represents the average loess trend when all datasets or all islands are combined

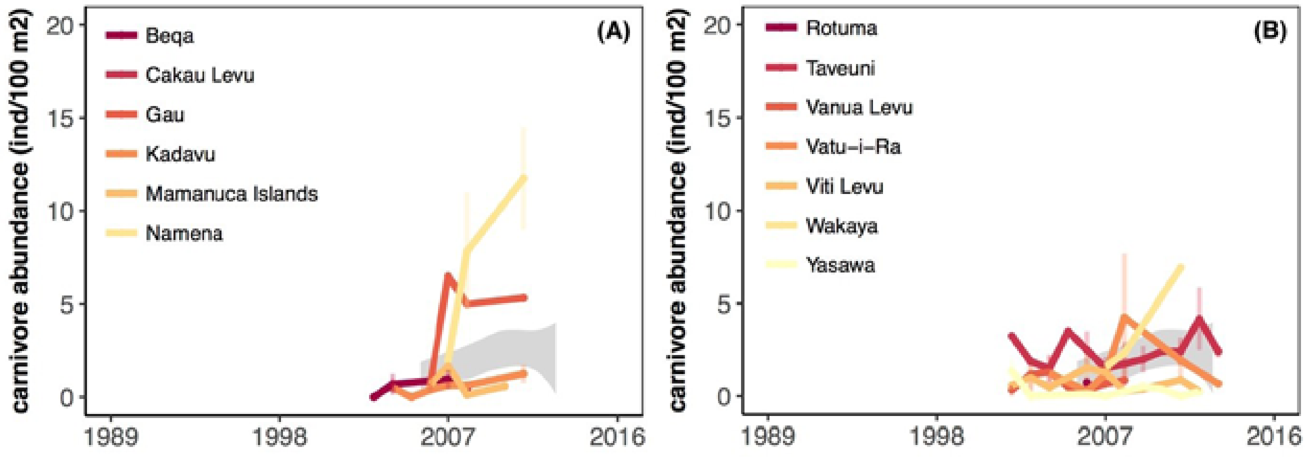

FIGURE 2.5
Carnivore fish abundance in Fiji: (A) Beqa, Cakau Levu, Gau, Kadavu, Mamanuca Islands, Namena; (B) Rituma, Taveuni, Vanua Levu, Vatu-i-ra, Viti Levu, Wakaya, Yasawa. The grey area represents the average loess trend when all datasets or all islands are combined

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The Fiji Coral Reef Monitoring network is supported in kind primarily by private sector tourism operations, without whom access to the sites would be impossible, and some of whom contribute monitoring data. We would particularly like to thank:

- Marine Ecology Consulting (Fiji) Ltd
- Resort Support (Fiji) Ltd
- Nai'a Fiji Liveaboard
- Taveuni Adventure Divers and Nakia Resort
- Waitabu Marine Park, Taveuni
- Matava Resort, Kadavu
- Jean-Michel Cousteau Resort, Fiji Islands
- Diveaway, Viti Levu
- Georgia Aquarium
- Waikiki Aquarium
- Aquarium Fish Fiji
- Walt Smith International
- The Henry Foundation

French Polynesia

Collaborators: Pauline Bosserelle, Yannick Chancerelle, René Galzin, Franck Lerouvreur, Vetea Liao, Thierry Lison-de-Loma, Charlotte Moritz, Serge Planes, and Gilles Siu

Geographic information

Maritime area: 5 030 000 km²	**Reef area: 12 000 km²**
Land area: 3 600 km²	**Coastal length: 2 525 km**
Number of islands: 118	**Distance to nearest continent: 6 000 km from Australia**
Island type: high volcanic, low coral atoll	**Island age: formation by hot spots. Tuamotu (40 to 63 Ma), Société (0 to 25 Ma), Australes (0 to 25 Ma) and Marquises (17 Ma)**
Population: 275 000	**Number of uninhabited islands: 51**
Climate: tropical marine-type wet	**Major wind regime: Southeast trade winds**
Total MPAs: 10	**GDP's/CAP: USD $20 100**

Overview

The 118 islands of French Polynesia are clustered into 5 main archipelagos. The majority of the population is concentrated in Tahiti and Moorea in the Society archipelago. The Gambier archipelago is 1600 km south southeast of Tahiti, the Marquesas islands are 1300 km northeast of Tahiti while the Austral archipelago is 650 km of Tahiti and the Tuamotu atolls are approximately 300 km east of Tahiti. French Polynesia is French overseas territory that has an autonomous status, except for tertiary education, police, justice, immigration, monetary policy, defense and foreign affairs. Consequently, environmental management is the responsibility of the territorial government. Fisheries, pearl culture, and tourism are the main economic activities of the territory.

Coral reefs of French Polynesia are at the edge of the Coral Triangle biodiversity gradient, and therefore have lower levels of biodiversity than reefs towards the west of the Pacific. There are about 346 species of algae, 170 species of corals, more than 2500 species of invertebrates (molluscs, sponges, etc.) and more than 1000 species of fish (800 recorded).

Timeline of major events

1969	Crown-of-thorns starfish (COTS) outbreaks in Tahiti and Raiatea
1970	COTS outbreak in Tahiti
1971	Two MPAs established in the western reaches of the Society Islands at the unin-habited Manuae (Scilly) and Motu One atolls. Four MPAs established in the Marquesas Archipelago at Eiao, Hatutaa, Motu One and Mohotane islands
1979-1986	COTS outbreak reported in Moorea, but likely other islands
1983	Bleaching event in Tahiti and Moorea
	Cyclone Nano in Marquesas and Tuamotus archipelagos
	Cyclone Orama in Tuamotu archipelago
	Cyclone Reva in Tuamotu archipelago
	Cyclone Veena in Tuamotu and East Tahiti
	Cyclone William in Tuamotu archipelago
1984	Bleaching event in Tahiti and Bora Bora
1986	Cyclone Sally in South Australs
1987	Bleaching event in Moorea, Tahiti and Manihi
1988	Cyclone Cilla in South Australs
1990	Cyclone Péni in South Australs
1991	Cyclone Wasa in Society and Australs archipelagos
	Bleaching event in Moorea, but likely other islands
1994	Bleaching event in Moorea, Tahiti, Tetiaroa and Rangiroa
1997	Bleaching event. Taiaro atoll in the Tuamotu was declared as a UNESCO 'Man and Biosphere' reserve and expanded to include seven atolls (including Taiaro) cover-ing 2564 km2; MPAs established for Moorea's reefs and lagoon (PGEM – Plan de Gestion de l'Espace Maritime de Moorea). There are five 'no-take' areas, and another three 'restricted' MPAs, in an area of 9.38 km².
	Cyclone Martin and Osea in Society archipelago, notably Bora Bora and Raiatea
1998	Bleaching event in Aratika, Nengo Nengo, Mataiva, Rangiroa, Tahiti, Takapoto, Tetiaroa and Tikehau, but likely other islands
2002	Bleaching event in Moorea and Raiatea, but likely other islands
2003	Bleaching event in Moorea, and likely other islands
2004	COTS outbreaks in Bora Bora, Raiatea
2006-2010	COTS outbreak in Moorea, Tahiti, and Tetiaroa
2007	Bleaching event in Moorea
2010	Cyclone Oli in Society archipelago
2011	COTS outbreak in Tetiaroa
2013	COTS outbreak in Tetiaroa
2014-2015	Mass mortality of sea urchin in Rapa
2015	Bleaching events in Society archipelago
2016	Bleaching events in Marquesas archipelago
2017	Bleaching events in Australs archipelago

Maps of individual surveys of substrate

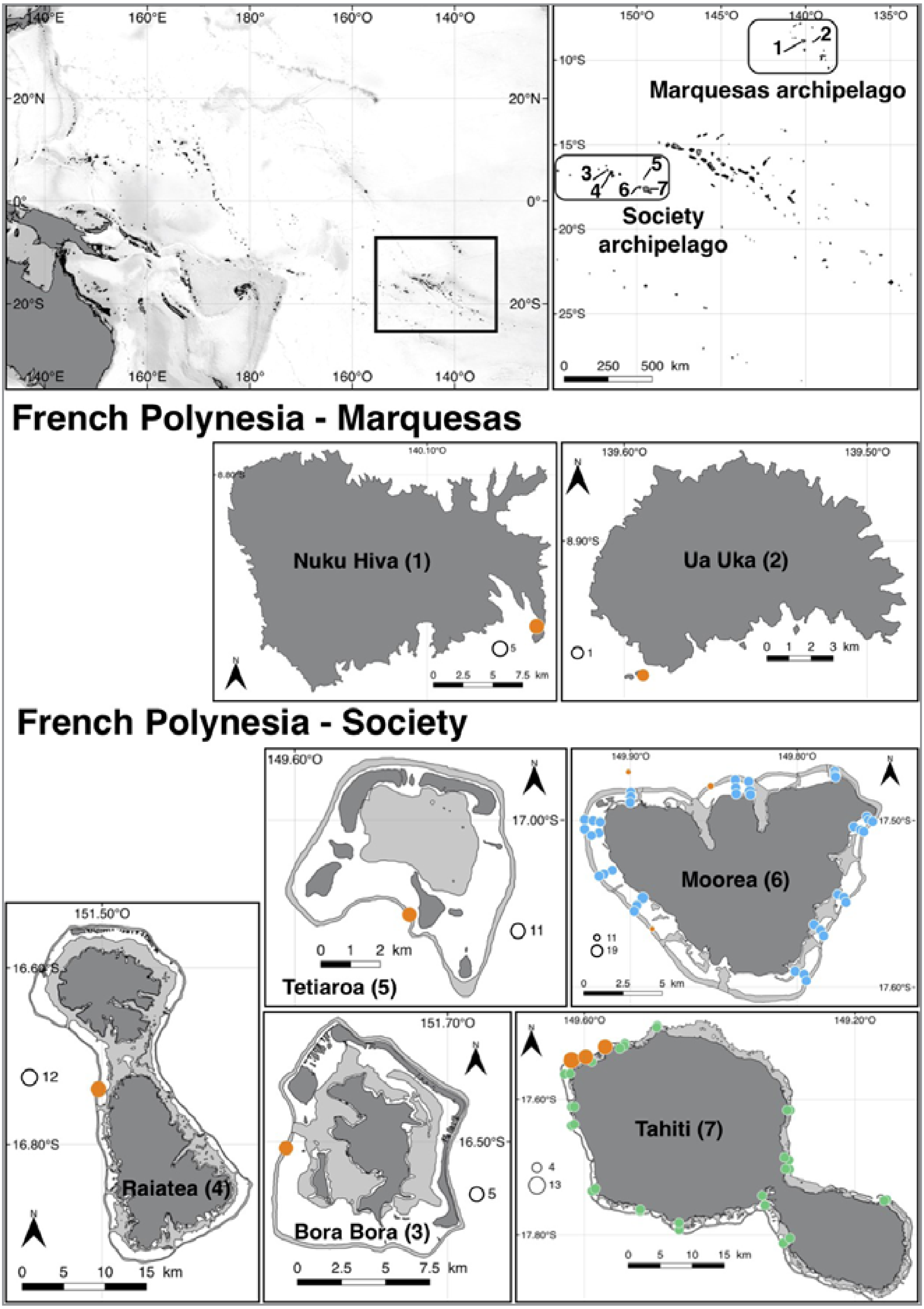

FIGURE 1.1
Map of French Polynesia and sampled islands in the Society and Marquesas archipelagos. Each colour represents a different substrate dataset (orange: dataset n°44; blue: dataset n°34; green: dataset n°38). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

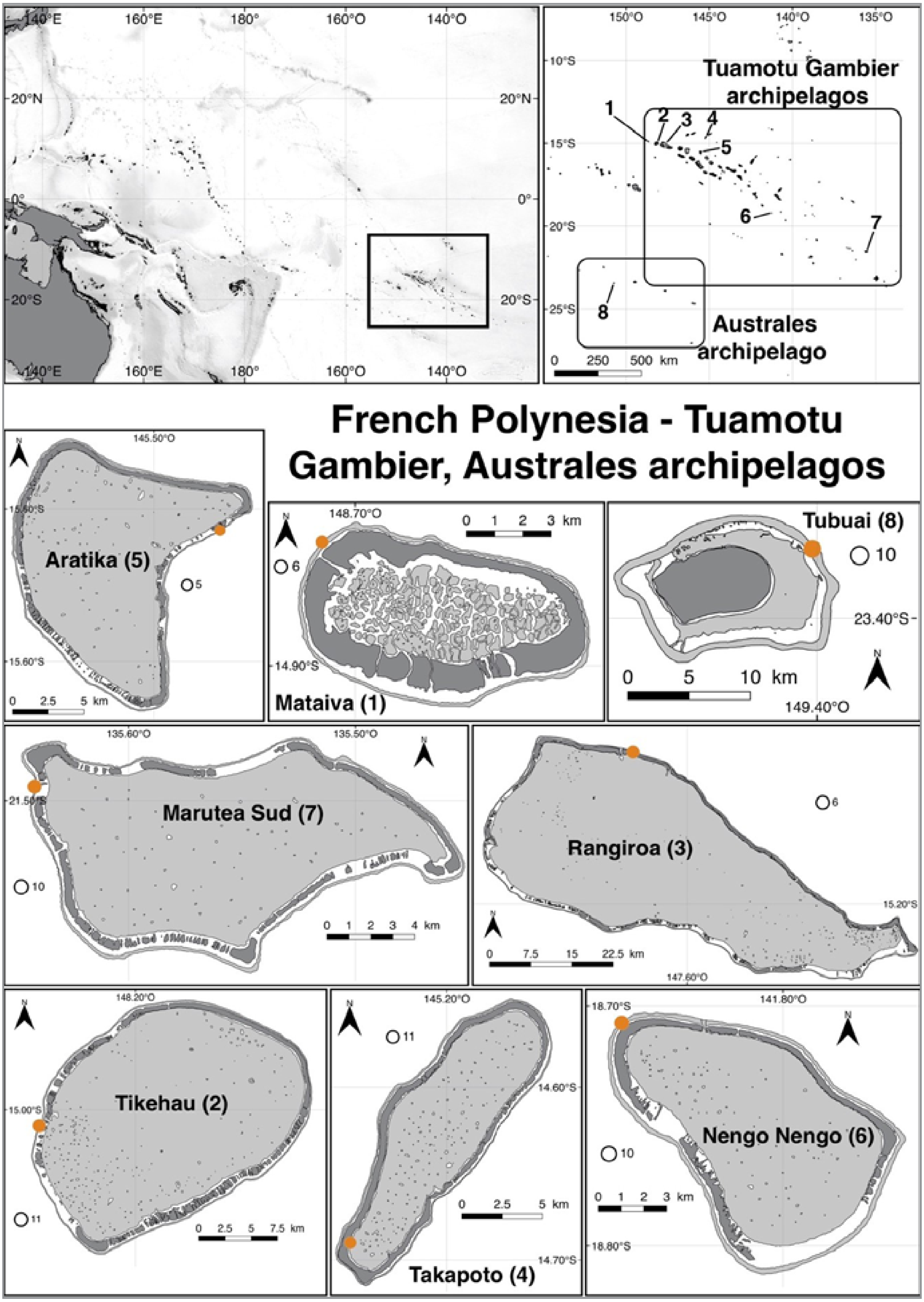

FIGURE 1.2

Map of French Polynesia and sampled islands in the Tuamotu-Gambier and Australs archipelagos. Each colour represents a different substrate dataset (orange: dataset n°44). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from French Polynesia used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
7	René Galzin – CRIOBE SO CORAIL, French Polynesia	1983 - 2016	33			X
34	Moorea MPA - CRIOBE SO CORAIL, French Polynesia	2004 - 2016	12	X	X	
35	Moorea MPA - CRIOBE SO CORAIL, French Polynesia	2004 - 2016	12			X
38	Réseau de Surveillance de Tahiti – CRIOBE SO CORAIL, French Polynesia – DIREN	2007 - 2015	8	X	X	
39	Réseau de Surveillance de Tahiti – CRIOBE SO CORAIL, French Polynesia - DIREN	2007 - 2015	5			X
44	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	1993 - 2016	22	X		
45	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	2004 - 2016	12			X

Trends

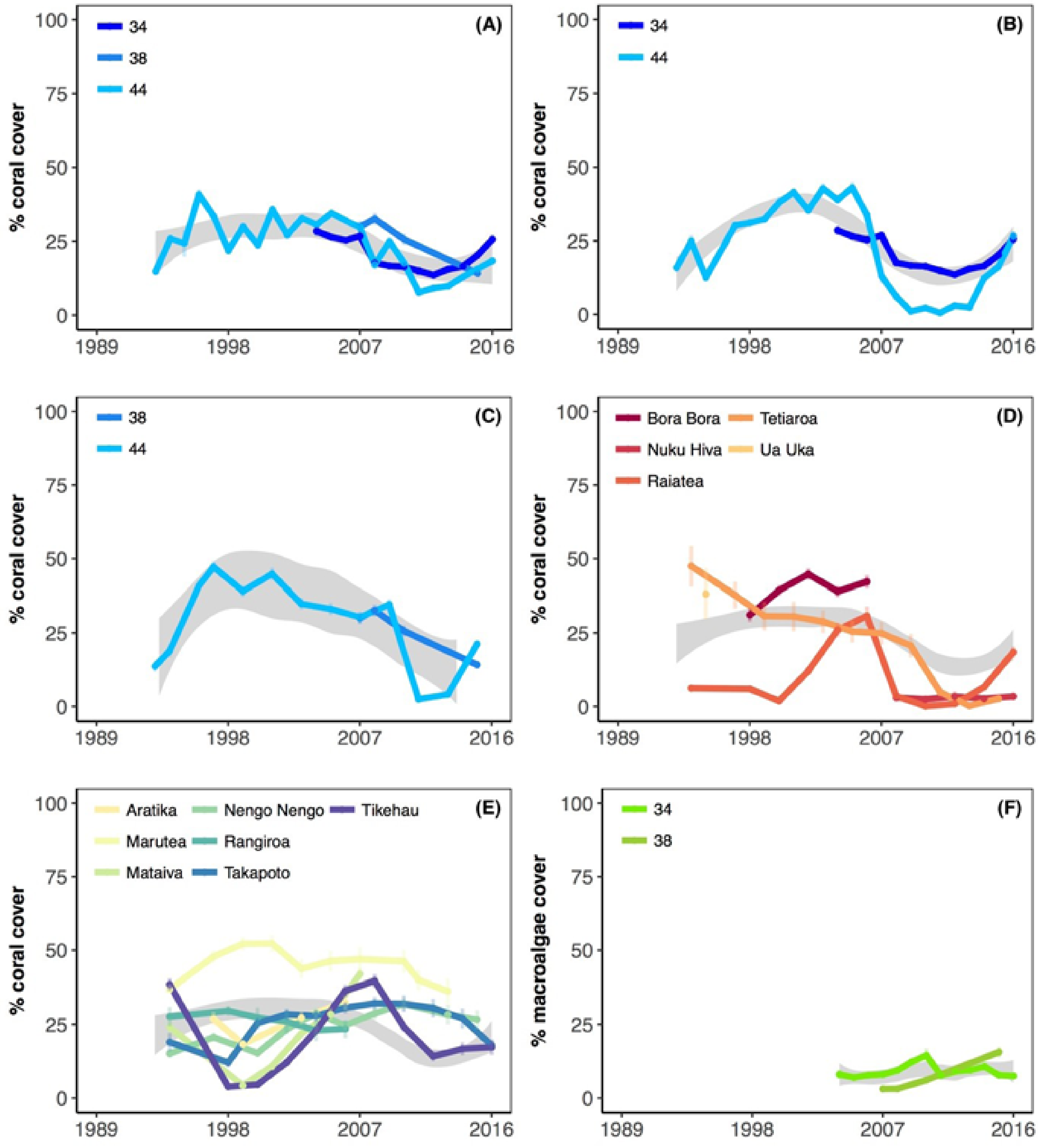

FIGURE 2.1
Average percent of live hard coral cover in French Polynesia: (A) Contribution of each dataset, all islands combined; (B) Moorea; (C) Tahiti; (D) Bora Bora, Nuku Hiva, Raiatea, Tetiaroa, Ua Uka; (E) Aratika, Marutea, Mataiva, Nengo Nengo, Rangiroa, Takapoto, Tikehau. (F): Average percent cover of macroalgae in Moorea and Tahiti. The grey area represents the average loess trend in coral and macroalgae cover when several datasets and islands are combined.

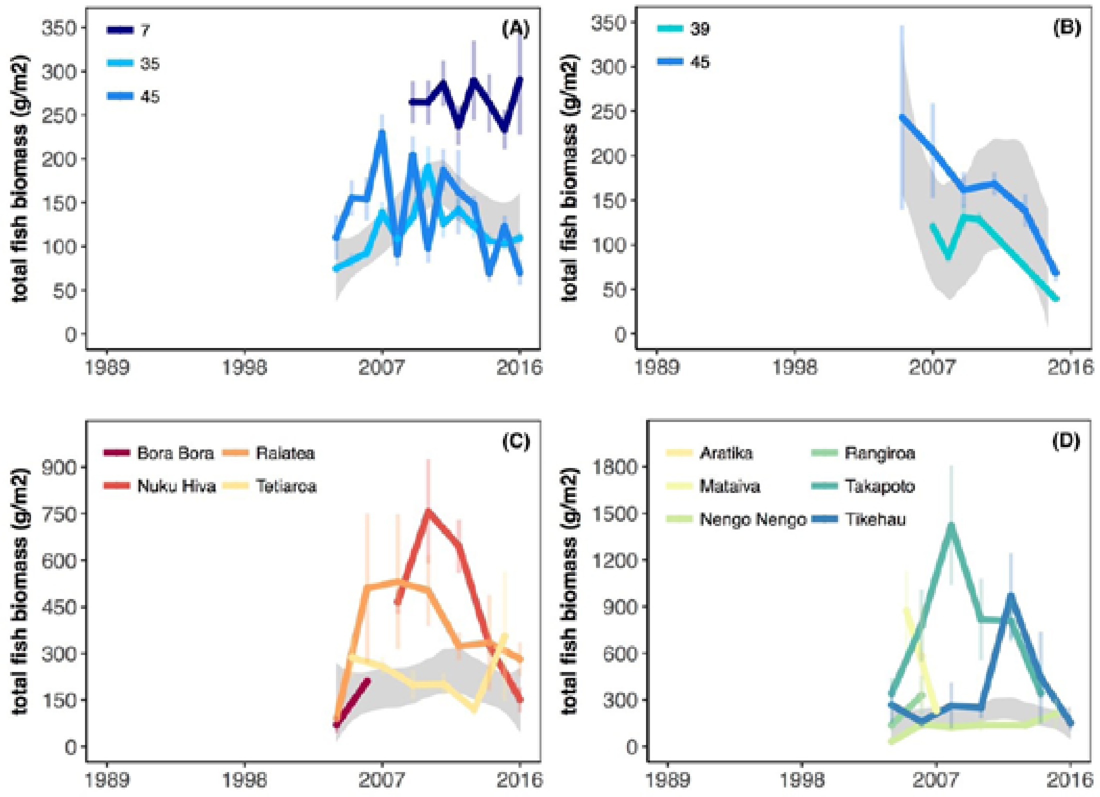

FIGURE 2.2

Average total fish biomass in French Polynesia: contribution of the different datasets for (A) Moorea and (B) Tahiti; (C) Bora Bora, Nuku Hiva, Raiatea, Tetiaroa; (D) Aratika, Mataiva, Nengo Nengo, Rangiroa, Takapoto, Tikehau. The grey area represents the average loess trend in total fish biomass when several datasets and islands are combined.

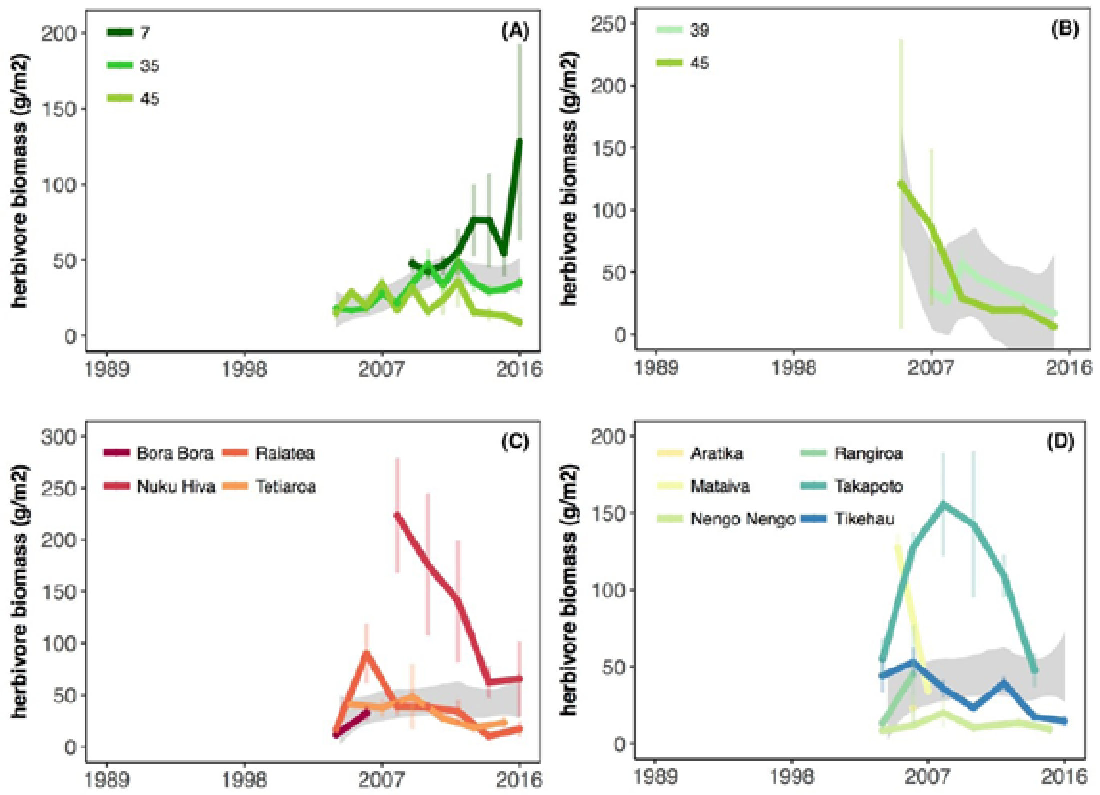

FIGURE 2.3

Average herbivore fish biomass in French Polynesia: contribution of the different datasets for (A) Moorea and (B) Tahiti; (C) Bora Bora, Nuku Hiva, Raiatea, Tetiaroa; (D) Aratika, Mataiva, Nengo Nengo, Rangiroa, Takapoto, Tikehau. The grey area represents the average loess trend in herbivore fish biomass when several datasets and islands are combined.

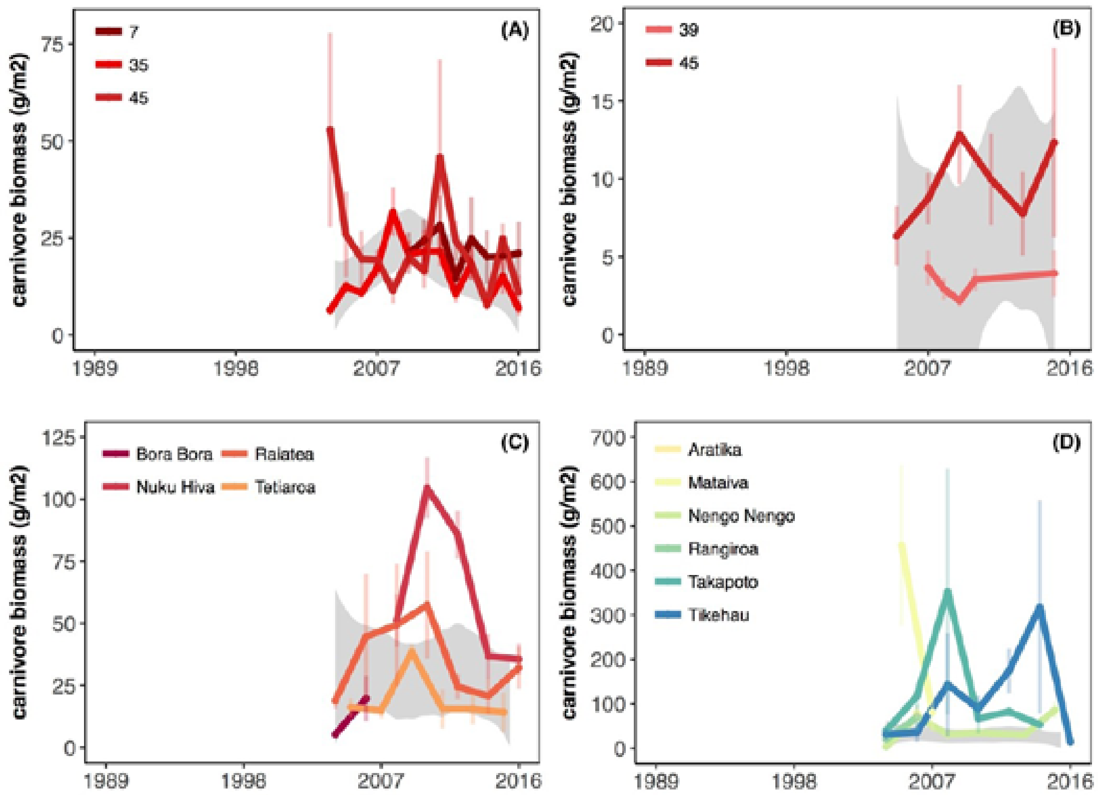

FIGURE 2.4
Average carnivore fish biomass in French Polynesia: contribution of the different datasets for (A) Moorea and (B) Tahiti; (C) Bora Bora, Nuku Hiva, Raiatea, Tetiaroa; (D) Aratika, Mataiva, Nengo Nengo, Rangiroa, Takapoto, Tikehau. The grey area represents the average loess trend in carnivore fish biomass when several datasets and islands are combined.

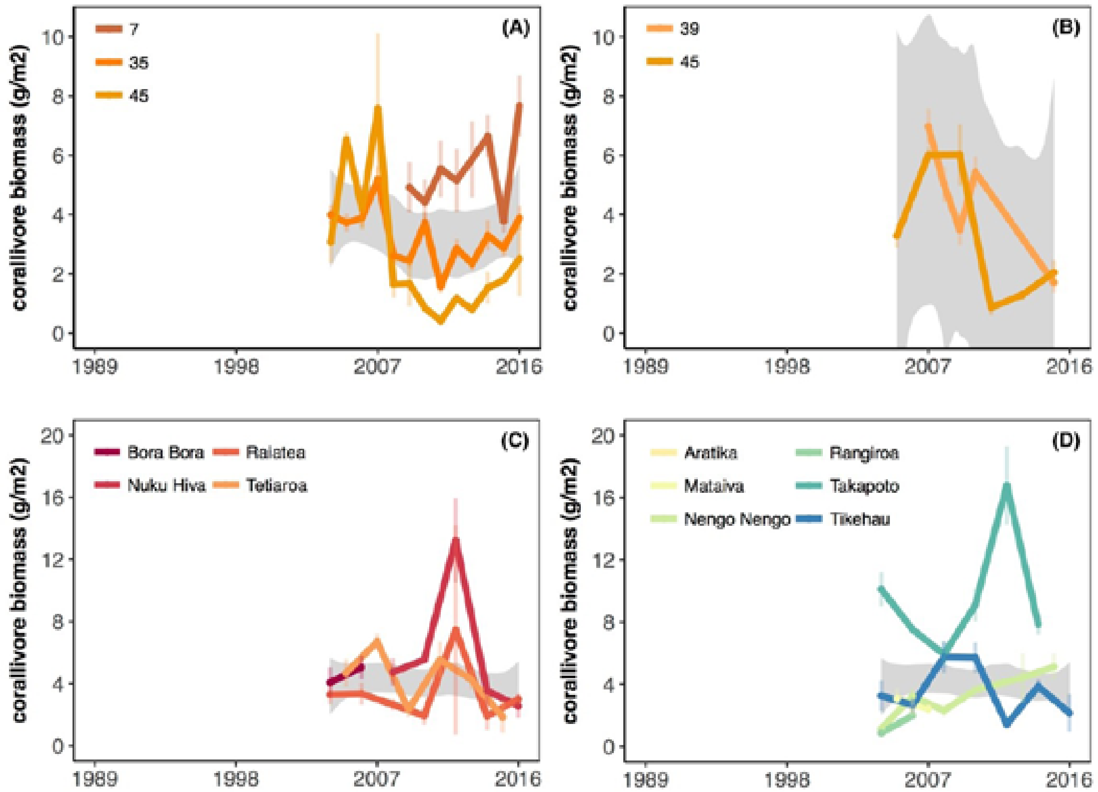

FIGURE 2.5
Average corallivore fish biomass in French Polynesia: contribution of the different datasets for (A) Moorea and (B) Tahiti; (C) Bora Bora, Nuku Hiva, Raiatea, Tetiaroa; (D) Aratika, Mataiva, Nengo Nengo, Rangiroa, Takapoto, Tikehau. The grey area represents the average loess trend in herbivore fish biomass when several datasets and islands are combined.

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Guam

Collaborators: Marie Ferguson, Adel Heenan, Peter Houk, Kelly Kozar, Sheila McKenna, Bernardo Vargas-Angel and Ivor Williams

Geographic information

Maritime area: 218 000 km²	Reef area: 183 km²
Land area: 540 km²	Coastal length: 125.5 km
Number of islands: 1	Distance to nearest continent: 2 500 km of Asia
Island type: volcanic, coralline limestone plateau	Island age: » 30 million years
Population: 169 885	Number of uninhabited islands: 0
Climate: tropical marine	Major wind regime: Northeast trade winds
Total MPAs: 5	GDP's/CAP: $30 500

Overview

Guam, the southernmost island of the Mariana chain, is an independent US territory and is a separate political entity. It is the largest island and the most heavily populated island in Micronesia. Tourism is a major activity that contributes up to 30% of the annual GDP. Guam is surrounded by fringing reefs and has a relatively narrow reef platform and lagoon (<1 km wide) along the western (leeward) shore. Guam is close to the Indo-Pacific centre of biodiversity with about 5000 aquatic species listed including about 1000 species of fish and 300 species of corals. Furthermore, the biogeographic differences between northern and southern Guam induce considerable variations on coral reef and reef resource conditions.

Data obtained from D. Burdick with the University of Guam Marine Laboratory's Guam Long-term Coral Reef Monitoring Program (Dataset 10) was collected at a handful of permanent monitoring sites established at non-randomized, high priority management sites around Guam. The sites were not established in the same year, nor were all sites monitored on a regular basis. As a result, the trend obtained when combining data from all sites across time does not reflect actual changes in benthic cover and obscures the slight downward trend detected by the island-wide NOAA PIFSC dataset.

Timeline of major events

1994	Bleaching event
1996	Bleaching event
1997	Typhoon Paka (category 5); Guam established 5 recognized MPAs covering 36km2;
2002	Typhoon Pongsona (category 4)
2006	The government expanded the goal of these MPAs to include conservation purposes; Bleaching event
2007	Bleaching event

Maps of individual surveys of substrate

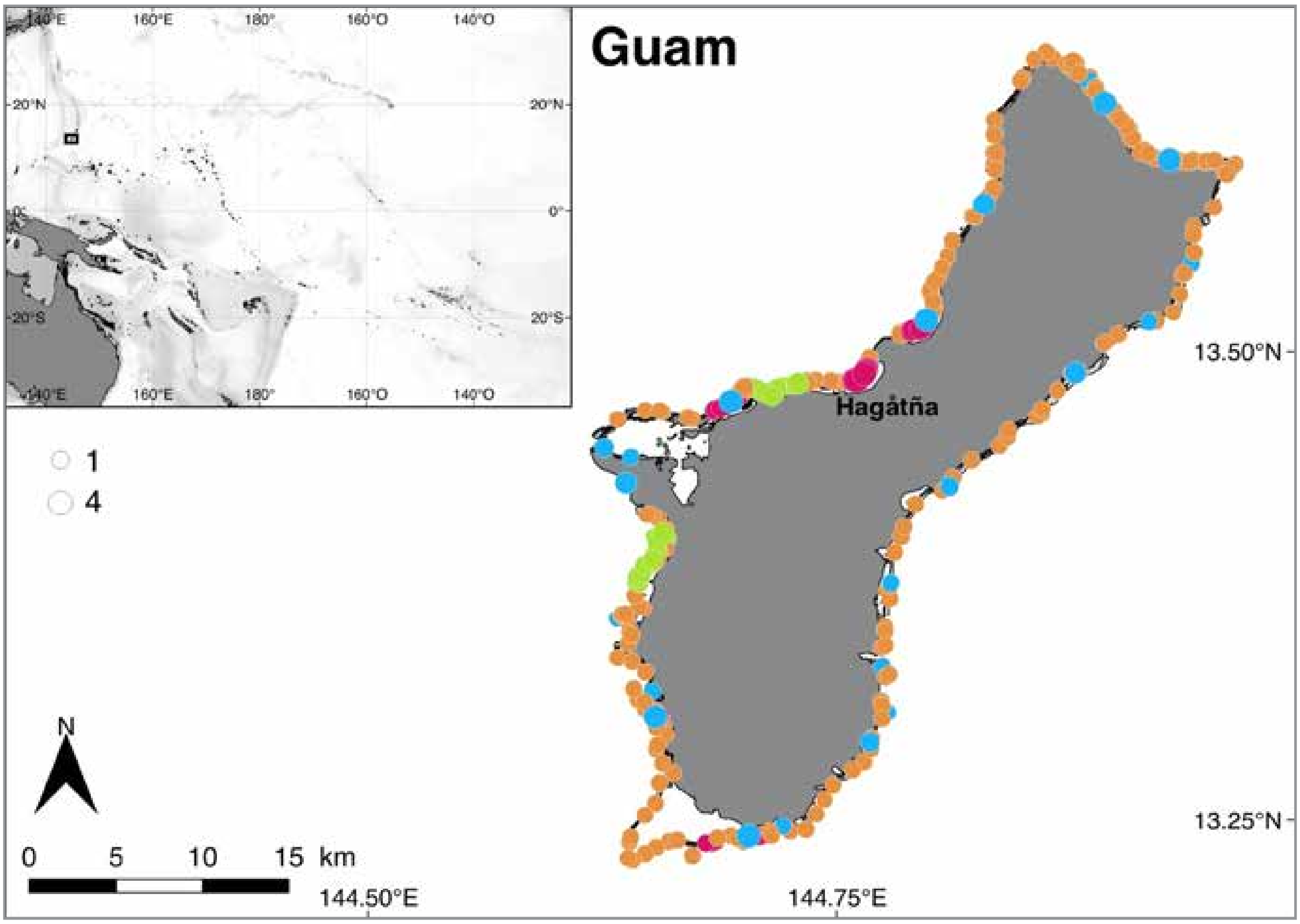

FIGURE 1
Map of Guam. Each colour represents a different dataset (orange: dataset n°43, blue: dataset n°40, green: dataset n°5, pink: dataset n°10). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from Guam used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
5	PACN – National Park Service – U.S. Department of the Interior	2008 - 2011 2014	5	X	X	
6	PACN – National Park Service – U.S. Department of the Interior	2008 - 2012 2014-2016	8			X
10	University of Guam, Guam	2010 - 2016	5	X	X	
40	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2005 - 2012	3	X	X	

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
43	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2011 - 2014	2	X	X	
49	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2007 - 2015	3			X

Trends

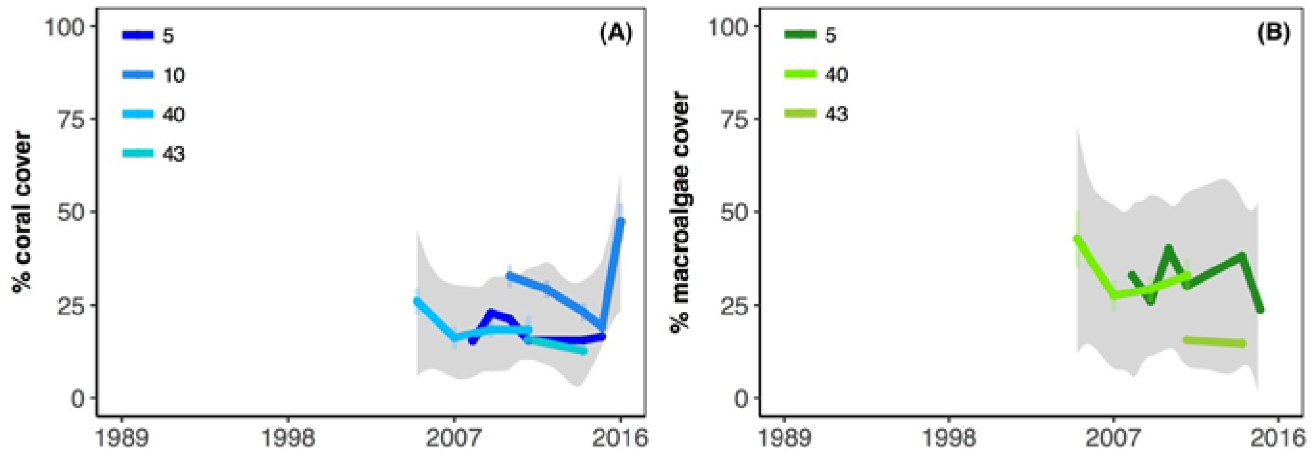

FIGURE 2.1
Average percent of (A) live hard coral cover and (B) macroalgae cover in Guam for the different datasets. The grey area represents the average loess trend in coral and macroalgae cover when several datasets are combined.

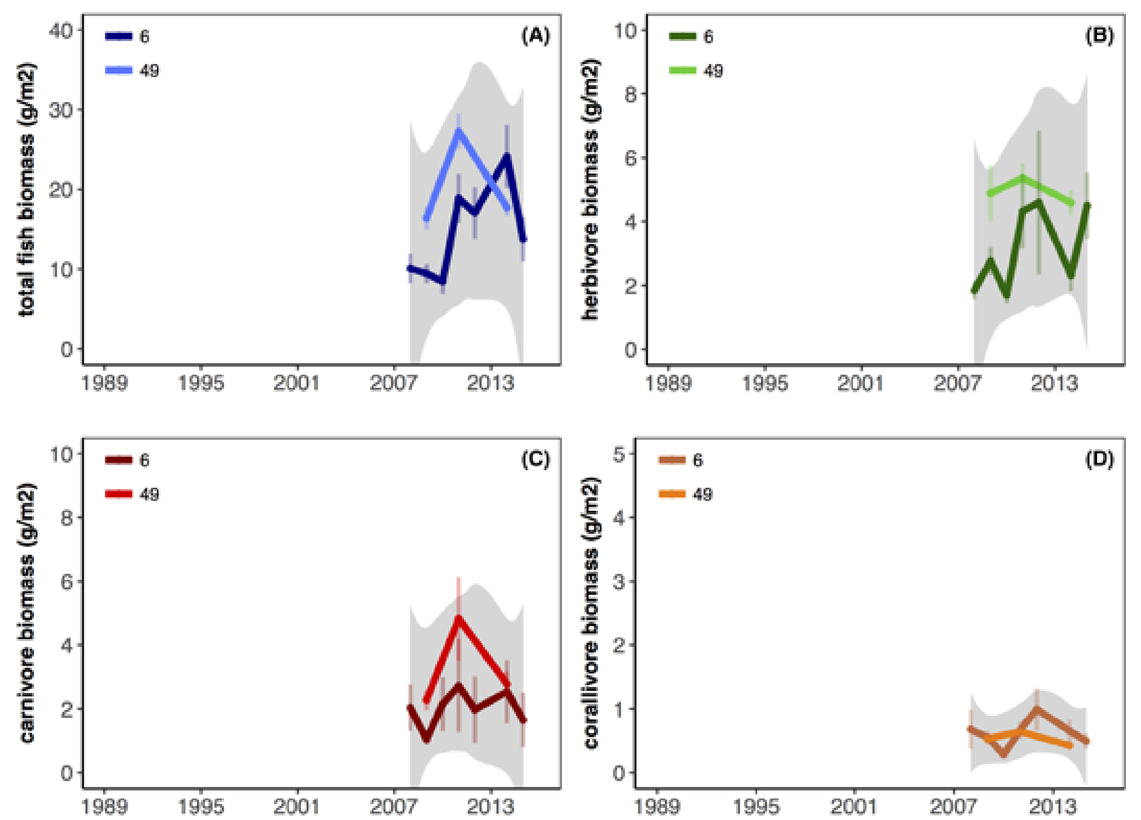

FIGURE 2.2
Average fish biomass in Guam for the different datasets: (A) Total; (B) Herbivore; (C) Carnivore; (D) Corallivore. The grey area represents the average loess trend in fish biomass when several datasets are combined

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Main and Northwestern Hawaiian Islands

Collaborators: Marie Donovan, Marie Ferguson, Adel Heenan, Kelly Kozar, Lindsey Kramer, Sheila McKenna, Stuart Sandin, Jennifer Smith, Bernardo Vargas-Angel, Bill Walsh, Ivor Williams and Brian Zgliczynski

Geographic information	
Maritime area: 1 823 000 km²	Reef area: 3 834 km²
Land area: 16 636 km²	Coastal length: 1 482 km
Number of islands: 137	Distance to nearest continent:
Island type: high volcanic, low coral atoll	Island ages: formation by hot spots. 28M (Kure atoll), 400 000 years (Hawaii)
Population: 1 450 000	Number of uninhabited islands: 129
Climate: tropical	Major wind regime: Trade winds
Total MPAs : > 19	GDP's/CAP: USD $54 515

Overview

The Hawaiian archipelago includes both the Main Hawaiian Islands (MHI) and the remote Northwestern Hawaiian Islands (NWHI), which are separated by approximately 250 km of open ocean. They all constitute the USA's State of Hawai'i. These islands stretch along a 2900 km chain in the north central Pacific and comprise nearly 25% of the coral reefs in US waters. The MHI, recent high volcanic islands, include 8 populated large islands. In contrast, the islands of the NHWI are largely uninhabited small islands and low-lying atolls, reefs, and submerged banks

The Hawaiian archipelago is an important biodiversity hotspot which contains more than 7000 marine species. The flora and fauna of the Hawaiian Archipelago contain some of the highest levels of endemic species for tropical ecosystems worldwide given the archipelagos isolation from elsewhere in the Pacific.

Coral reefs of Hawai'i are an important component of the island's culture and way of life, and provide an important component of Hawai'i's economy from tourism and fisheries. The majority of the human population resides on the island of Oahu, with greater than 1 million residents and nearly 7 million visitors each year. Human pressures have caused some declines in the status of the coral reef ecosystems, but many reefs remain in good condition due to the large physical and human gradients within the archipelago.

Timeline of major events

<1819	Kapu system of marine resource management
1893	Overthrow of the Hawaiian Kingdom
1927	Division of Fish and Game established
1951	Introduction of groupers and snapper species from South Pacific
1967	Establishment of first Marine Life Conservation District in Hanauma Bay on Oahu
1969	Marine Life Conservation District established in Kealakekua Bay on Hawaii
1976	Marine Life Conservation District established in Manele-Hulopoe on Lanai
1977	Marine Life Conservation District established in Molokini
1978	Marine Life Conservation District established in Honolulu-Mokuleia Bays on Maui
1979	Marine Life Conservation District established in Lapakahi on Hawaii
1980s	Multiple wastewater outfalls moved offshore, including Kaheohe Bay
1982	Hurricane Iwa
1985	Marine Life Conservation District established in Waialaea Bay on Hawaii
1988	Marine Life Conservation District established in Waikiki on Oahu
1992	Hurricane Iniki
1992	Marine Life Conservation District established in Old Kona Airport on Hawaii
1996	Bleaching event in on O'ahu
2000s	Proliferation of invasive macroalgae species on Oahu and Maui
2000	Marine Life Conservation District established in Pupukea on Oahu
2000	A network of 9 Fish Replenishment Areas (FRA) which prohibit aquarium fish collection were established around West Hawai'i
2002	Bleaching event in the NHWI
2003	Marine Life Conservation District established in Wai Opae Tidepools on Hawaii
2004	Bleaching event in the NHWI
2005	COTS outbreaks in the north shore of O'ahu
2006	NWHI was declared as a National Monument, the Papahānaumokuākea Marine National Monument covering 362 600 km2
2006	Large scale macroalgae die off in Kaneohe Bay
2014	Bleaching event in the Main Hawaiian Islands
2015	Bleaching even in the Main Hawaiian Islands
2015	First legislative designation of a Community Based Subsistence Fishing Area in Hā'ena on Kauai
2016	Beginning of the World-Wide Voyage of the Hōkūle'a, and the Mālama Honua Declarations
2016	Expansion of the the Papahānaumokuākea Marine National Monument to 937,569 km
2017	Announcement of the Sustainable Hawai'i Initiative marine goal to 'effectively manage 30% of nearshore ecosystems by 2030.'
2018	Marine Life Conservation District in Wai Opae Tidepools on Hawai'i covered in lava

Maps of individual surveys of substrate

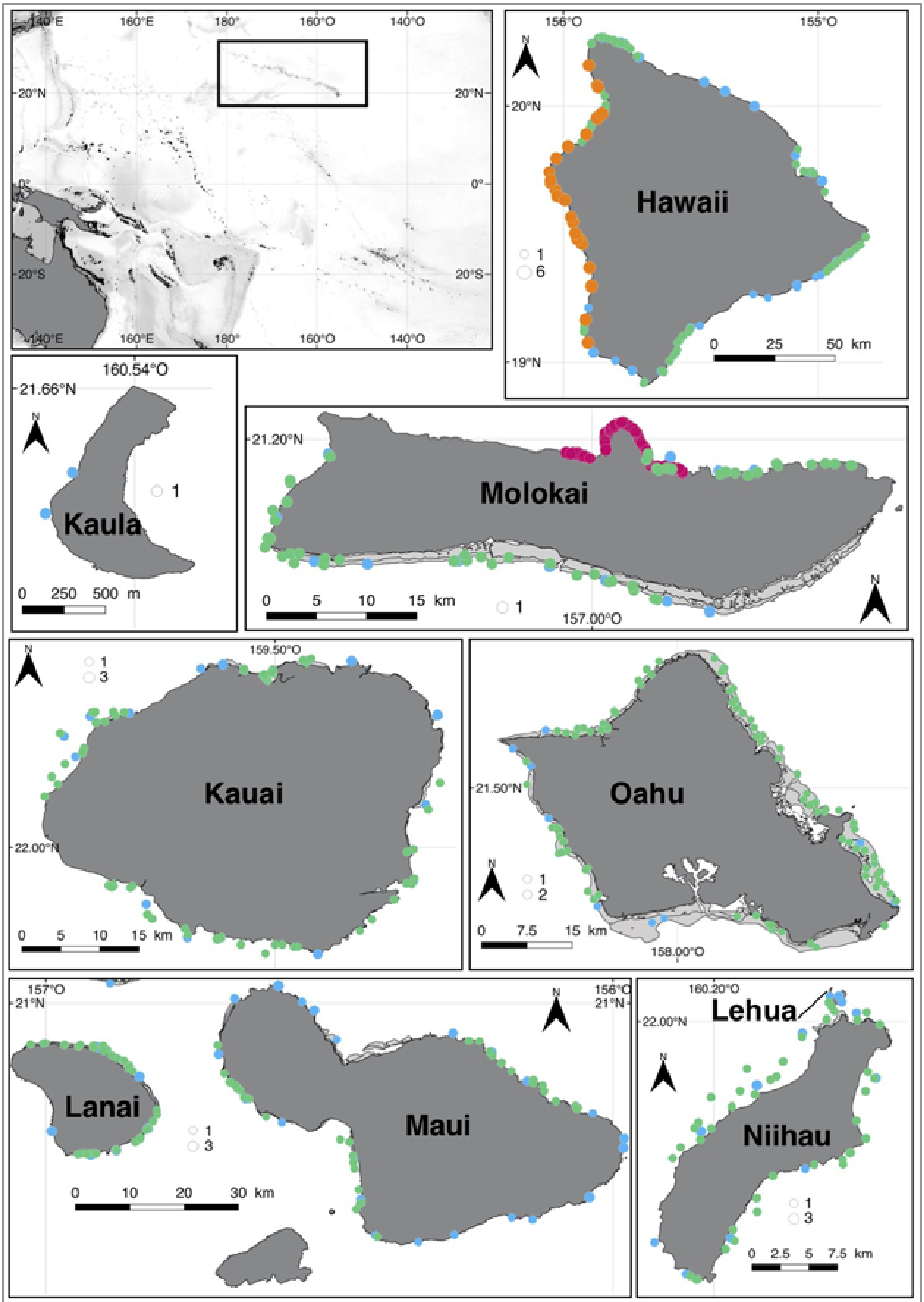


FIGURE 1.1

Map of the sampled Main Hawaiian Islands. Each colour represents a different substrate dataset (orange: dataset n°46; blue: dataset n°40; green: dataset n°43; pink: dataset n°5). Circle size represents the total number of times the site was sampled.

Maps of individual surveys of substrate

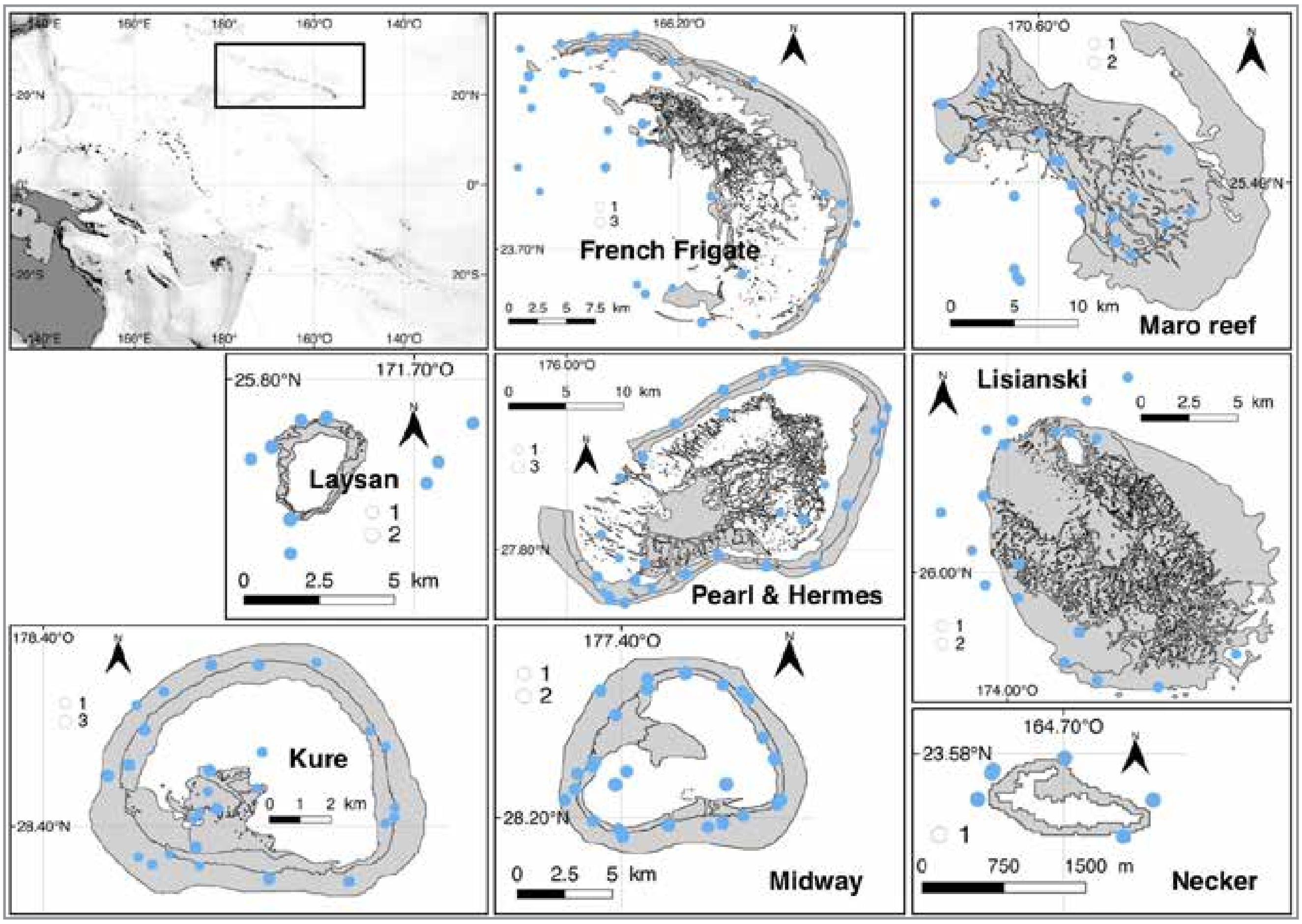


FIGURE 1.2
Map of the sampled Northwestern Hawaiian Islands. Each colour represents a different substrate dataset (blue: dataset n°40). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

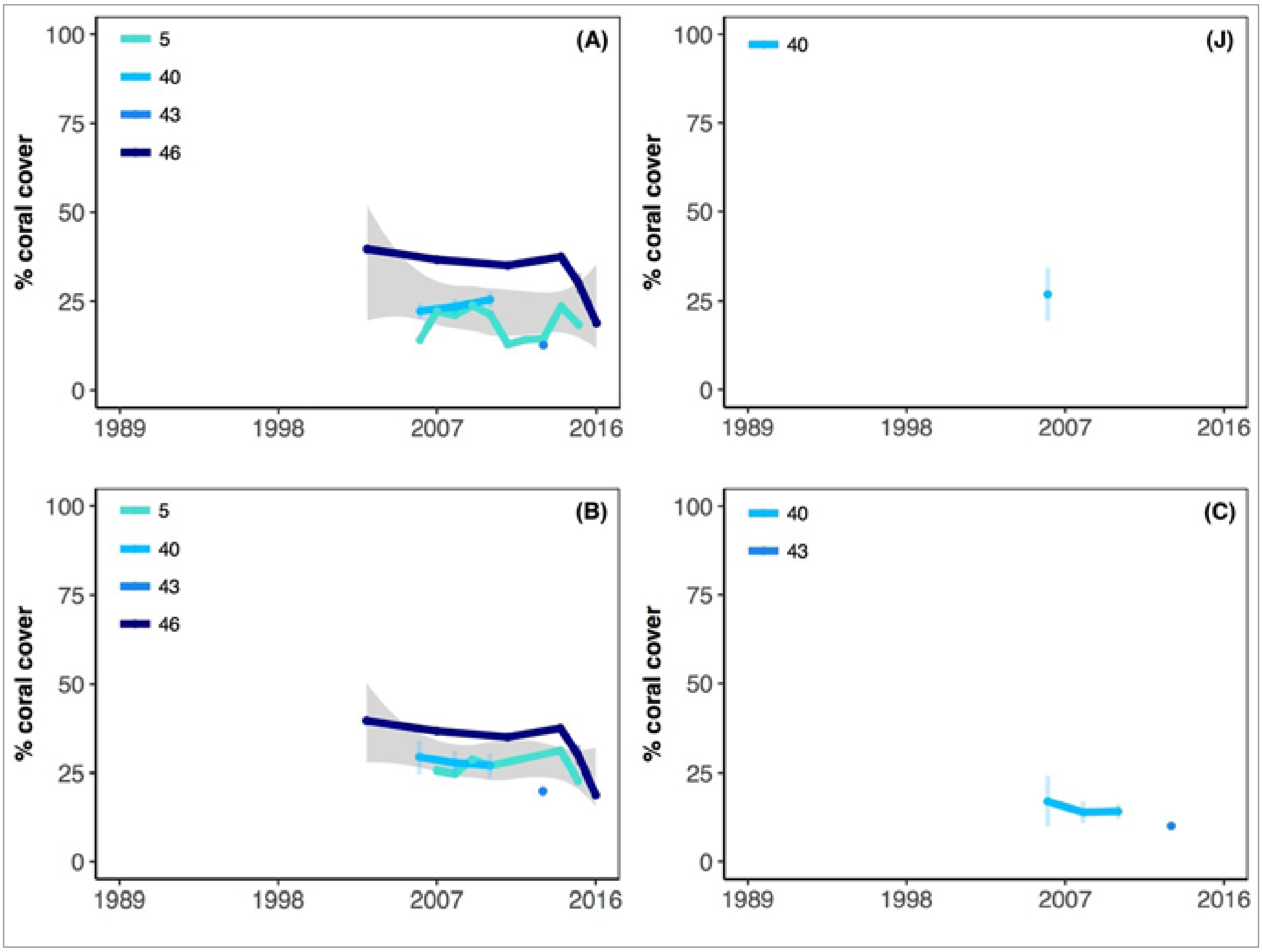
Table of data sources

TABLE 1
Data sources from Hawaiian Islands used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
5	PACN – National Park Service – U.S. Department of the Interior	2006- 2015	10	X	X	
6	PACN – National Park Service – U.S. Department of the Interior	2006- 2016	11			X
40	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2005 – 2012	3	X	X	
42	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2010 - 2015	4			X

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
43	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2011 - 2014	1	X	X	
46	Division of Aquatic Resources – State of Hawai'i	2003 – 2016	6	X	X	
47	Division of Aquatic Resources – State of Hawai'i	1999 - 2015	13			X
49	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2007 - 2015	4			X

Trends



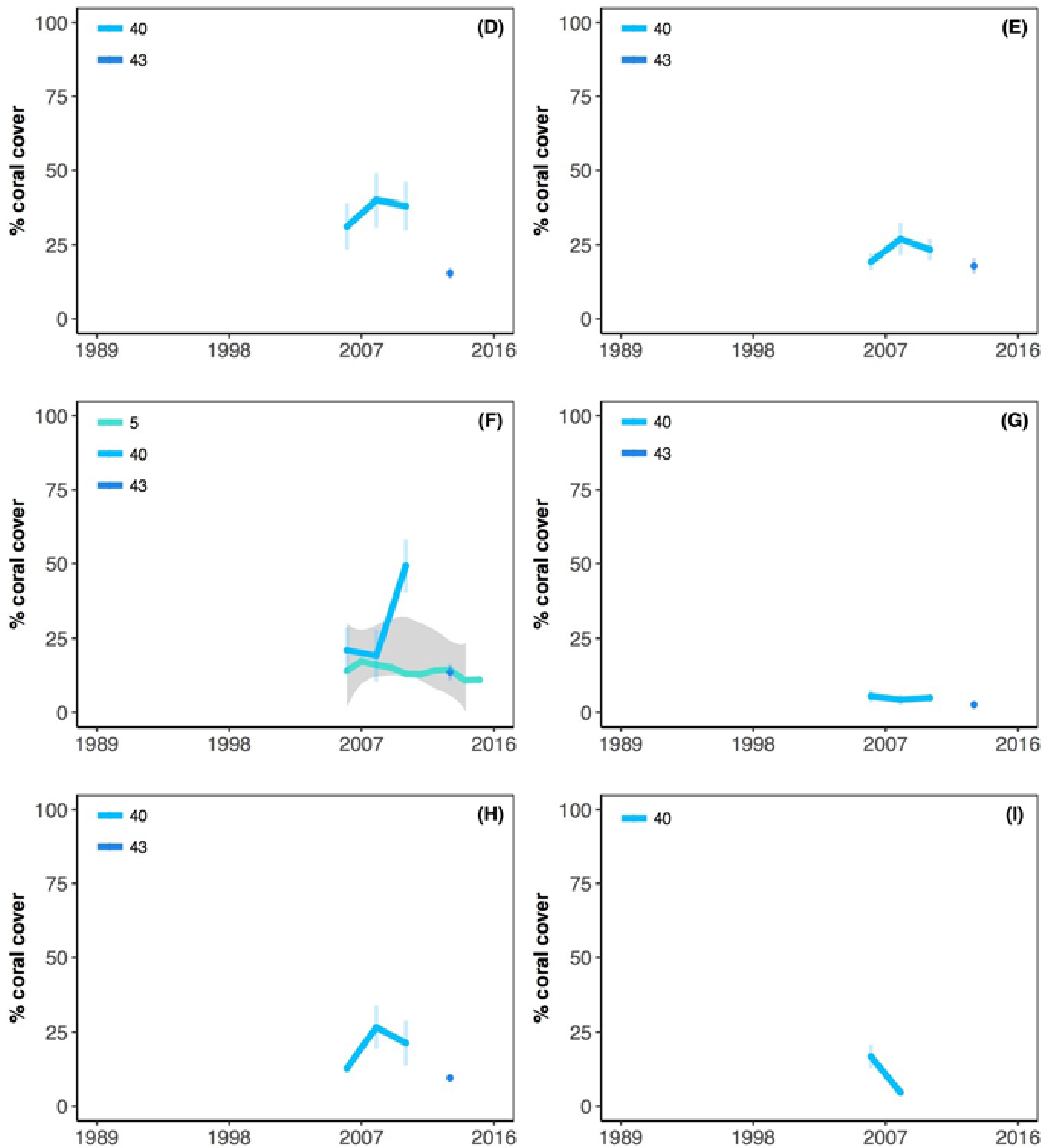
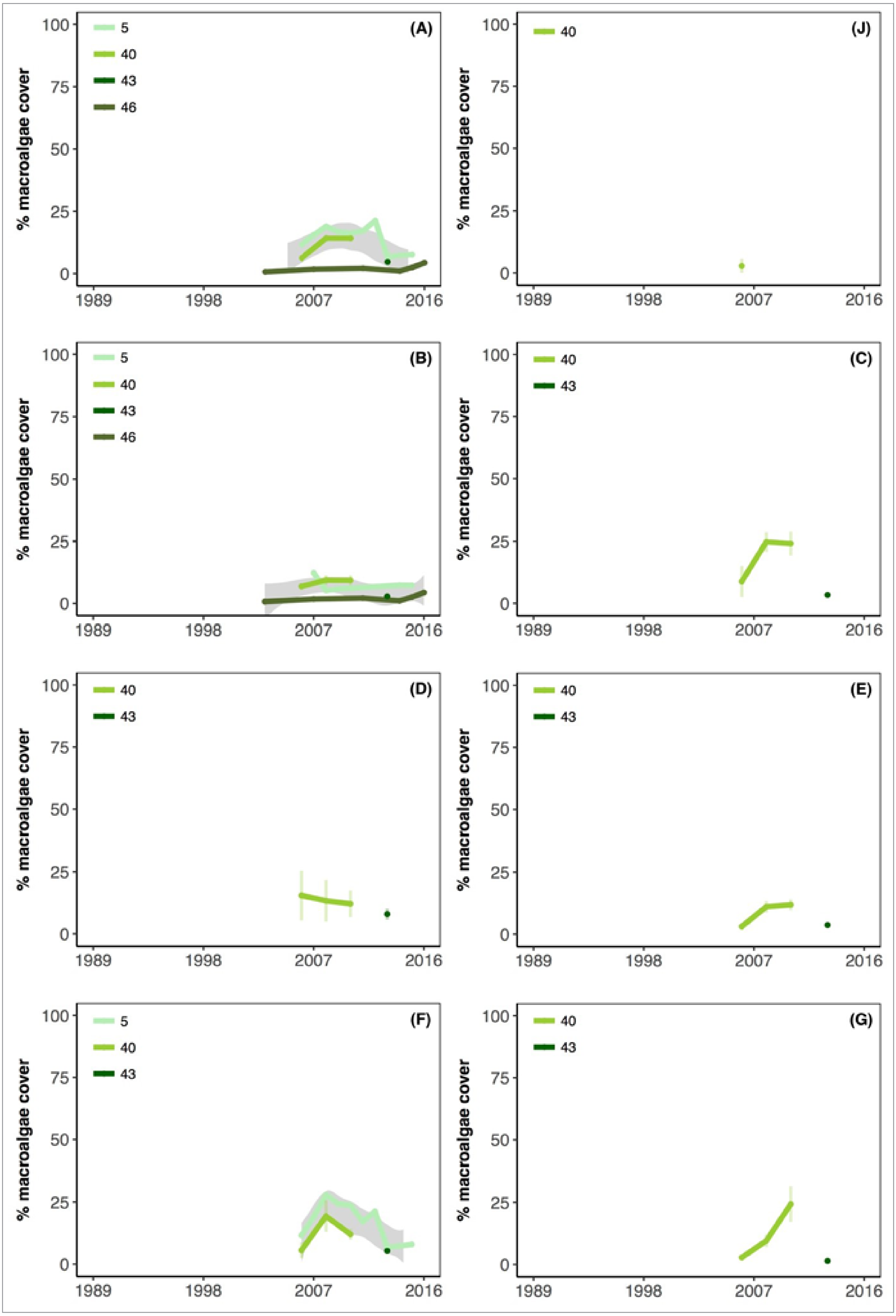


FIGURE 2.1

Average percent of live hard coral cover in the Main Hawaiian Islands: (A) Contribution of each dataset, all islands combined; (B) Hawaii; (C) Kauai; (D) Lanai; (E) Maui; (F) Molokai; (G) Niihau; (H) Oahu; (I) Lehua; (J) Kau-la. The grey area represents the average loess trend in coral cover when several datasets are combined.


(A)
(J)
(B)
(C)
(D)
(E)
(F)
(G)
% macroalgae cover
5
40
43
46
100
75
50
25
0
1989
1998
2007
2016

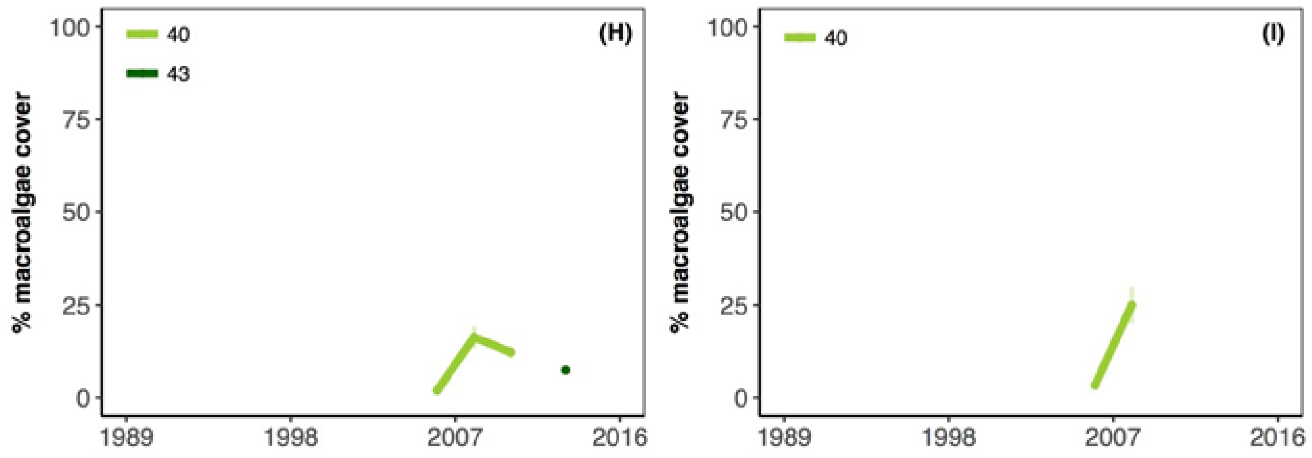


FIGURE 2.2
Average percent of macroalgae cover in the Main Hawaiian Islands: (A) Contribution of each dataset, all islands combined; (B) Hawaii; (C) Kauai; (D) Lanai; (E) Maui; (F) Molokai; (G) Niihau; (H) Oahu; (I) Lehua; (J) Kaula. The grey area represents the average loess trend in macroalgae cover when several datasets are combined.

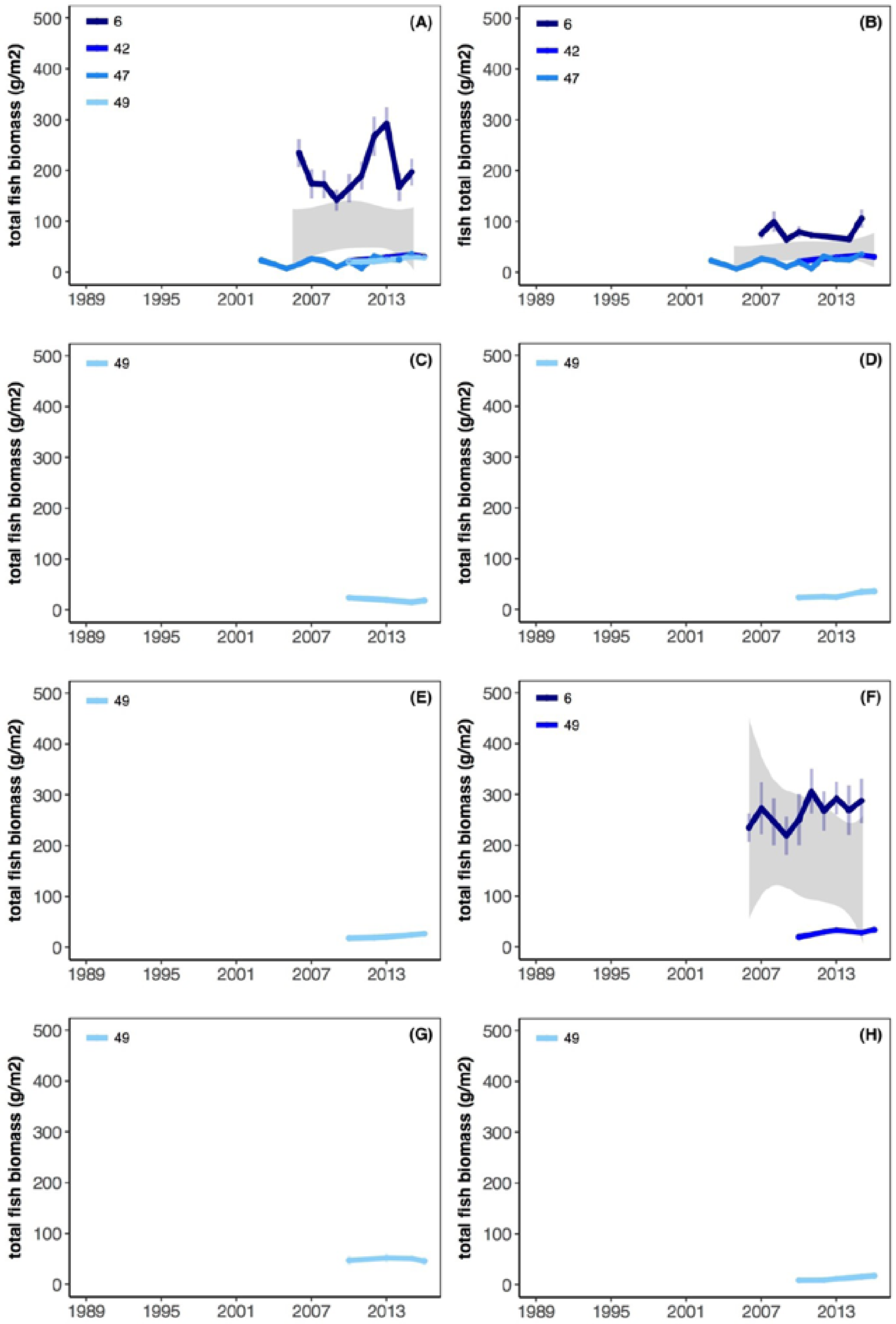


FIGURE 2.3
Average total fish biomass in the Main Hawaiian Islands: (A) Contribution of each dataset, all islands combined; (B) Hawaii; (C) Kauai; (D) Lanai; (E) Maui; (F) Molokai; (G) Niihau; (H) Oahu; (I) Lehua; (J) Kaula. The grey area represents the average loess trend in total fish biomass when several datasets are combined.

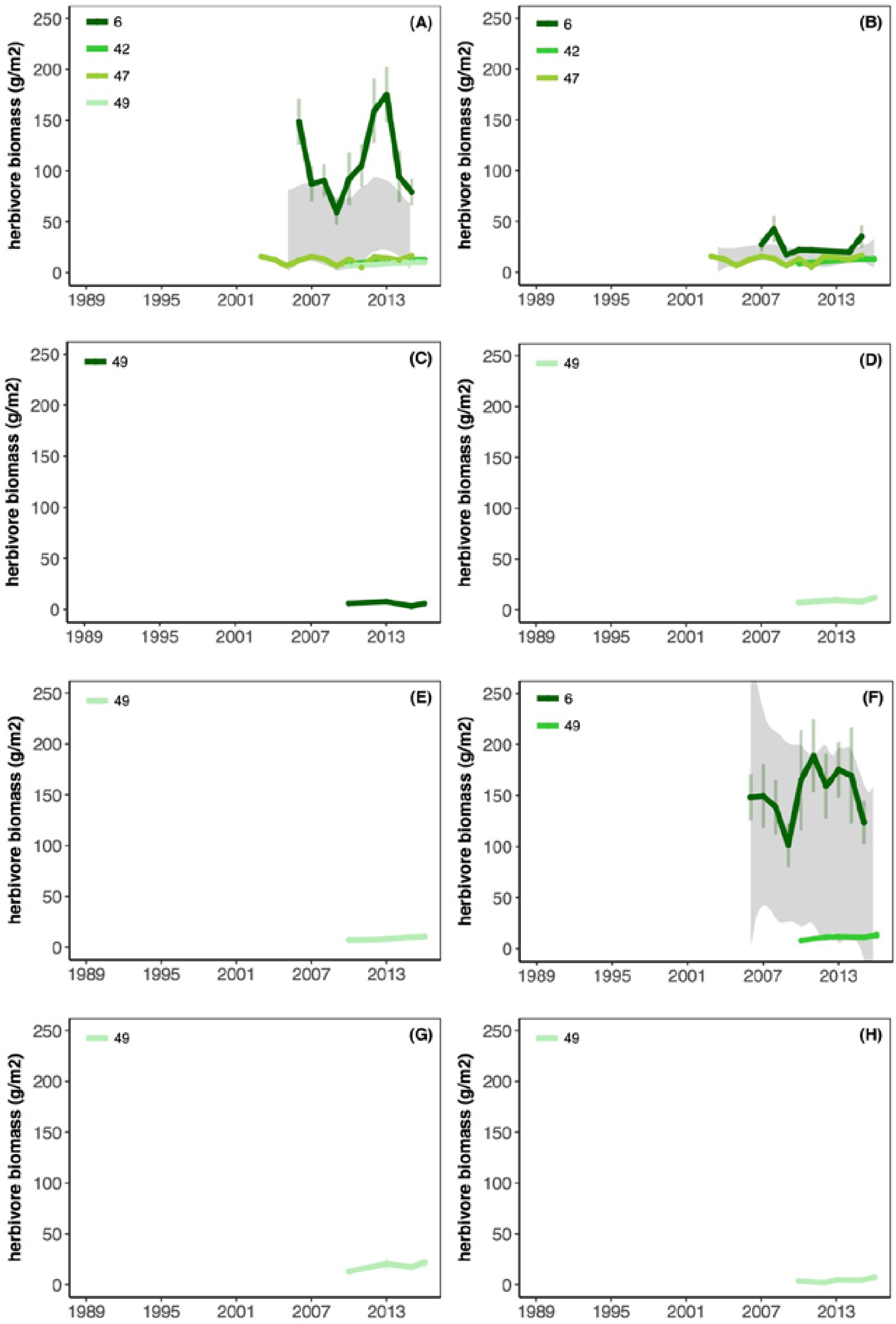


FIGURE 2.4
Average herbivore fish biomass in the Main Hawaiian Islands: (A) Contribution of each dataset, all islands combined; (B) Hawaii; (C) Kauai; (D) Lanai; (E) Maui; (F) Molokai; (G) Niihau; (H) Oahu; (I) Lehua; (J) Kaula. The grey area represents the average loess trend in herbivore fish biomass when several datasets are combined.

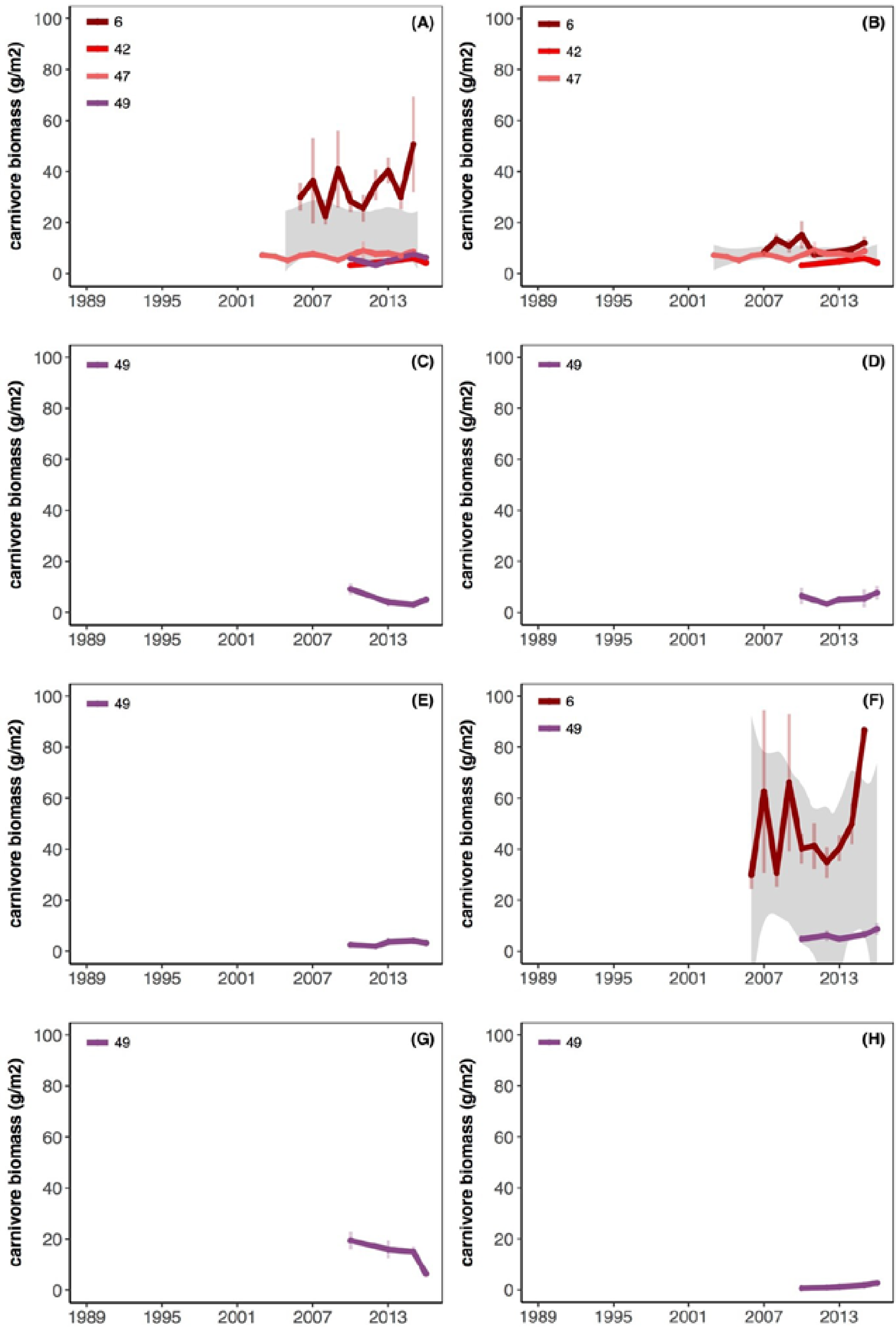


FIGURE 2.5

Average carnivore fish biomass in the Main Hawaiian Islands: (A) Contribution of each dataset, all islands combined; (B) Hawaii; (C) Kauai; (D) Lanai; (E) Maui; (F) Molokai; (G) Niihau; (H) Oahu; (I) Lehua; (J) Kaula. The grey area represents the average loess trend in carnivore fish biomass when several datasets are combined.

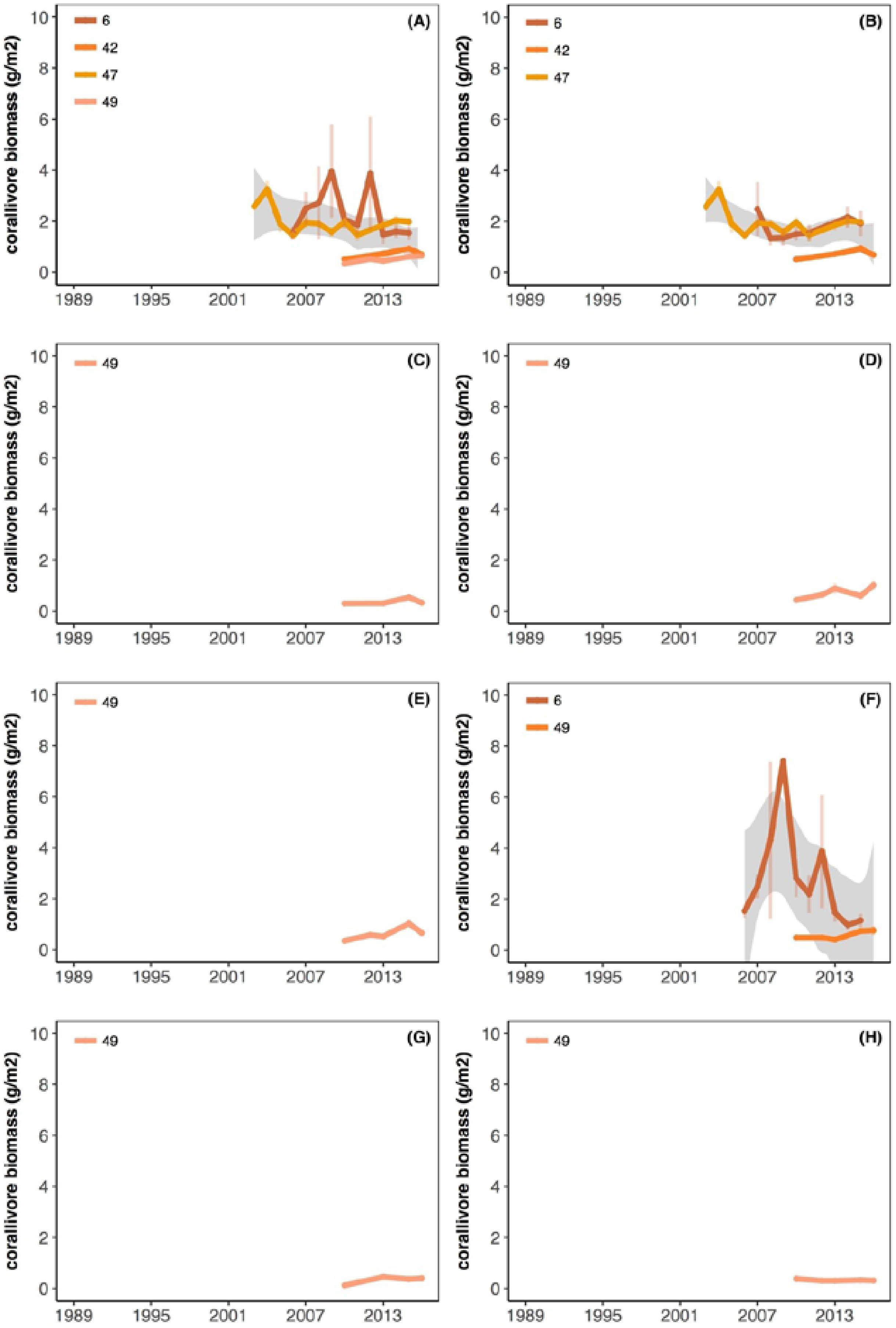
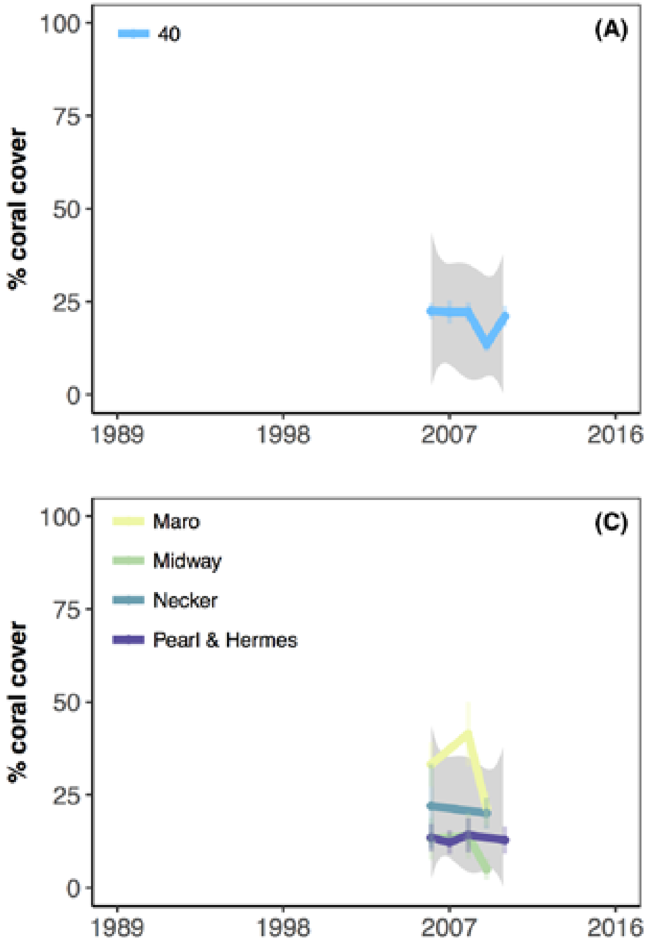


FIGURE 2.6

Average corallivore fish biomass in the Main Hawaiian Islands: (A) Contribution of each dataset, all islands com-bined; (B) Hawaii; (C) Kauai; (D) Lanai; (E) Maui; (F) Molokai; (G) Niihau; (H) Oahu; (I) Lehua; (J) Kaula. The grey area represents the average loess trend in corallivore fish biomass when several datasets are combined.



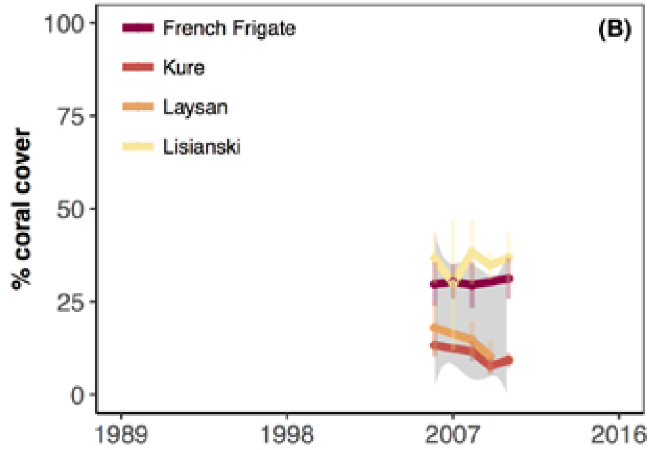
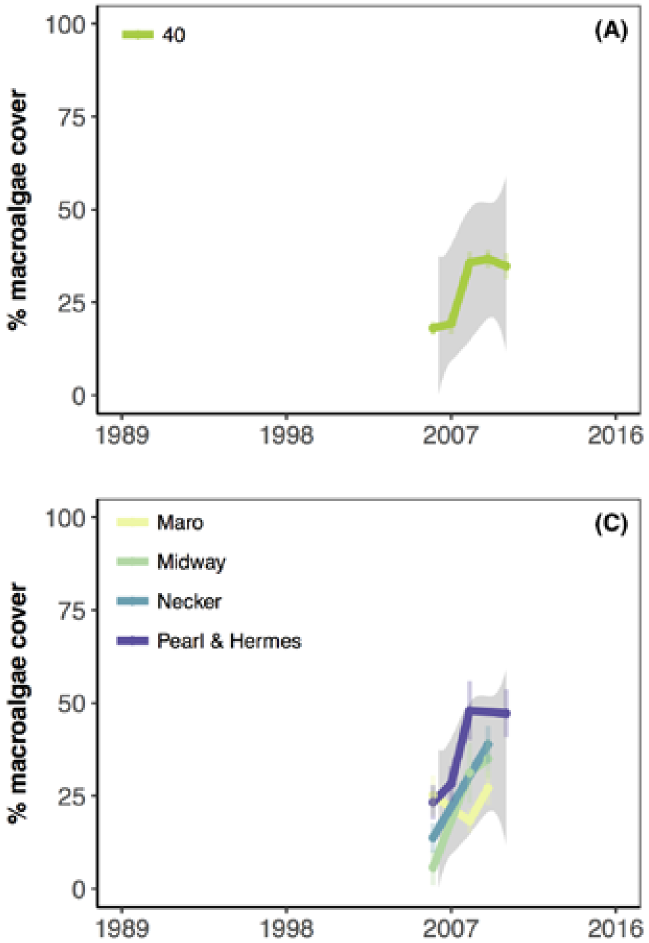


FIGURE 3.1
Average percent of live hard coral cover in the Northwestern Hawaiian Islands: (A) Contribution of each dataset, all islands combined; (B) French Frigate, Kure, Laysan, Lisianski; (C) Maro, Midway, Necker, Pearl & Hermes. The grey area represents the average loess trend when several islands are combined.



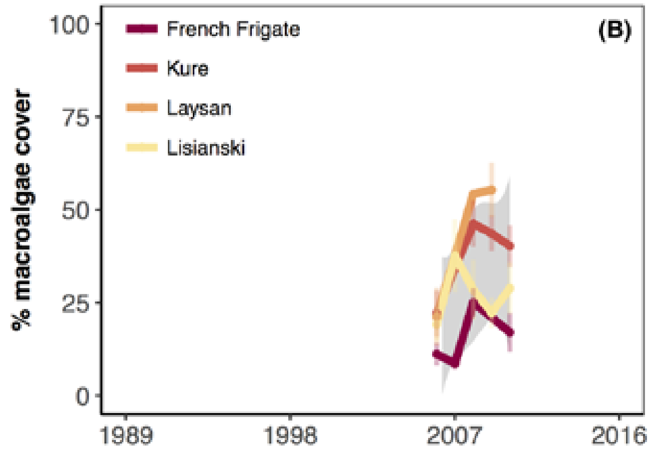
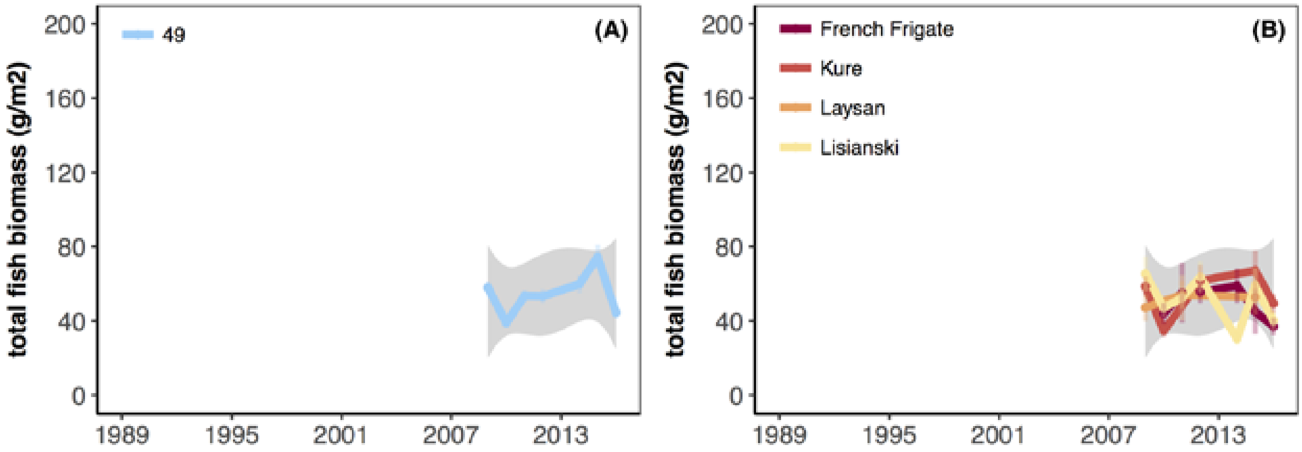


FIGURE 3.2
Average percent of macroalgae cover in the Northwestern Hawaiian Islands: (A) Contribution of each dataset, all islands combined; (B) French Frigate, Kure, Laysan, Lisianski; (C) Maro, Midway, Necker, Pearl & Hermes. The grey area represents the average loess trend when several islands are combined.



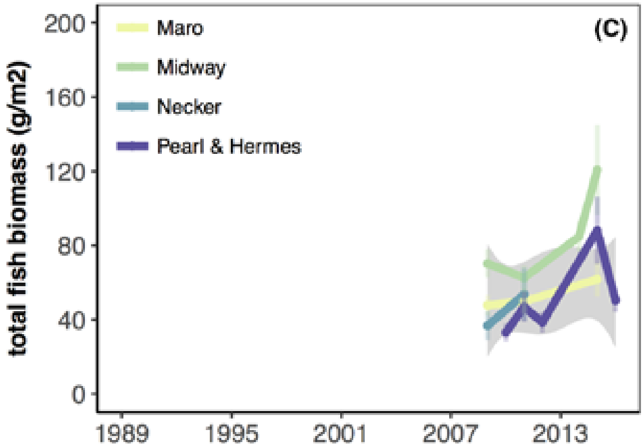
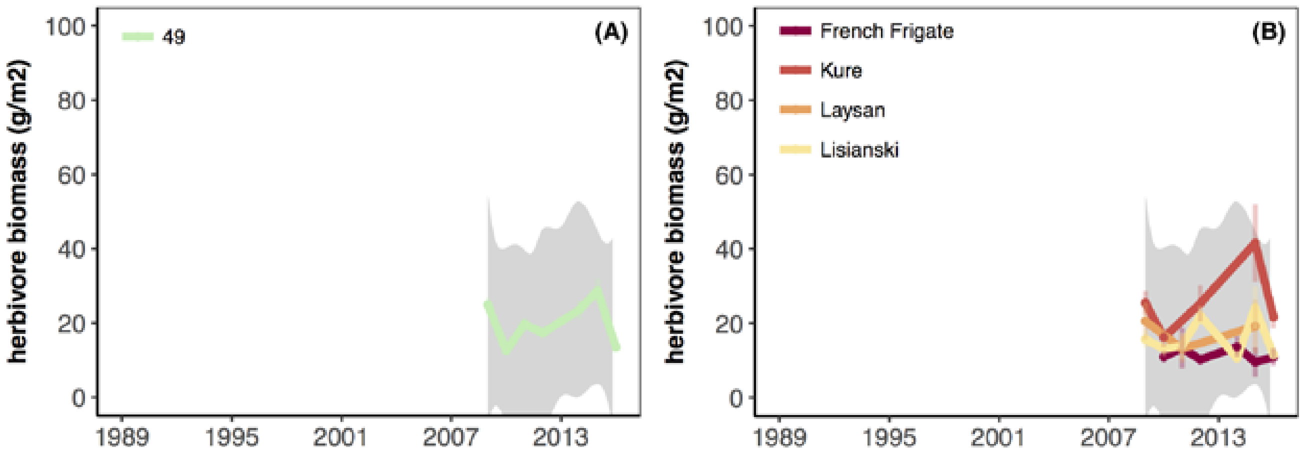


FIGURE 3.3
Average total fish biomass in the Northwestern Hawaiian Islands: (A) Contribution of each dataset, all islands combined; (B) French Frigate, Kure, Laysan, Lisianski; (C) Maro, Midway, Necker, Pearl & Hermes. The grey area represents the average loess trend when several islands are combined.



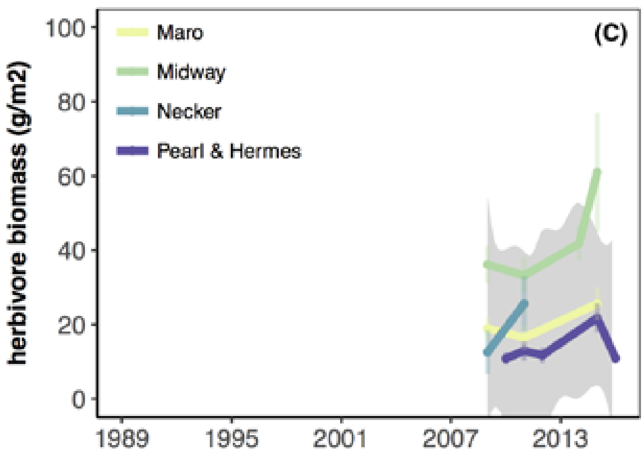
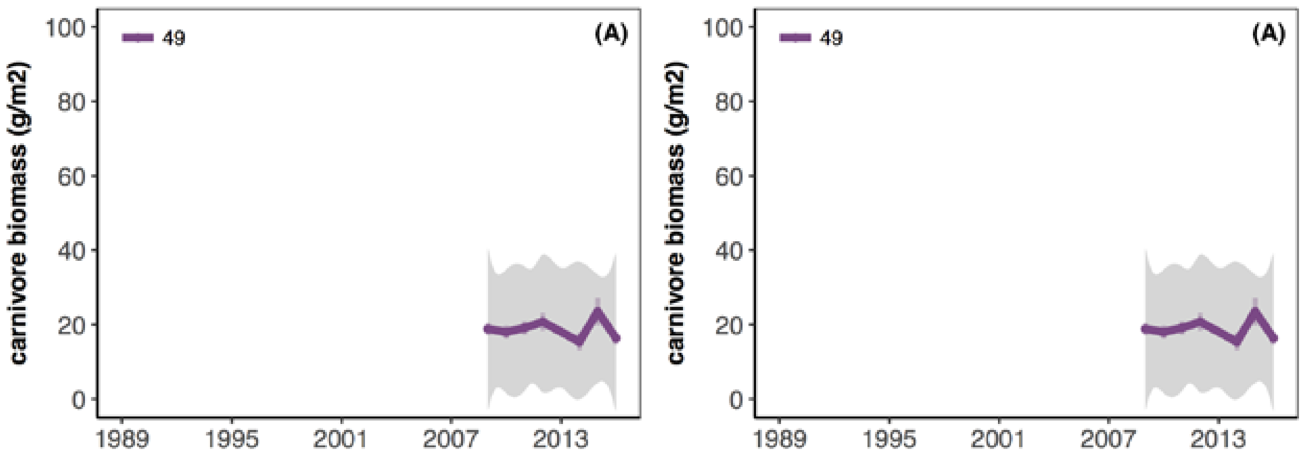


FIGURE 3.4
Average herbivore fish biomass in the Northwestern Hawaiian Islands: (A) Contribution of each dataset, all islands combined; (B) French Frigate, Kure, Laysan, Lisianski; (C) Maro, Midway, Necker, Pearl & Hermes. The grey area represents the average loess trend when several islands are combined.



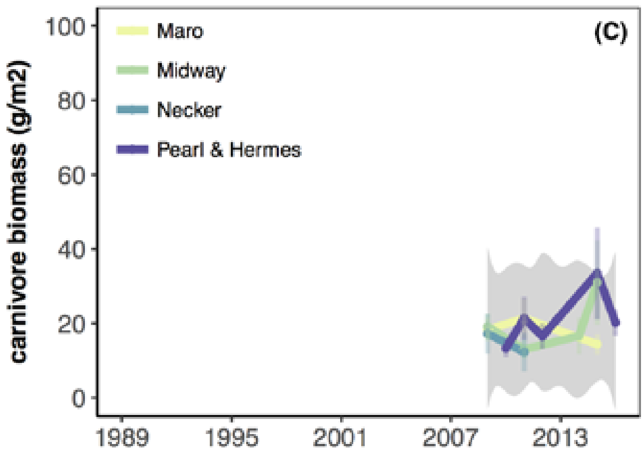
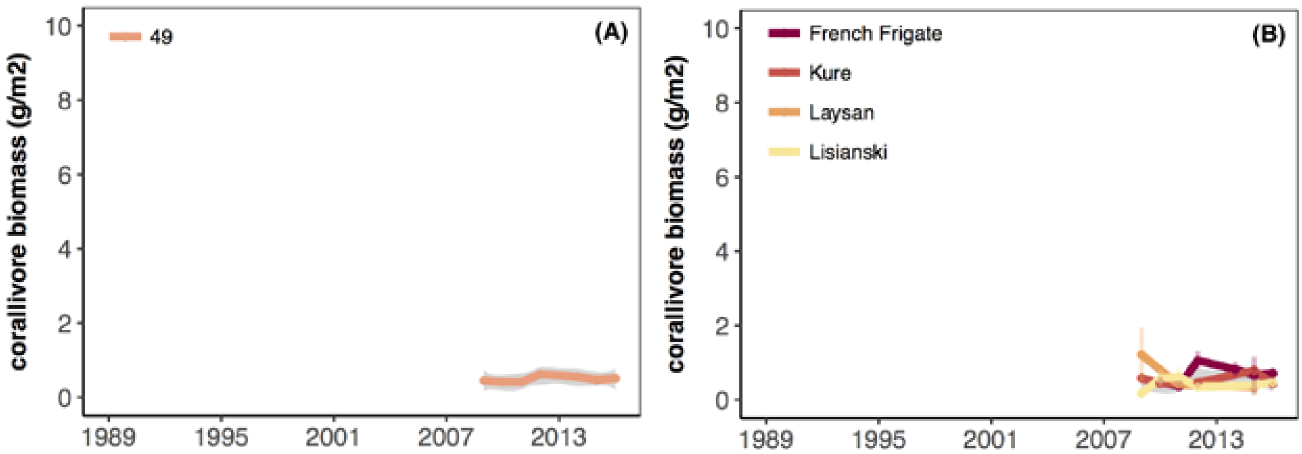


FIGURE 3.5
Average carnivore fish biomass in the Northwestern Hawaiian Islands: (A) Contribution of each dataset, all islands combined; (B) French Frigate, Kure, Laysan, Lisianski; (C) Maro, Midway, Necker, Pearl & Hermes. The grey area represents the average loess trend in carnivore fish biomass when several datasets are combined.



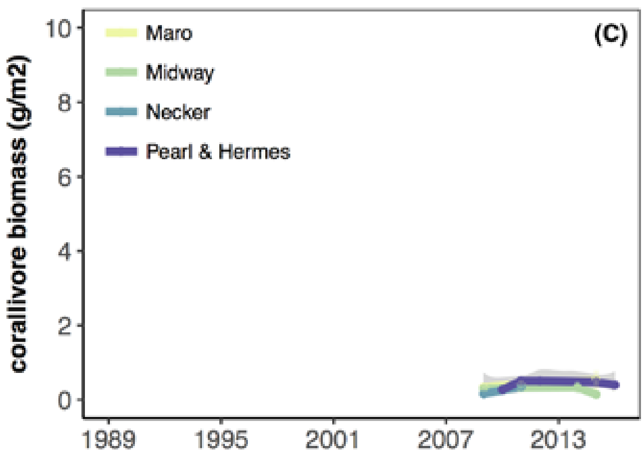


FIGURE 3.6
Average corallivore fish biomass in the Northwestern Hawaiian Islands: (A) Contribution of each dataset, all islands combined; (B) French Frigate, Kure, Laysan, Lisianski; (C) Maro, Midway, Necker, Pearl & Hermes. The grey area represents the average loess trend in corallivore fish biomass when several datasets are combined.

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Republic of Kiribati

Collaborators: Yannick Chancerelle, Vetea Liao, Sangeeta Mangubhai, Serge Planes, Randi Rotjan, Stuart Sandin, Gilles Siu, Jennifer Smith and Brian Zgliczynski

Geographic information

Maritime area: 3 600 000 km²	Reef area: 1967 km²
Land area: 811 km²	Coastal length: 1143 km
Number of islands: 33	Distance to nearest continent : 6000 km of Australia
Island type: atoll and one high island	Island ages: > 10 million years
Population: 110 110	Number of uninhabited islands: 13
Climate: maritime tropical	Major wind regime: Trade winds
Total MPAs: 27	GDP's/CAP: USD $1592

Overview

Kiribati is the largest atoll nation in the world with an EEZ that covers 3.6 million km² of ocean and consists of 3 island groups. The western Gilbert Islands group has 16 islands with 96 % of the population. Tarawa is the main island in the Gilbert group and the Republic's centre of government and administration. The Phoenix Islands are the central group with 10 islands and the eastern Line Islands group consists of 8 islands. Kiritimati Island is in the northern Line Islands, and like South Tarawa, functions as a centre of government and administration for the Phoenix and Line Islands. Three of the Line Islands (Jarvis, Kingman and Palmyra) and two of the Phoenix Islands (Howland and Baker) are US dependencies and not part of Kiribati. The Phoenix Islands Protected Area (PIPA) is a natural laboratory for global change, and PIPA coral reefs have regularly experienced major thermal events, and shown rapid regrowth and resilience (Rotjan et al. 2014).

The economy depends on foreign assistance from international development assistance programs and revenue from fisheries licences. The population of Kiribati has one of the highest levels of seafood consumption in the Pacific, and the people are heavily dependent on marine fisheries for their livelihood with limited land-based resources.

Timeline of major events

1999	Kiribati is a signatory to the Convention on Biological Diversity.
2001	Kiribati's National Biodiversity Strategy and Action Plan
2002 – 2003	Coral bleaching in the Phoenix group
2004	Bleaching event around Tarawa (Gilbert Islands)
2008	The Phoenix Islands Protected Area (PIPA) was declared. This covers 410 500 km² and is one of the world's largest MPAs, and also the world's largest UNESCO World Heritage Site

Maps of individual surveys of substrate

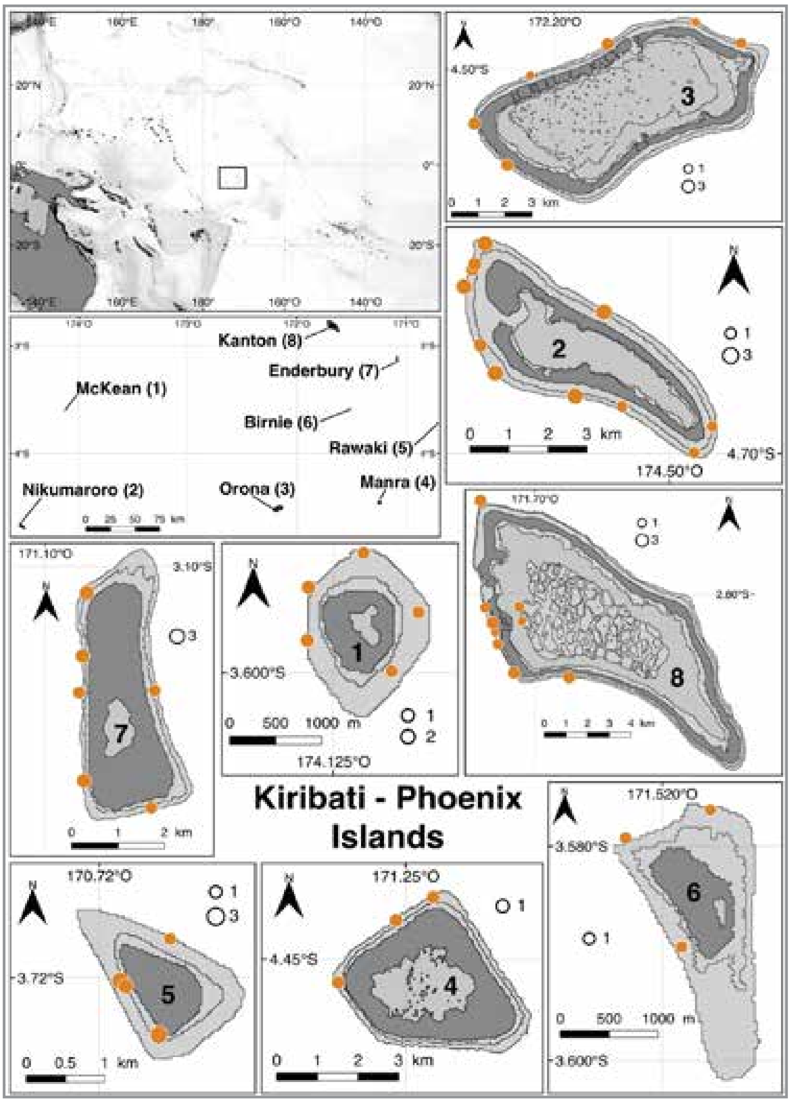

FIGURE 1
Map of Kiribati and sampled islands in the Phoenix Islands. Each colour represents a different substrate dataset (orange: dataset n°55). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

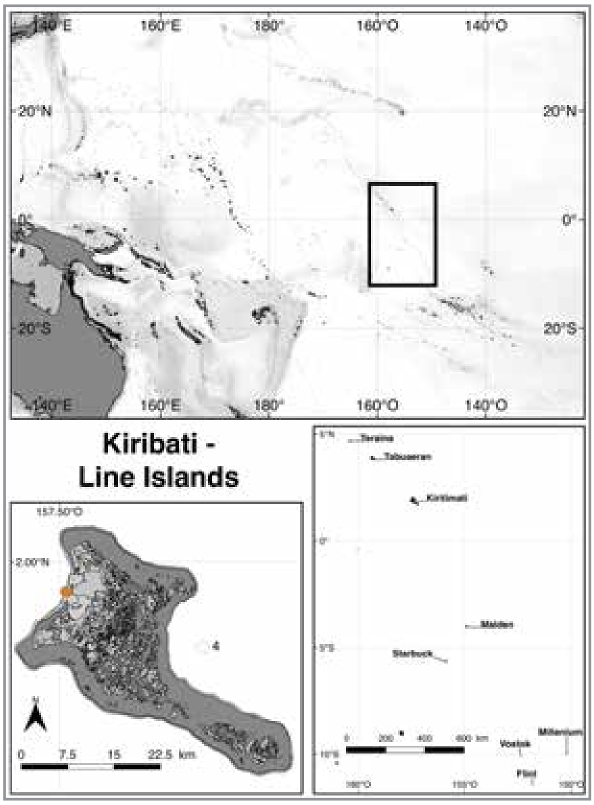

FIGURE 2
Map of Kiribati and sampled islands in the Line Islands. Each colour represents a different substrate dataset (orange: dataset n°44). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from Republic of Kiribati used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
11	University of California in San Diego	2005 - 2015	1			X
44	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	1993-2016	4	X		
45	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	2004-2016	4			X
55	PIPA – New England Aquarium	2009 - 2015	3	X	X	

Trends

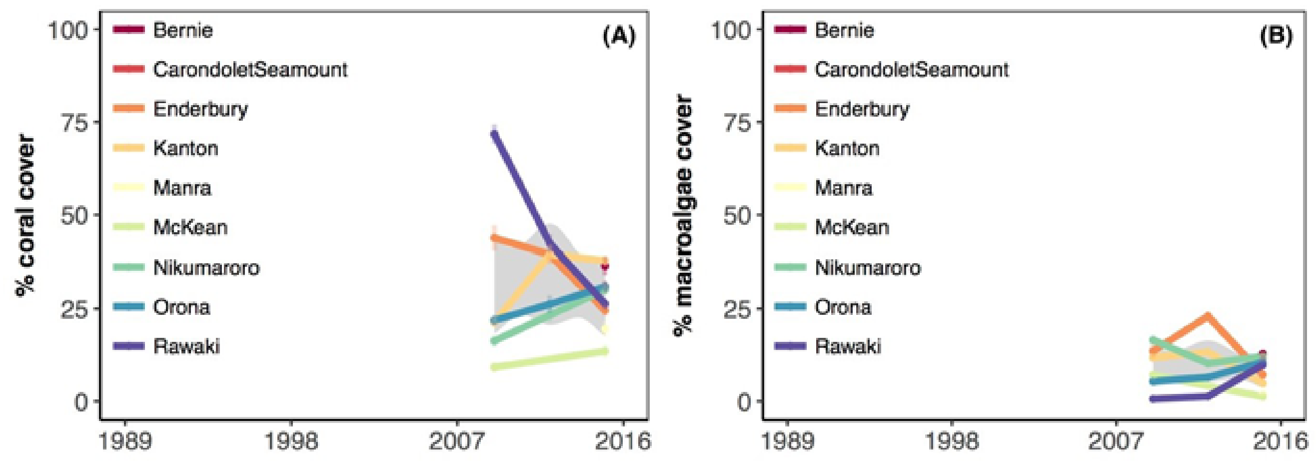

FIGURE 3.1
Average percent of (A) live hard coral cover and (B) macroalgae cover for the PIPA. The grey area represents the average loess trend for all islands combined.

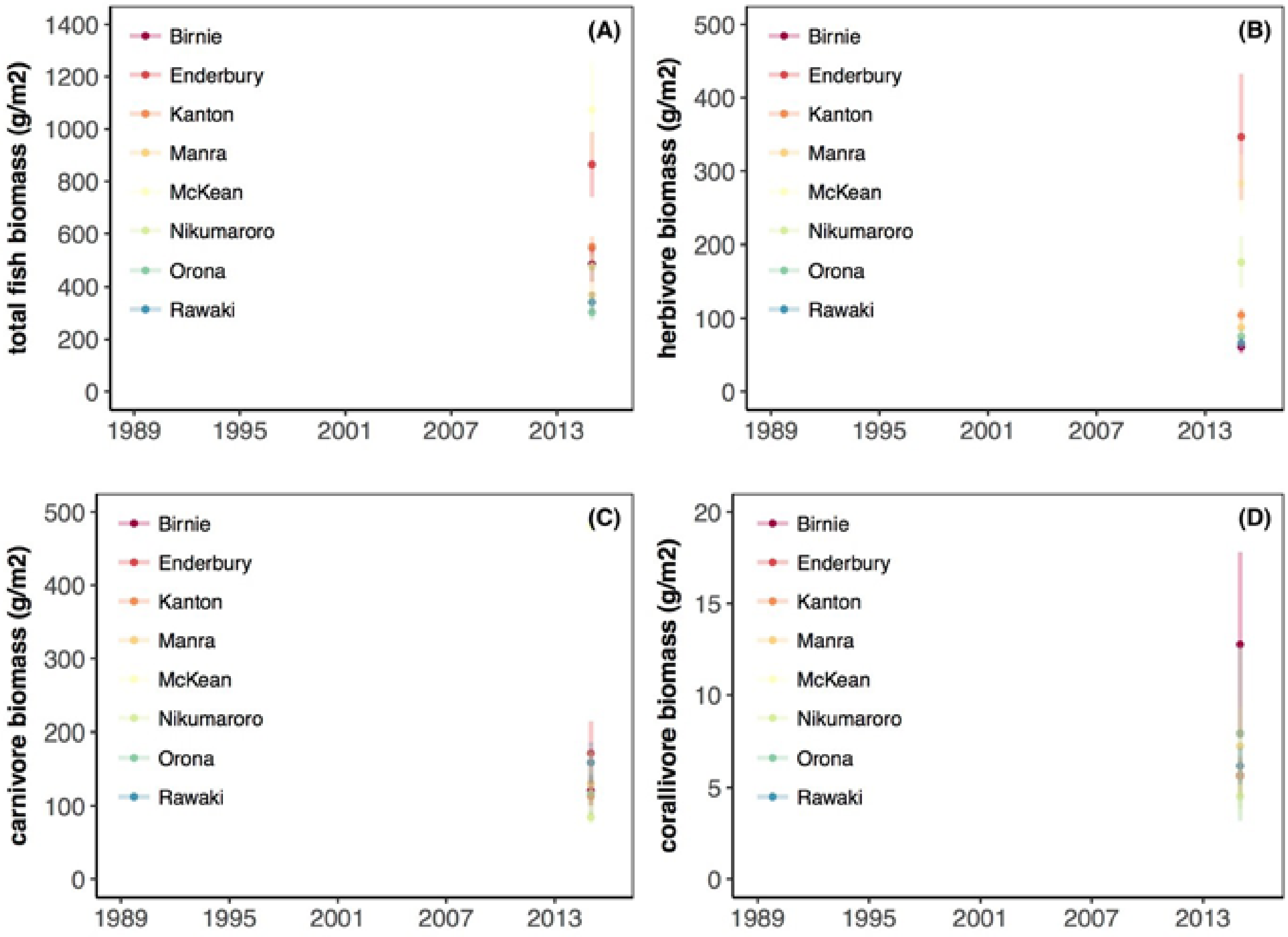

FIGURE 3.2
Average fish biomass in the PIPA: (A) Total; (B) Herbivore; (C) Carnivore; (D) Corallivore.

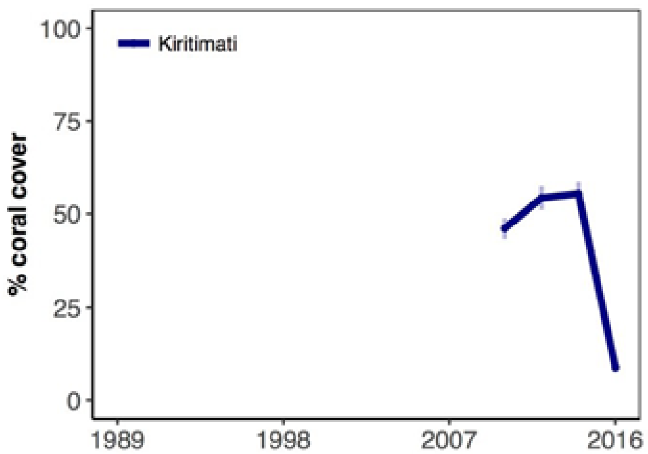

FIGURE 3.3
Average percent of live hard coral cover in Kiritimati (Line Islands).

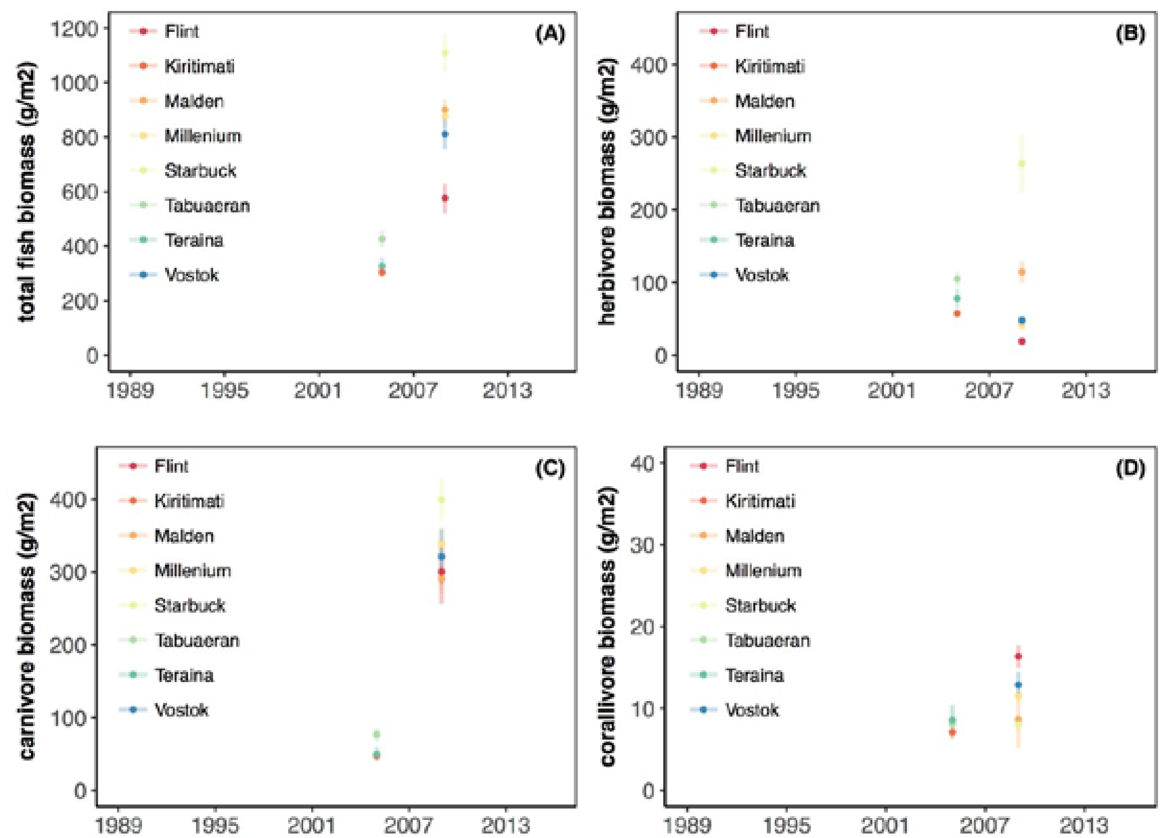

FIGURE 2.4
Average fish biomass in the Line Islands: (A) Total; (B) Herbivore; (C) Carnivore; (D) Corallivore.

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Republic of the Marshall Islands

Collaborators: Jessie Capelle, Karl Fellenius, Don Hess, Peter Houk,
Emma Kabua-Tibon and Lyla Lemari

Geographic information

Maritime area: 2 131 000 km²	**Reef area: 1 995 km²**
Land area: 181.4 km²	**Coastal length: 370.4 km**
Number of islands: 34	**Distance to nearest continent: > 3400 to Australia**
Island type: atoll and islet	**Island age: 50 million years**
Population: 52 993	**Number of uninhabited islands: 10**
Climate: tropical	**Major wind regime: Northeast trade winds**
Total MPAs: 41	**GDP's/CAP: $2900**

Overview

Since 1986, the Republic of the Marshall Islands (RMI) has been an independent state. As part of the Compact of Free Association (COFA), the RMI and the United States of America have arrangements to share access, services and defence agreements. RMI encompasses approximately 1 225 individual islands and islets. The islands are grouped into 29 coral atolls and 5 low-lying coral islands lying in two island chains: Ralik (sunset) chain in the west and Ratak (sunrise) chain in the east. The coral reefs of the RMI support a diverse marine assemblage including 222 species of macroalgae, 3 species of seagrass, 1655 species of molluscs, 362 species of corals, 728 species of crustaceans, 126 species of echinoderms, and 860 species of reef fishes.

Two thirds of the population live on the islands of Majuro and Ebeye, and the small tourism industry is focused around Majuro's northern lagoon which has small-scale resorts and dive shops. Also, an active aquarium fish trade exports tens of thousands of live fish every year.

Timeline of major events

1946-1958	67 nuclear tests in the northern Marshalls
1988	The Marshall Islands Marine Authority Act regulates foreign fishing and vessel activities in RMI waters, regulates domestic fisheries (essentially on the methods use) and protects some marine species (e.g. marine turtle)
1991	Typhoon Zelda hit the southern atolls
1992	Typhoon Axel hit Majuro; Typhoon Gaye hit the northern atolls
1997	Typhoon with considerable damage to Ailinglaplap
2000	The National Biodiversity Strategy and Action Plan and the National Biodiversity Report were approved. Both address the need for management and conservation of natural resources
2004	Severe COTS (Crown-of-Thorns starfish, *Acanthaster planci*) outbreaks around Majuro, Acropora species have been decimated (over 90% mortality)
2006	The RMI is a signatory to the Micronesia Challenge, which commits the RMI to effectively conserving 30% of marine resources and 20% of terrestrial resources by 2020
2010	Bikini Atoll became the Marshall Island's first World Heritage site on 31 July.
2013	Moderate coral bleaching event around many of the atolls including Majuro

Maps of individual surveys of substrate

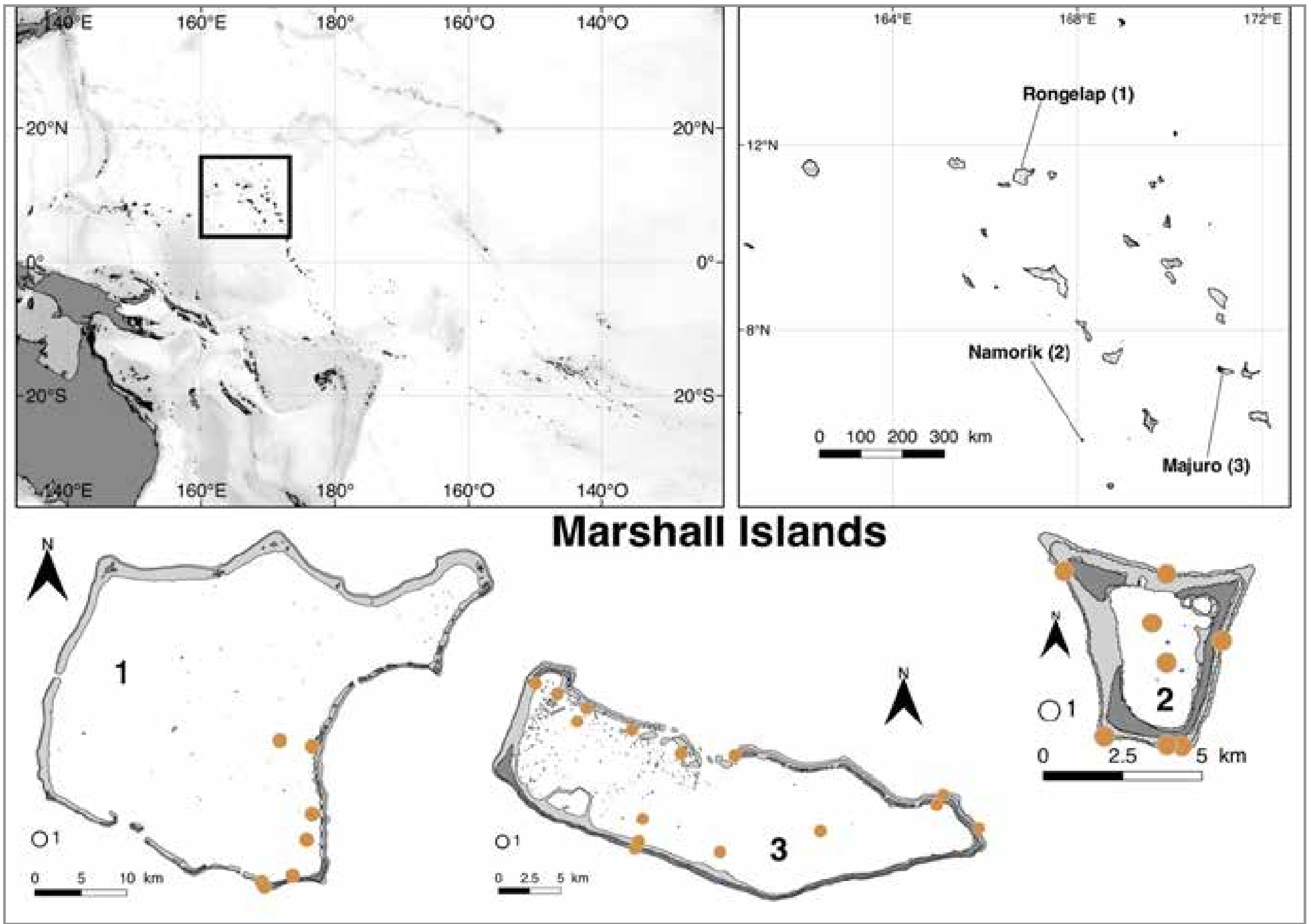

FIGURE 1

Map of the Marshall Islands. Each colour represents a different dataset (orange: dataset n°22). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from the Marshall Islands used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
22	Micronesia Challenge – University of Guam	2011 - 2014	3	X	X	
23	Micronesia Challenge – University of Guam	2011 - 2013	1			X

Trends

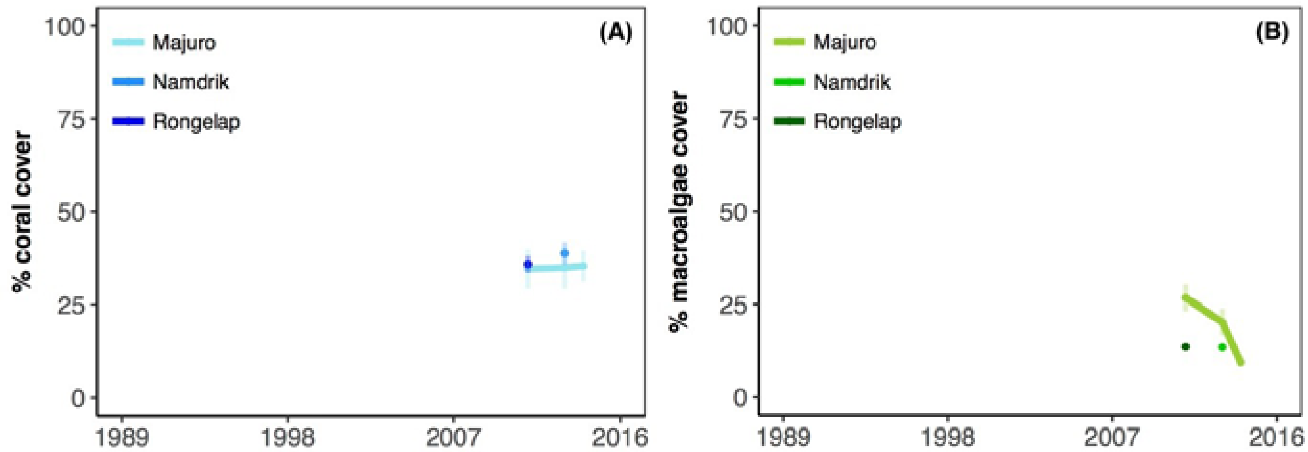

FIGURE 2.1
Average percent of (A) live hard coral cover and (B) macroalgae cover for Majuro, Namdrik and Rongelap in the Marshall Islands.

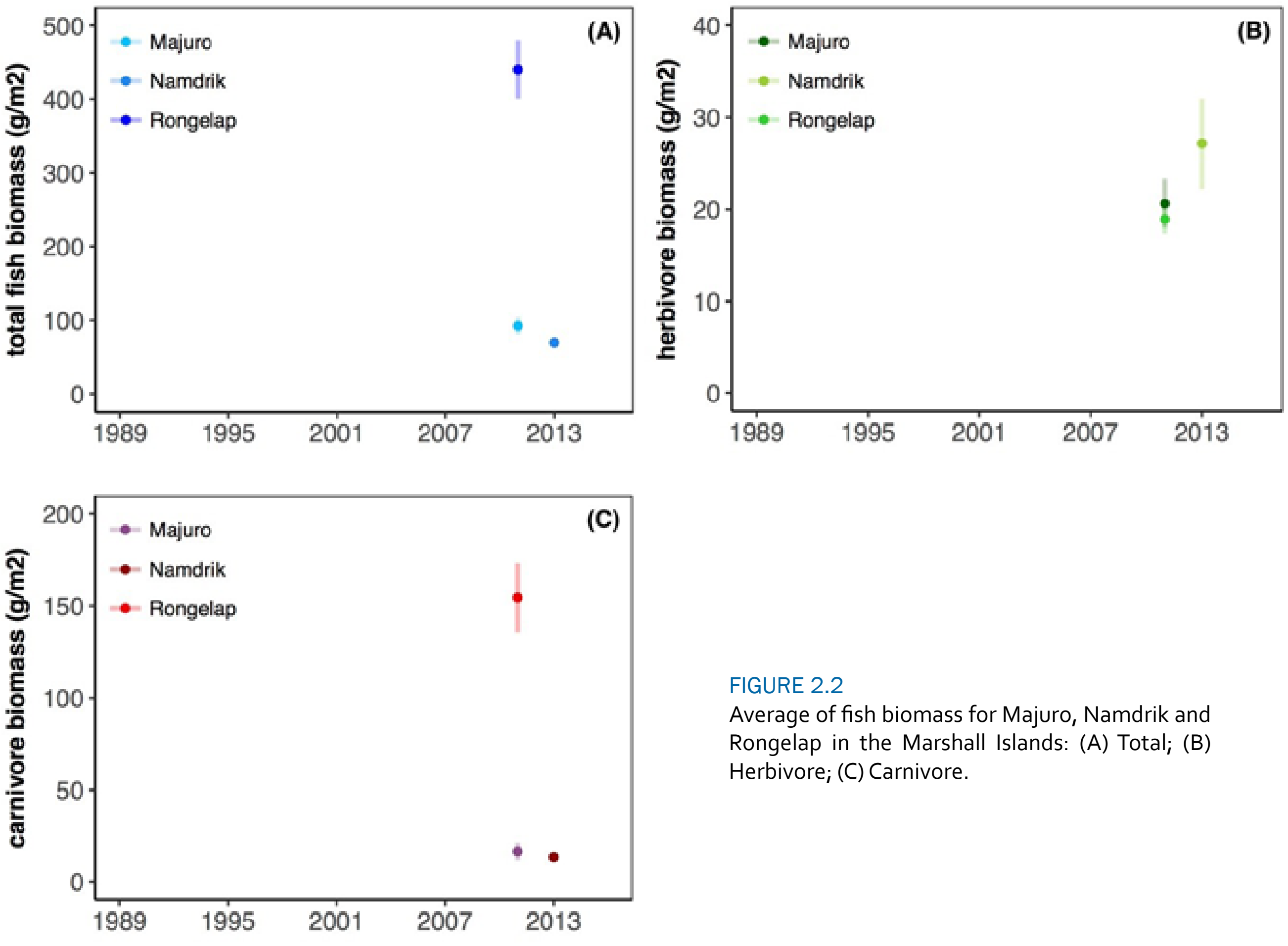

FIGURE 2.2
Average of fish biomass for Majuro, Namdrik and Rongelap in the Marshall Islands: (A) Total; (B) Herbivore; (C) Carnivore.

General Literature

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New Caledonia

Collaborators: Nicolas Guillemot, Andy Wright, Sandrine Job, Antoine Gilbert and Tom Heintz

Geographic information:

Maritime area: 1 740 000 km^2	Reef area: 4 537 km^2 (only reef formation)
Land area: 18 757 km^2	Coastal length: 2 254 km
Number of islands: 5 main islands, > 100 small islands and islets	Distance to nearest continent: 1 500 km of Australia
Island type: volcanic, atoll	Island age: separated from Australia, 66 million years ago
Population: 268 767	Number of uninhabited islands: > 50
Climate: Tropical	Major wind regime: Southeast trade winds
Total MPAs: 13	GDP's/CAP: USD $38 921

Overview

New Caledonia has been an overseas French collectivity since 1946, whose main island is Grande Terre. New Caledonia contains nine major reef types, including fringing reefs, single barrier reefs, double barrier reefs, atolls with lagoons, raised atolls and coral islets (Andréfouët S & Torres-Pulliza D 2004). New Caledonia's population is concentrated in the southern province of Grande Terre (more than 70% of the population), and particularly in Nouméa, the capital city with 40% of the population. Ore mining (especially nickel) is one of the major sources of the economy. Tourism is also an important activity in New Caledonia.

Reefs of New Caledonia, due to their proximity to the Coral Triangle, have high biodiversity with at least 350 species of hard corals, 650 species of other cnidarians (jellyfish and soft corals), 151 species of sponges, 220 species of ascidians, 254 species of echinoderms, 802 species of molluscs, 841 species of crustaceans, 1695 species of fishes, 14 species of sea snakes, 4 species of turtles and 22 species of marine mammals (Chin et al. 2011).

Timeline of major events

2003	Cyclone Erica (affecting Grande Terre and Île des pins)
2008	The lagoons of New Caledonia were listed on the UNESCO World Heritage List, covering an area of 15 743 km2 that includes 60% of New Caledonia's total reef area.
2009	3 MPAs were established on the north-eastern coast (between Hienghene and Pouebo)
2011	Strong tropical depression Vania (impact on outer reefs)
2014	Natural Park of the Coral Sea (1 291 000 km²)
2016	Bleaching event in February-April; COTS outbreaks (high but localised) at Touho on the Grande Terre between April and October

Maps of individual surveys of substrate

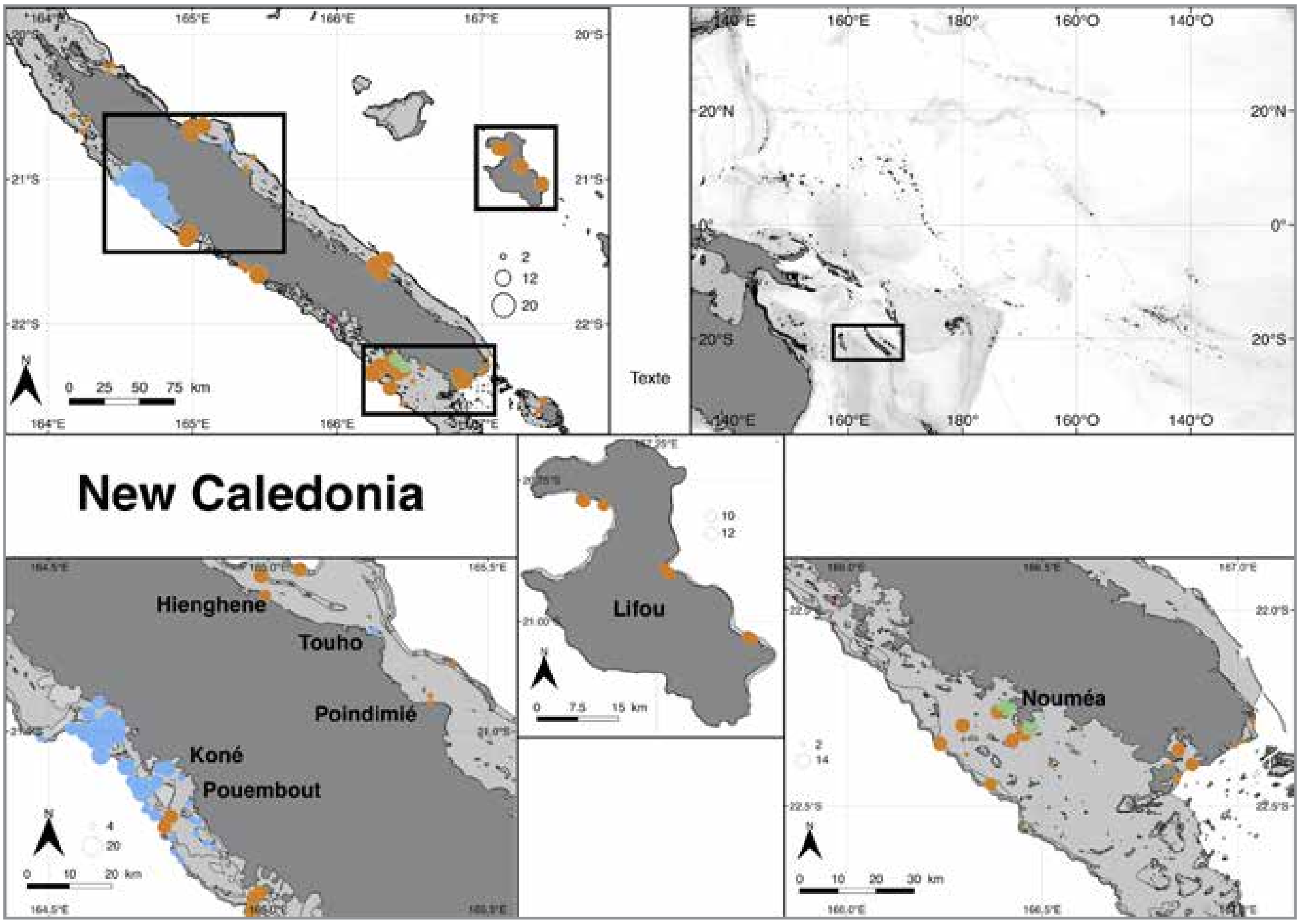


FIGURE 1

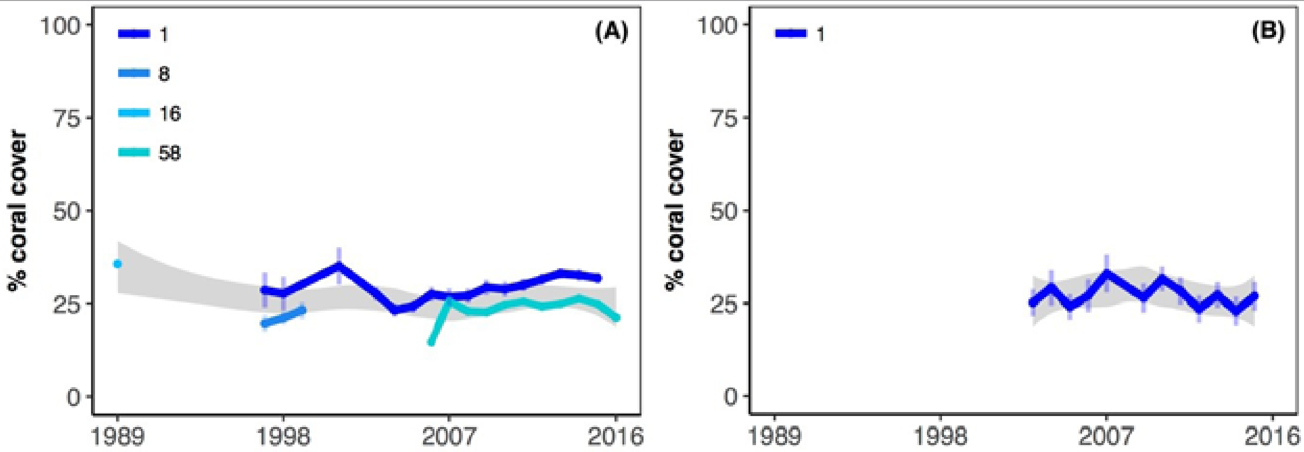
Map of New Caledonia. Each colour represents a different dataset (orange: dataset n°1; blue: dataset n°58; green: dataset n°8; violet: dataset n°16). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from New Caledonia used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
1	RORC - Cortex	1997 - 2015	16	X	X	
2	RORC - Cortex	1997 – 2015	16			X
3	RORC - Cortex	2012 - 2015	3			X
4	Michel Kulbicki – IRD, Perpignan, France	1997 - 1999	3			X
8	Michel Kulbicki – IRD, Perpignan, France	1997 - 1999	3	X	X	
16	Michel Kulbicki – IRD, Perpignan, France	1989	1	X	X	
17	Michel Kulbicki – IRD, Perpignan, France	1989	1			X
58	Koniambo Nickel SAS – GINGER-SOPRONER – IRD, Nouméa, Nouvelle Calédonie	2006 - 2016	11	X	X	
59	Koniambo Nickel SAS – GINGER-SOPRONER – IRD, Nouméa, Nouvelle Calédonie	2006 - 2015	10			X

Trends



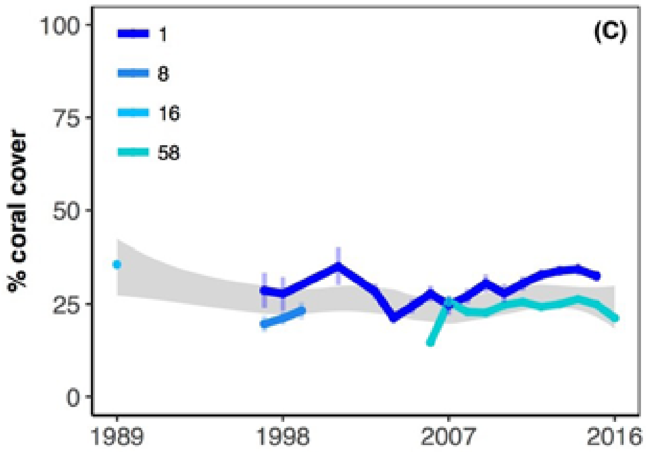
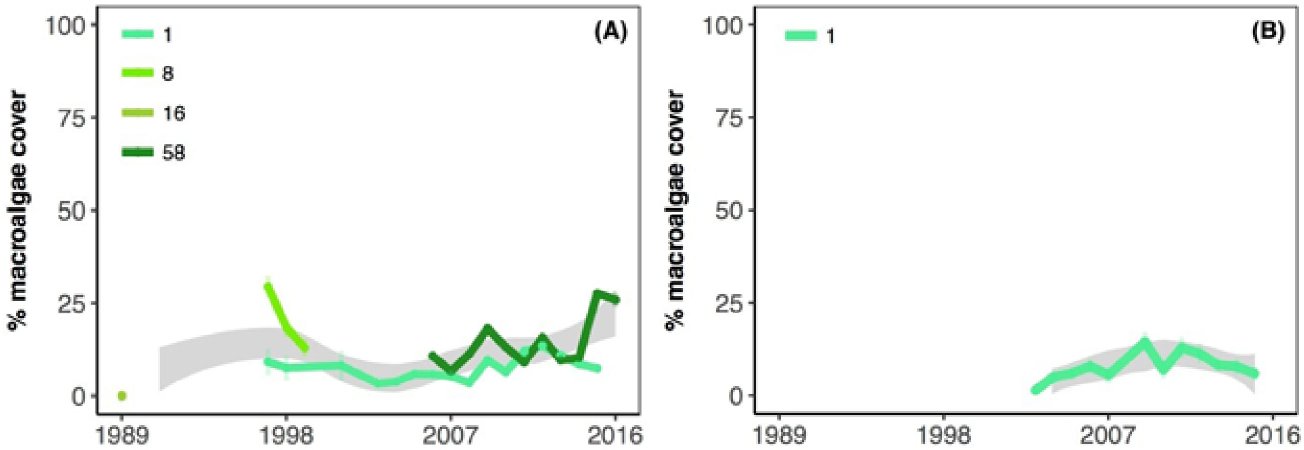


FIGURE 2.1

Average percent of live hard coral cover in New Caledonia: (A) Contribution of each dataset, all islands combined; (B) Lifou; (C) Grande Terre. The grey area represents the average loess trend in coral cover when several datasets are combined.



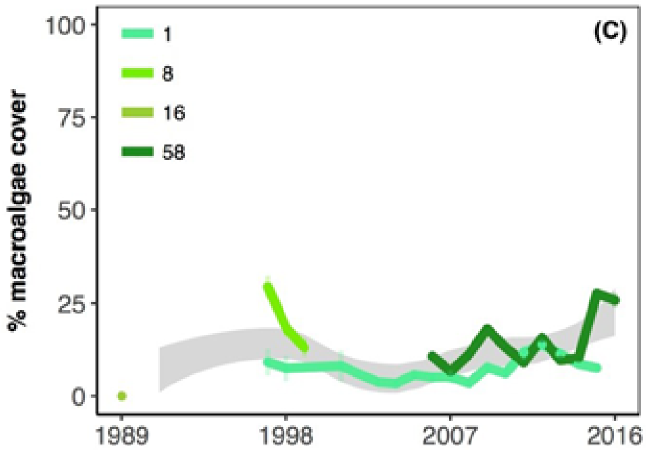


FIGURE 2.1

Average percent of macroalgae cover in New Caledonia: (A) Contribution of each dataset, all islands combined; (B) Lifou; (C) Grande Terre. The grey area represents the average loess trend in macroalgae cover when several datasets are combined.

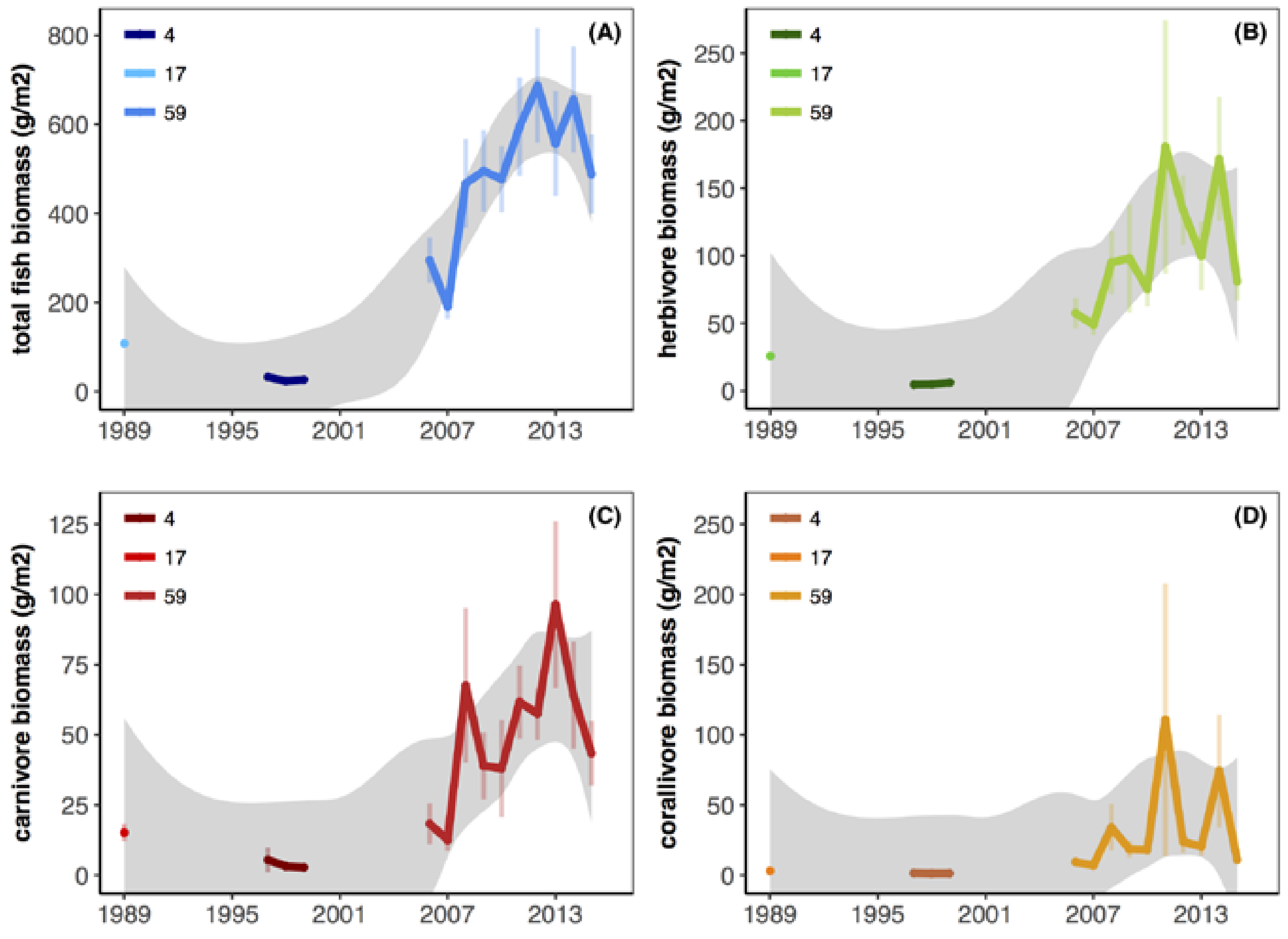


FIGURE 2.3
Average fish biomass in New Caledonia and contribution of different datasets: (A) Total; (B) Herbivore; (C) Carnivore; (D) Corallivore. The grey area represents the average loess trend in fish biomass when several datasets are combined.

General Literature

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Pacific Remote Island Area

Collaborators: Marie Ferguson, Adel Heenan, Stuart Sandin, Jennifer Smith, Bernardo Vargas-Angel, Ivor Williams and Brian Zgliczynski

Geographic information

Maritime area: 407 635 km²	Reef area: > 253 km²
Land area: 22 km²	Coastal length: > 37.2 km
Number of islands: 7	Distance to nearest continent: -
Island type: low coral atoll	Island ages: < 160 million years for the older
Population: < 125	Number of uninhabited islands: 6
Climate: tropical (Johnston, Kingman) ; equatorial (for the others)	Major wind regime: Trade winds
Total MPAs : 8	GDP's/CAP: USD

Overview

The U.S Pacific Remote Island Area (PRIA) contains 7 islands, atolls and reefs in the Central Pacific, under US jurisdiction especially managed by the Fish and Wildlife Service of the United States Department of the Interior. Most of the PRIAs were materially modified during the World War II. The U.S constructed and occupied military bases at Johnston, Palmyra, Wake, Midway and Baker.

Timeline of major events

1979	Bleaching event at Wake
1984	Cyclone Keli
1990	Bleaching event at Johnston and Kingman
1992	Cyclone Ekeka have been observed in the Kingman/Palmyra EEZ
1993	Cyclone Keoni in Johnston
1994	Cyclone John in Johnston
2004	Termination of military activities at Johnston Atoll permanently closed all sport-fishing activity at the atoll
2009	The Pacific Remote Islands Marine National Monument was established by presidential proclamation

Maps of individual surveys of substrate

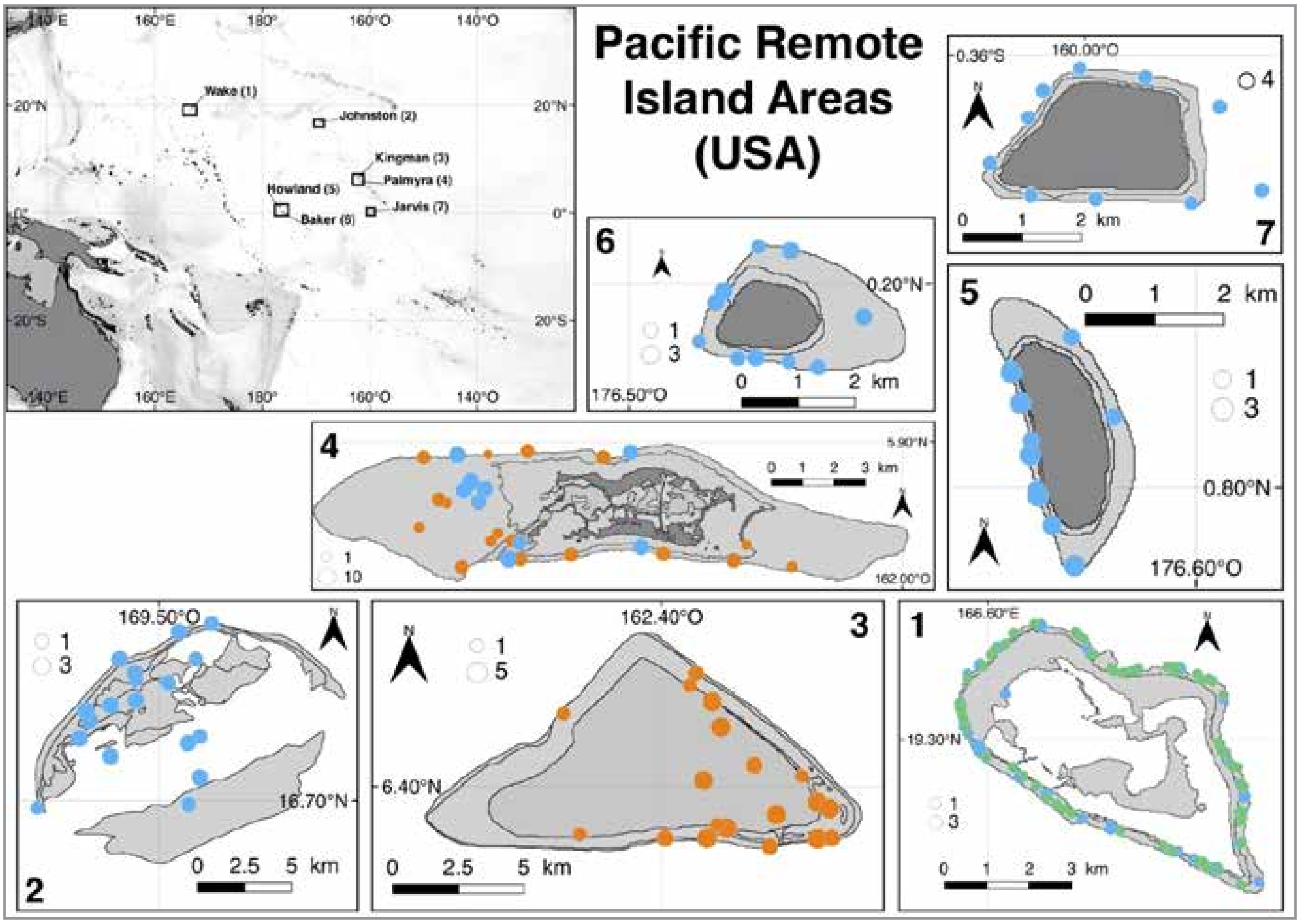

FIGURE 1
Map of the Pacific Remote Island Areas (PRIAs). Each colour represents a different substrate dataset (orange: dataset n°40; blue: dataset n°54; green: dataset n°43). Circle size represents the total number of times the site was sampled.

Table of data sources

TABLE 1
Data sources from the Pacific Remote Island Area used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
40	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2005 - 2012	4	X	X	
43	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2011 - 2014	1	X	X	
49	Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA IRC, USA	2007 - 2015	3			X
54	Jennifer Smith – University of California San Diego	2009 - 2015	6	X	X	

Trends

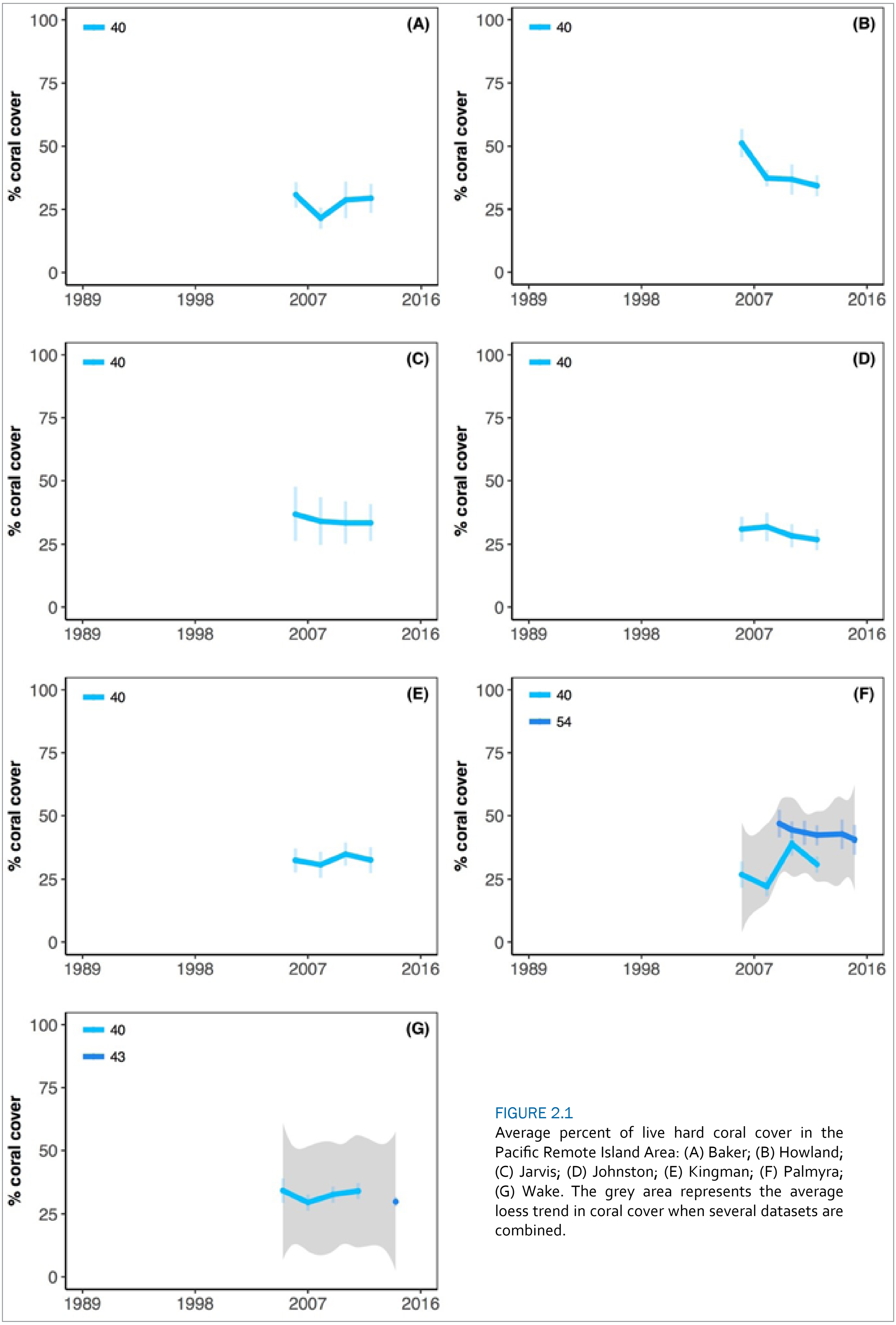

FIGURE 2.1
Average percent of live hard coral cover in the Pacific Remote Island Area: (A) Baker; (B) Howland; (C) Jarvis; (D) Johnston; (E) Kingman; (F) Palmyra; (G) Wake. The grey area represents the average loess trend in coral cover when several datasets are combined.

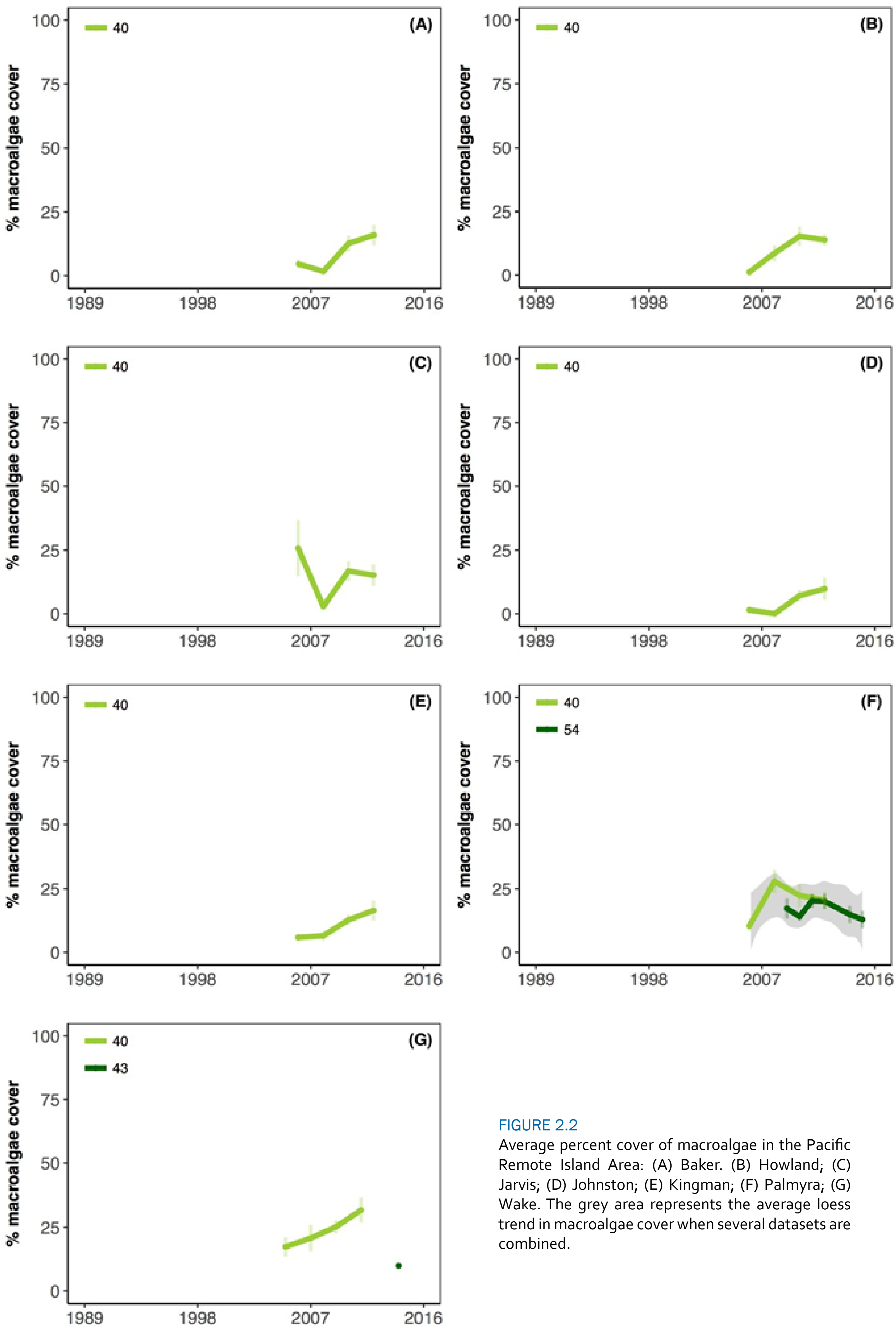

FIGURE 2.2
Average percent cover of macroalgae in the Pacific Remote Island Area: (A) Baker. (B) Howland; (C) Jarvis; (D) Johnston; (E) Kingman; (F) Palmyra; (G) Wake. The grey area represents the average loess trend in macroalgae cover when several datasets are combined.

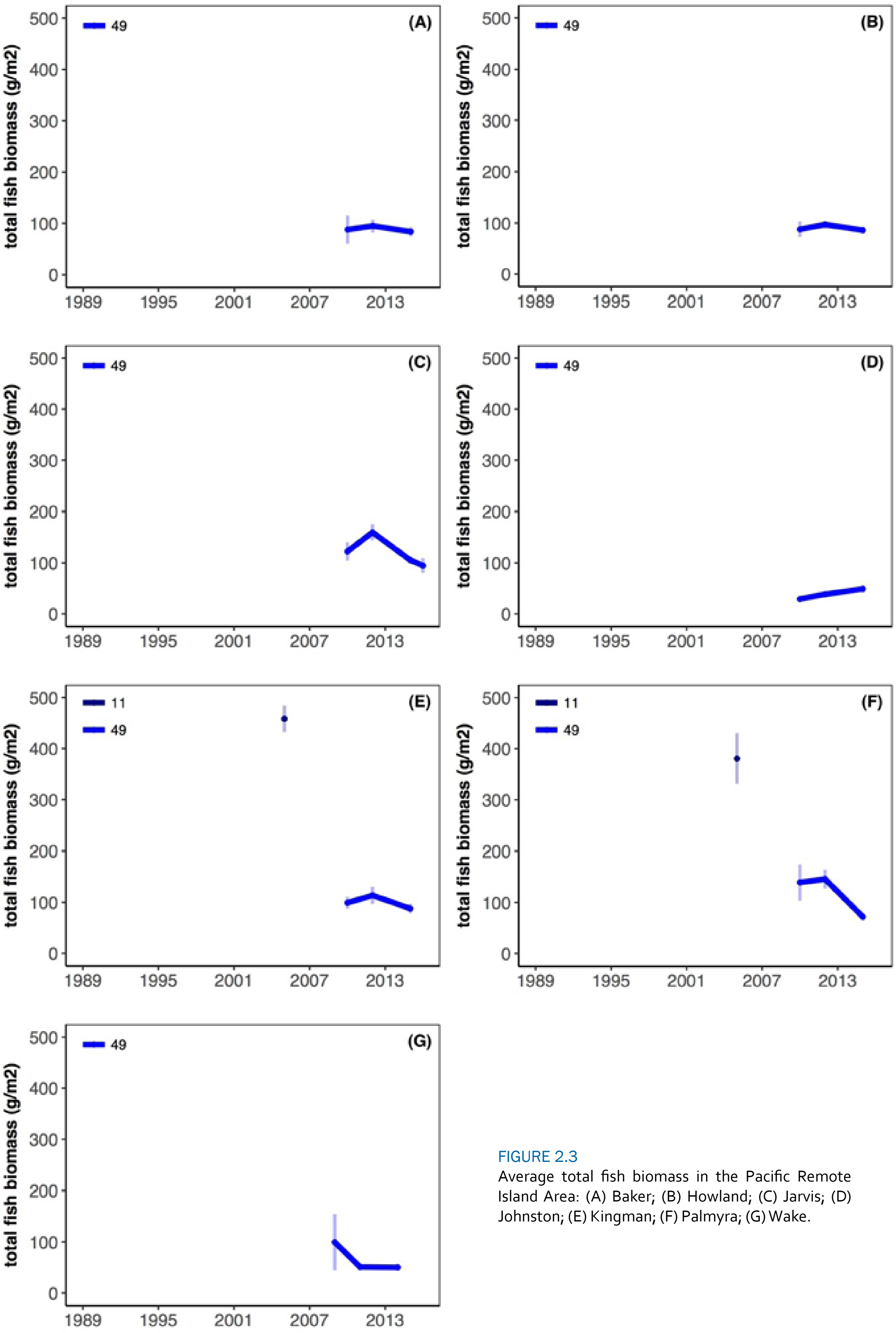

FIGURE 2.3
Average total fish biomass in the Pacific Remote Island Area: (A) Baker; (B) Howland; (C) Jarvis; (D) Johnston; (E) Kingman; (F) Palmyra; (G) Wake.

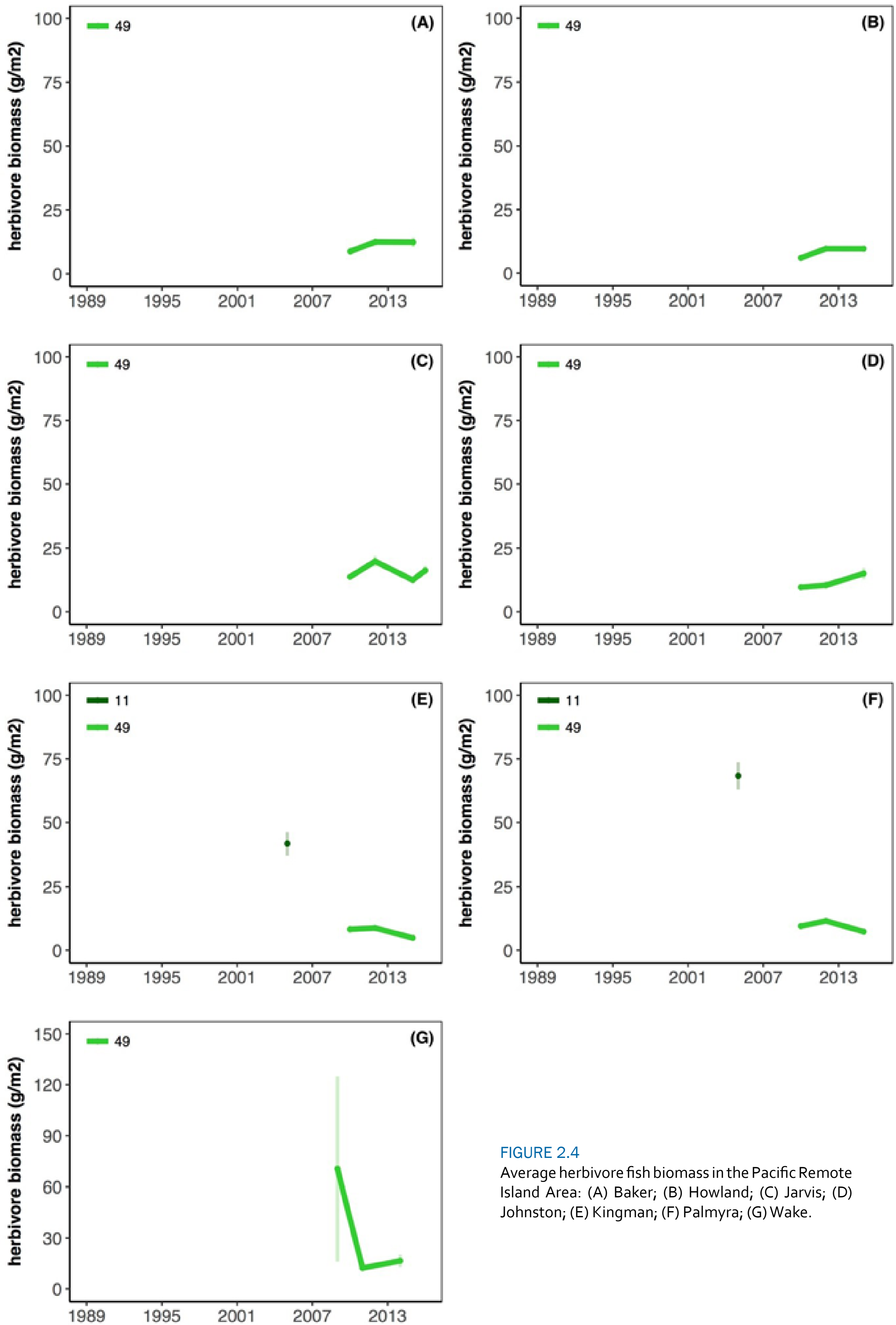

FIGURE 2.4
Average herbivore fish biomass in the Pacific Remote Island Area: (A) Baker; (B) Howland; (C) Jarvis; (D) Johnston; (E) Kingman; (F) Palmyra; (G) Wake.

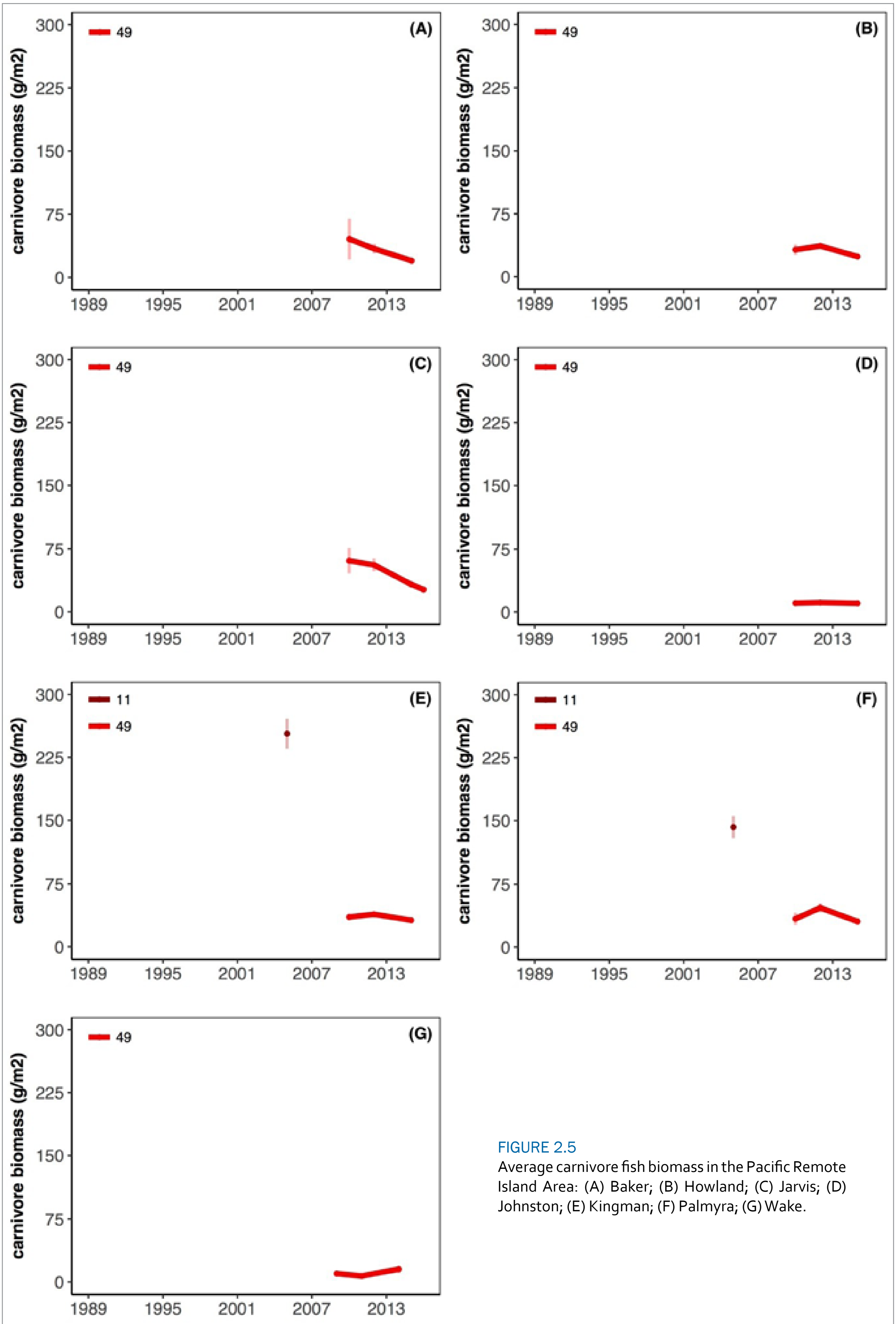

FIGURE 2.5
Average carnivore fish biomass in the Pacific Remote Island Area: (A) Baker; (B) Howland; (C) Jarvis; (D) Johnston; (E) Kingman; (F) Palmyra; (G) Wake.

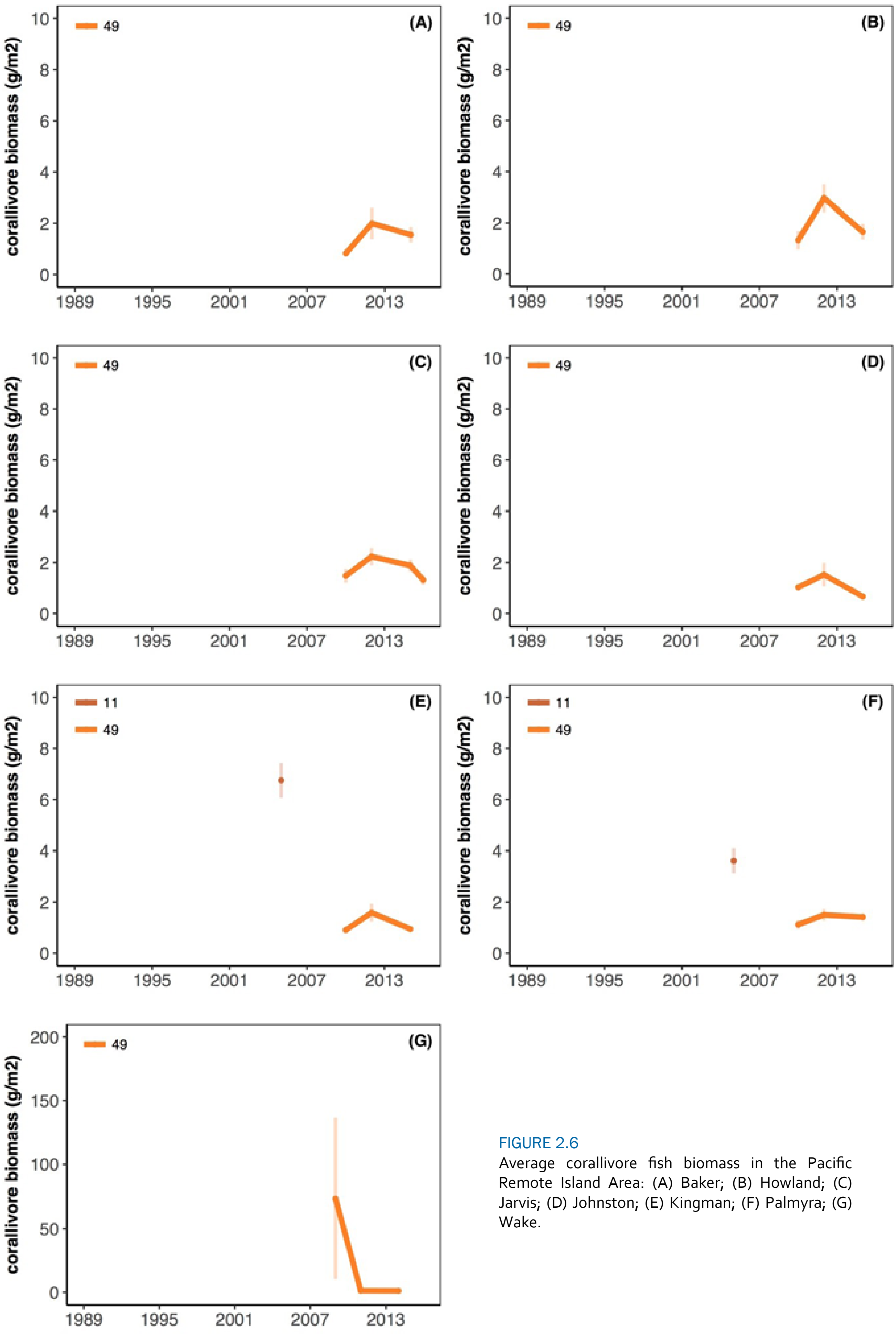

FIGURE 2.6

Average corallivore fish biomass in the Pacific Remote Island Area: (A) Baker; (B) Howland; (C) Jarvis; (D) Johnston; (E) Kingman; (F) Palmyra; (G) Wake.

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Republic of Palau

Collaborators: Yimnang Golbuu, Marine Gouezo, Geory Mereb,
Victor Nestor and Dawnette Olsudong

Geographic information

Maritime area: 629 000 km²	Reef area: 525 km²
Land area: 488 km²	Coastal length: 1 519 km
Number of islands: > 700 small islands and islets	Distance to nearest continent: 2 500 km of Australia
Island type: volcanic, atoll, raised limestone, low coral islands	Island age: 20 – 37.7 million years
Population: 21 291	Number of uninhabited islands: > 700
Climate: tropical	Major wind regime: Northeast trade winds
Total MPAs: 32	GDP's/CAP: $16 300

Overview

The islands of Palau, included in the Caroline Islands chain, are divided into 16 states. A remote group of six islands, the Southwest Islands, are 340 to 600 km southwest of the main islands composed of Kayangel, Babeldaob, Koror, Peleliu and Angaur, while the uninhabited Rock Islands (over 700) are located in the south-western lagoon area of the main island.

Palau has a diversity of rich coral reefs including fringing, barrier and atoll reefs. Palau's reef has the most diverse coral reef fauna in Micronesia with a record of 1700 fishes, 425 coral species, 235 crustaceans, and 302 molluscs. These reefs are important to subsistence, artisanal and commercial fisheries. Tourism is one of the main economic activities of the country, with 86% of Palau's visitors coming for scuba diving and snorkeling.

Timeline of major events

1969-1979	COTS outbreaks in many areas
1998	Severe bleaching event across all the islands
2006	Implementation of the Protected Areas Network (PAN) and Signatory to the Micronesia Challenge Initiative
2009-2012	Shark sanctuary
2010	Low thermal stress event
2012	Typhoon Bopha (category 5) in outer reef located on the East
2013	Typhoon Haiyan (category 5) in outer reef located on the East
2015-2020	Palau national marine sanctuary, protecting 80% of EEZ from commercial fisheries

Maps of individual surveys of substrate

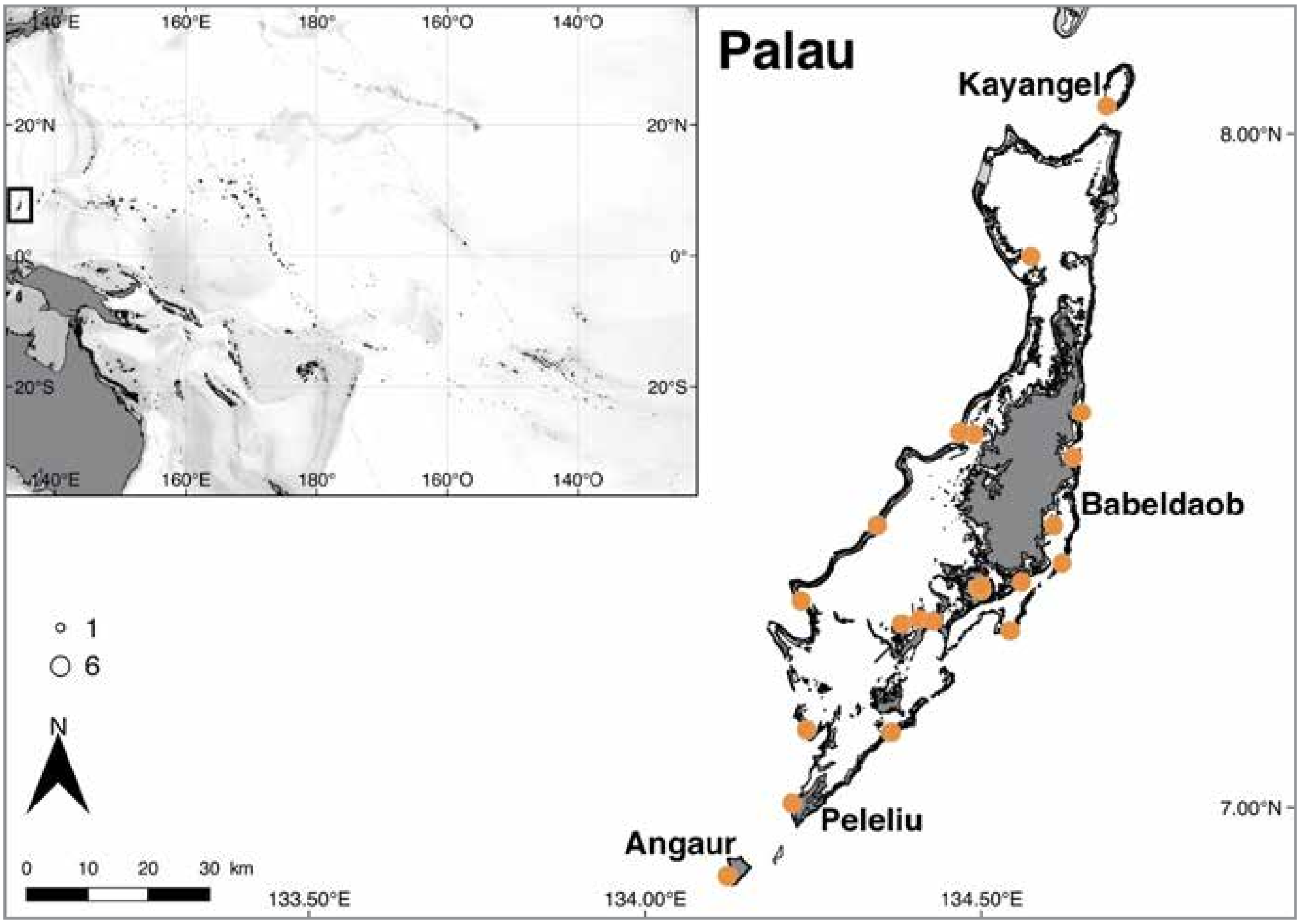


FIGURE 1
Map of Palau. Each colour represents a different dataset (orange: dataset n°14). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from Palau used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
14	PICRC, Koror, Palau	2010 - 2014	3	X	X	
15	PICRC, Koror, Palau	2010 - 2014	3			X

Trends

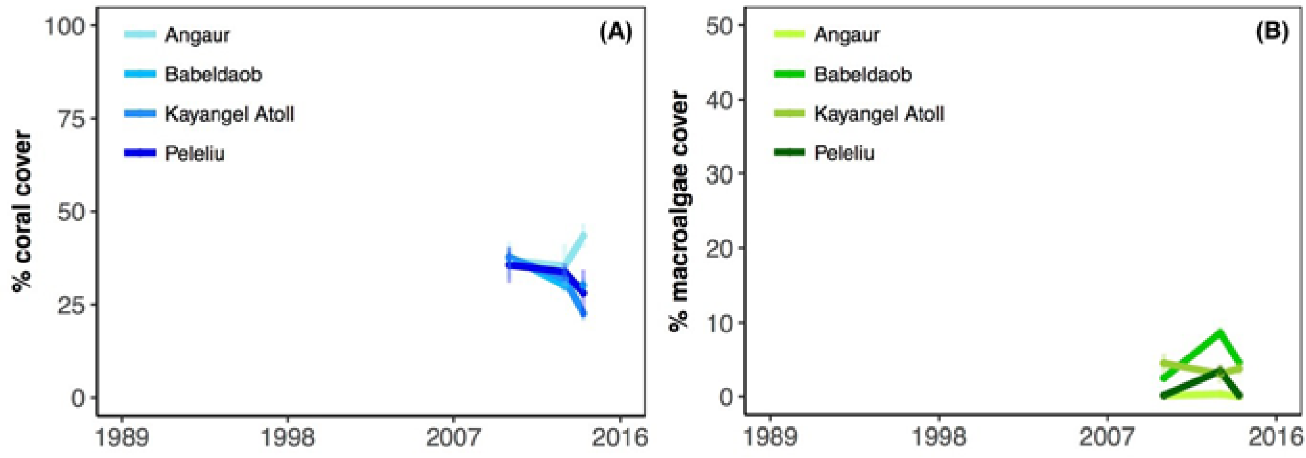
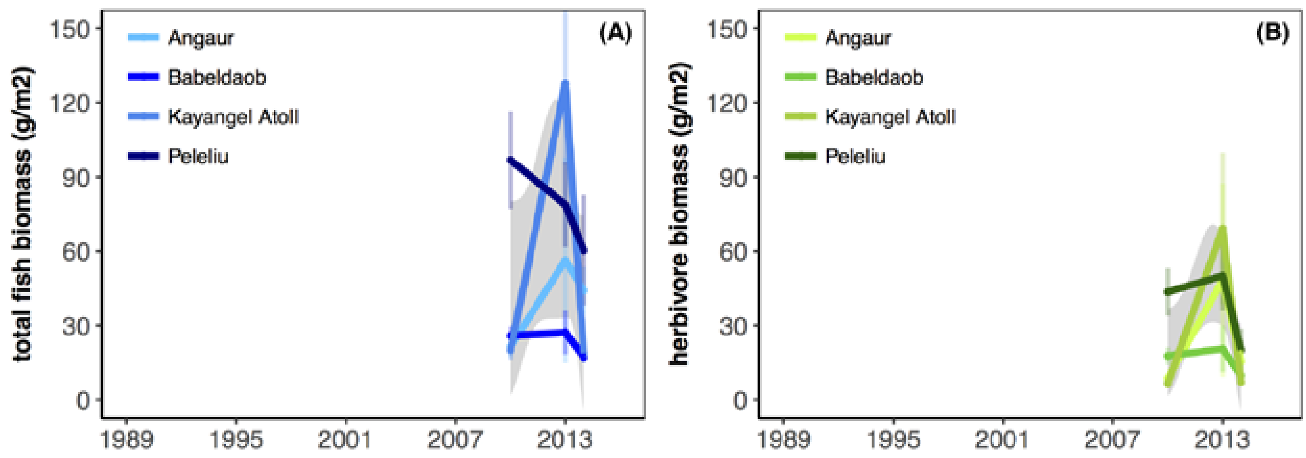


FIGURE 2.1
Average percent of (A) live hard coral cover and (B) macroalgae cover for Angaur, Babeldaob, Kayangel Atoll and Peleliu in Palau.



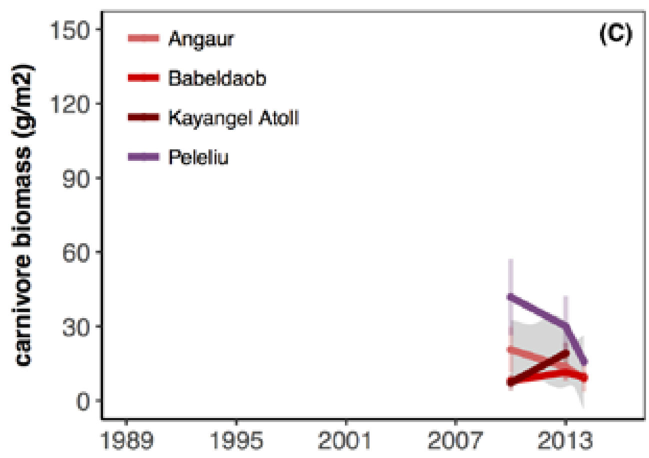


FIGURE 2.2
Average fish biomass for Angaur, Babeldaob, Kayangel Atoll and Peleliu in Palau: (A) Total; (B) Herbivore; (C) Carnivore. The grey area represents the average loess trend in fish biomass.

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Acknowledges

J. Andrew, A. Bukurrou, D. Chokai, H. Herman, J. Idechong, D. Idip, A. L. Isechal, R. Johnathan, J. Kloulechad, J. Kuartei, S. Koshiba, S. and L. Marino, C. Mersai, A. Merep, N. W. Oldiais, E. I. Otto, L. Penland, L. Rehm, M. Udui, S. Victor

Papua New Guinea

Collaborators: Maya Srinivasan, Mark McCormick, Janelle Eagle,
Stephen Neale, Mary Bonin and Geoffrey Jones

Geographic information

Maritime area: 3 120 000 km²	Reef area: 40 000 km²
Land area: 452 860 km²	Coastal length: 20 197 km
Number of islands: > 600	Distance to nearest continent: 160 km to Australia
Island type: Australian plate, volcanic, atoll	Island age: 96 million years
Population: 7 059 653	Number of uninhabited islands: > 400
Climate: equatorial	Major wind regime: winds from Intertropical Convergence Zone; trade winds and winds from monsoon
Total MPAs: > 36	GDP's/CAP: $2517

Overview

Papua New Guinea (PNG) is the largest Pacific Island nation. It comprises the eastern part of the island of New Guinea and smaller islands that include Manus to the north of the main island, New Britain and New Ireland to the northeast, and Bougainville to the east.

Most of PNG's reefs are fringing or patch reefs which dominate the northern coast and islands, and barrier reefs, which occur along the south coast. Included within the 'Coral Triangle' of biodiversity, which contains the highest marine biodiversity in the world, these reefs are extremely rich in marine species. For example, there are an estimated 400 species of coral and 860 species of fish on the coral reefs of Kimbe Bay on the island of New Britain. Many local communities in PNG are highly dependent on natural resources for food security, with an estimated 85% of the population reliant on subsistence activities to meet daily needs.

Timeline of major events

1994:	'Fisheries Act' regulates fishing activity through licensing and gear restrictions; bans the use of explosives
	The Nature Conservancy conducts a Rapid Ecological Assessment of Kimbe Bay coral reefs
1997:	Bleaching event (Kimbe Bay)
1998:	Bleaching event (Kimbe Bay)
1999:	Locally managed marine area (LMMA) comprising 4 inshore reefs established in Kimbe Bay
2000:	Bleaching event (Kimbe Bay)
	'Environment Act', the main legislation for natural resource management (became fully operational in 2004)
2001:	Bleaching event (Kimbe Bay)
2004:	Bleaching event (Kimbe Bay)
2006:	The Wildlife Conservation Society (WCS) PNG Marine Program monitors 3 'tambu' sites
2008:	Bleaching event (Kimbe Bay); moderate COTS outbreaks (Kimbe Bay)
2017:	Bleaching event (Kimbe Bay)
2018/2019:	The whole of Kimbe Bay to be protected as PNG's first MPA

Maps of individual surveys of substrate

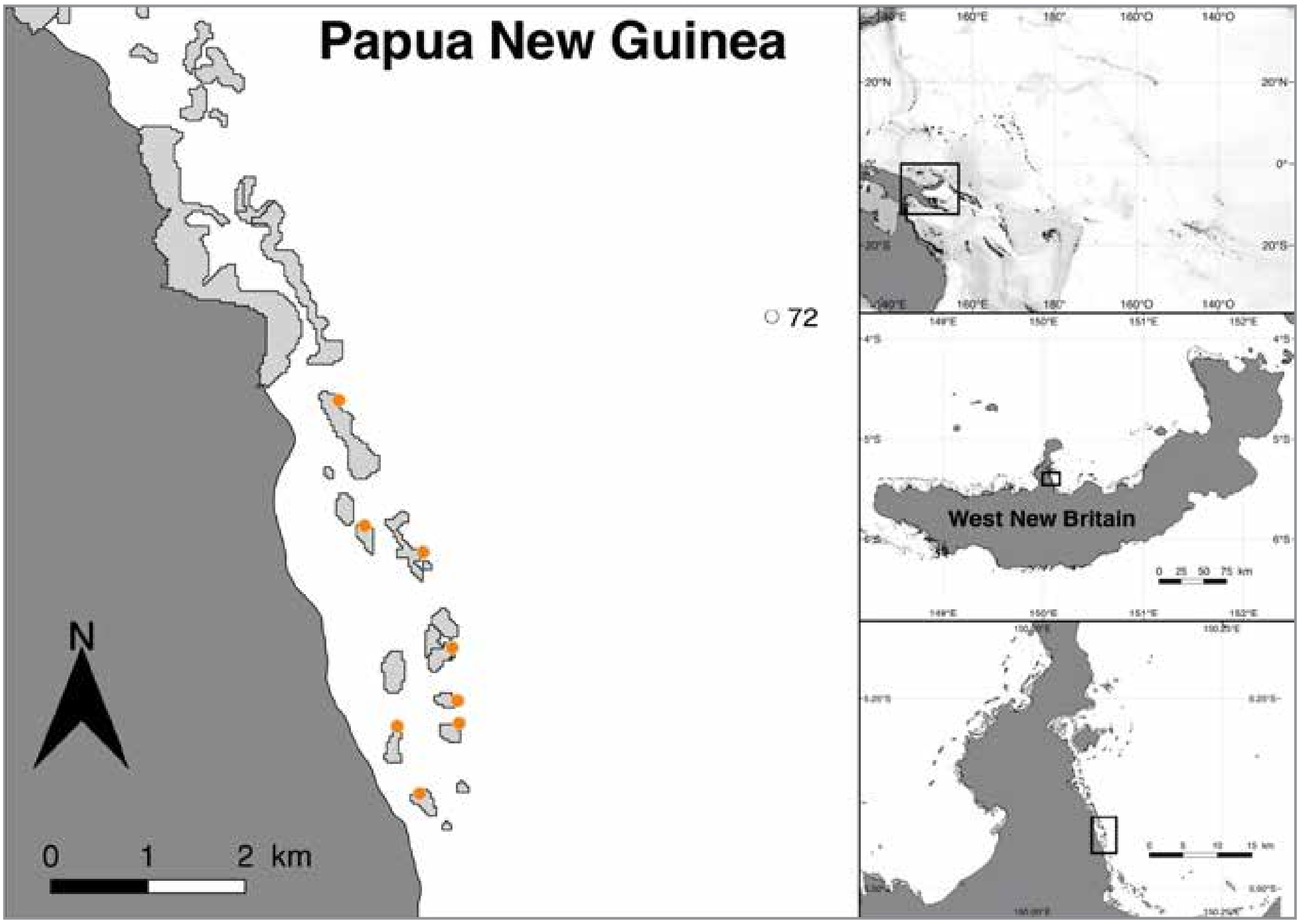

FIGURE 1

Map of Papua New Guinea. Each colour represents a different dataset (orange: dataset n°24). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

Table 1

Data sources from Papua New Guinea used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
24	Geoffrey Jones – College of Science and Engineering, and ARC Centre of Excellence for Coral Reef Studies, James Cook University Townsville, QLD, Australia	1998 - 2015	15	X	X	
25	Geoffrey Jones – College of Science and Engineering, and ARC Centre of Excellence for Coral Reef Studies, James Cook University Townsville, QLD, Australia	1997 - 2015	16			X

Trends

PNGs only long-term coral reef monitoring project was started in Kimbe Bay in 1997 to examine the effectiveness of the LMMA, which was established in 1999. The abundances of three shallow-water surgeonfish species have increased in the LMMA, which are targeted by local subsistence fishers. There have been several periods of decline and subsequent recovery in coral cover on the inshore coral reefs of Kimbe Bay (Fig 2.1A) following coral bleaching events in 1997-1998, 2000-2001, 2004 and 2008. In addition to bleaching events, crown-of-thorns starfish (COTS) outbreaks and sedimen-tation have also contributed to a general trend of decline in the condition of inshore coral reefs in the bay. This decline is not evident from the patterns of total coral cover over time but when coral fami-lies are examined individually, a shift in the community composition of corals is evident. There has been a clear decline in the cover of Acropora corals over time, which has led to a decline in fish species richness and a decline in abundance of approximately 75% of fish species. The trends in total fish abundance (Fig 2.2A) are roughly similar to those for total coral cover, declining as coral cover declines and increasing as coral cover increases, however there has been an overall decline in the total abundance of fish during the survey period.

The most recent coral bleaching event in 1997 (not included in the data presented here) affected a wide range of coral species and caused a high percentage of mortality, even among the typically more resilient coral genera (e.g. Porites, Diploastrea).

There is currently a bill going through parliament to create protected land and sea areas. The first and only MPA in PNG will be created in Kimbe Bay, spanning the length of the bay (approx 140 km) and 70 km out from shore. The current LMMAs will be incorporated into this larger MPA.

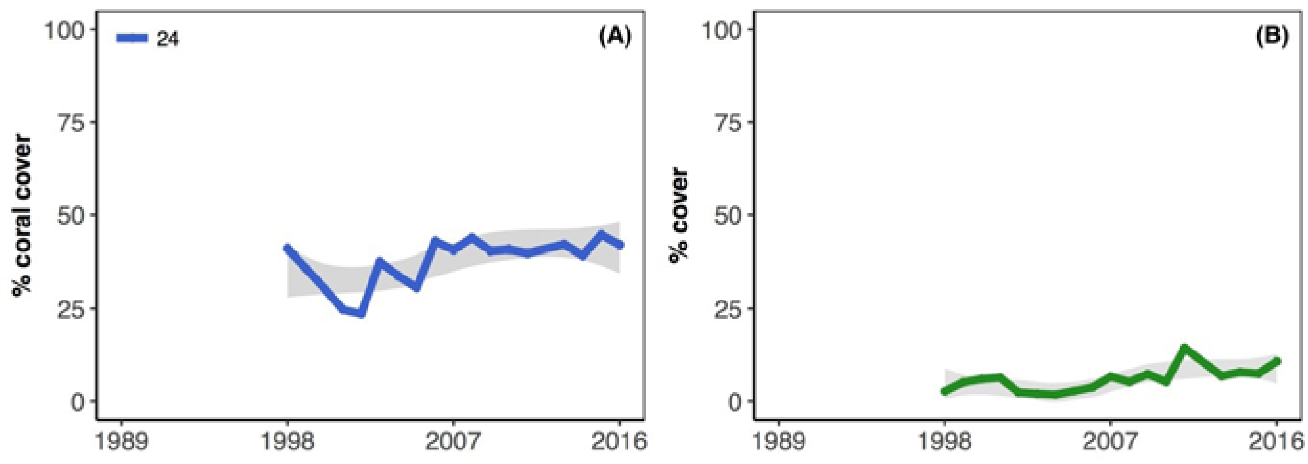

FIGURE 2.1
Average percent of (A) live hard coral cover and (B) macroalgae cover in Papua New Guinea. The grey area represents the average loess trend in coral and macroalgae cover.

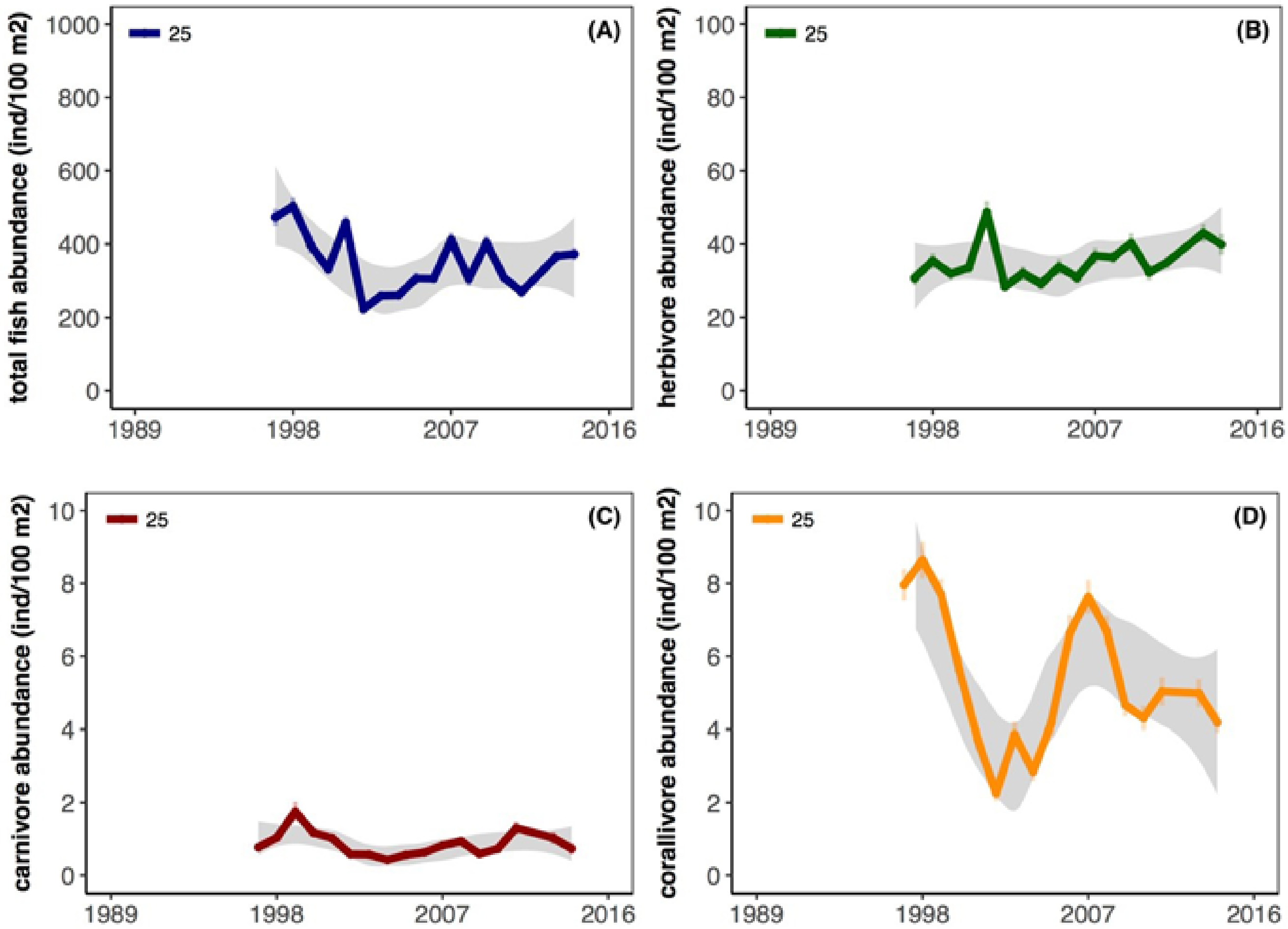

FIGURE 2.2
Average of fish biomass in Papua New Guinea: (A) Total; (B) Herbivore; (C) Carnivore; (D) Corallivore. The grey area represents the average loess trend in fish biomass.

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Pitcairn Islands

Collaborators:Yannick Chancerelle, Vetea Liao, Gilles Siu and Serge Planes

Geographic information:	
Maritime area: 836 108 km^2	Reef area: > 10 km^2
Land area: 49 km^2	Coastal length: 54.9 km
Number of islands: 4	Distance to nearest continent: 5500 km to South America
Island type: volcanic, low-lying coral atoll	Island age: Ducie (8Myr), Henderson (13Myr), Oeno (16Myr) and Pitcairn (0.8Myr)
Population: 57	Number of uninhabited islands: 3
Climate: tropical	Major wind regime: Southeast trade winds
Total MPAs: 1	GDP's/CAP: -

Overview

The Pitcairn Islands are a group of four pristine small islands and remain the last UK Overseas Territory in the Pacific. It is located at the south-eastern extremity of the Indo-West Pacific biogeographic province and composed by: Ducie, Henderson, Oeno and Pitcairn. Pitcairn is exceptionnaly remote with a small population. In fact, Pitcairn is the only island that is inhabited. The economic activities depend essentially on fishing and agriculture.

Timeline of major events

2008	The Pitcairn Islands Environment Management Plan
2015	The British government established the largest continuous marine protected area. The MPA covers the entire exclusive economic zone of the Pitcairn Islands

Maps of individual surveys of substrate

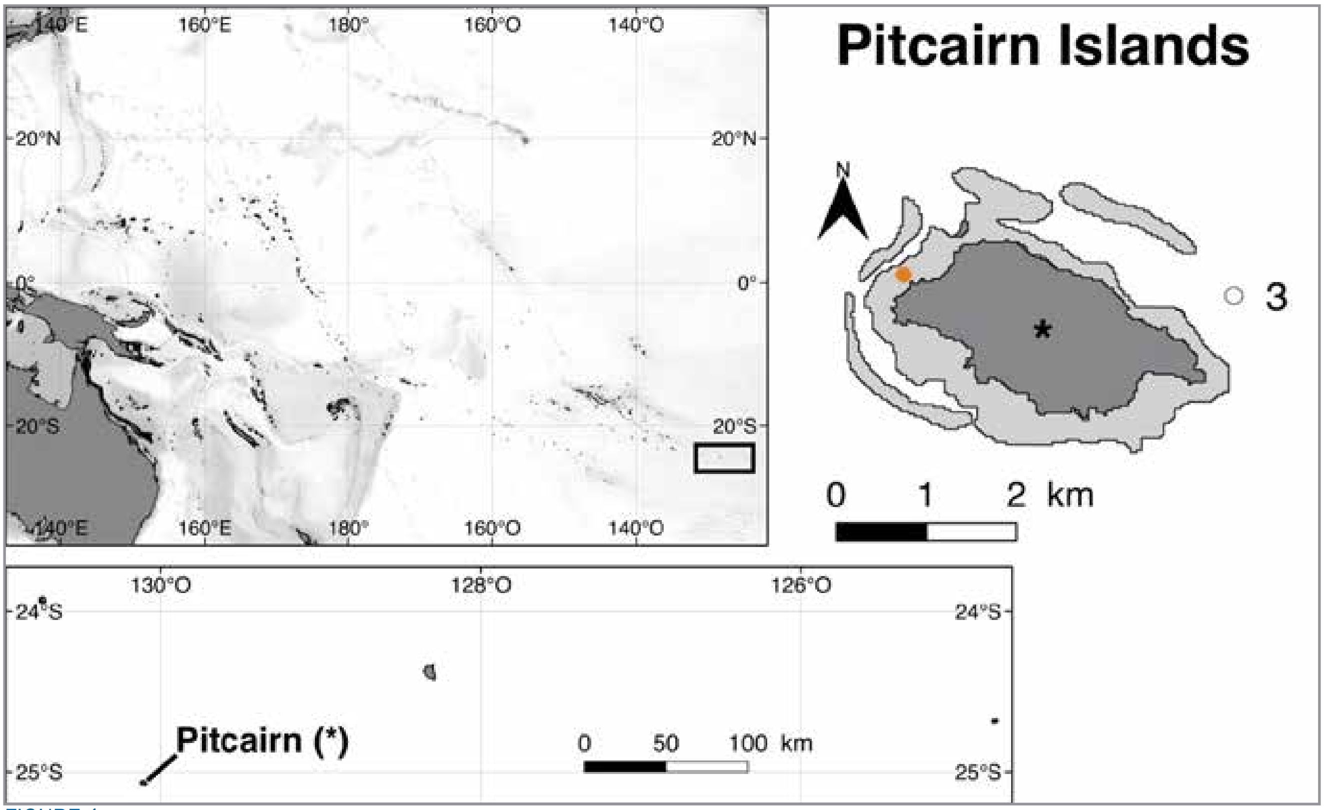

FIGURE 1
Map of the Pitcairn Islands. Each colour represents a different dataset (orange: dataset n°66). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from the Pitcairn Islands used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
44	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	1993-2016	3	X		
45	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	2004-2016	2			X

Trends

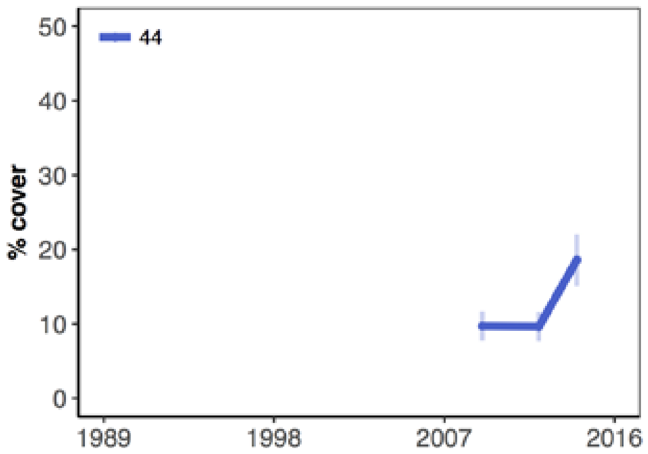

FIGURE 2.1
Average percent of live hard coral cover in Pitcairn.

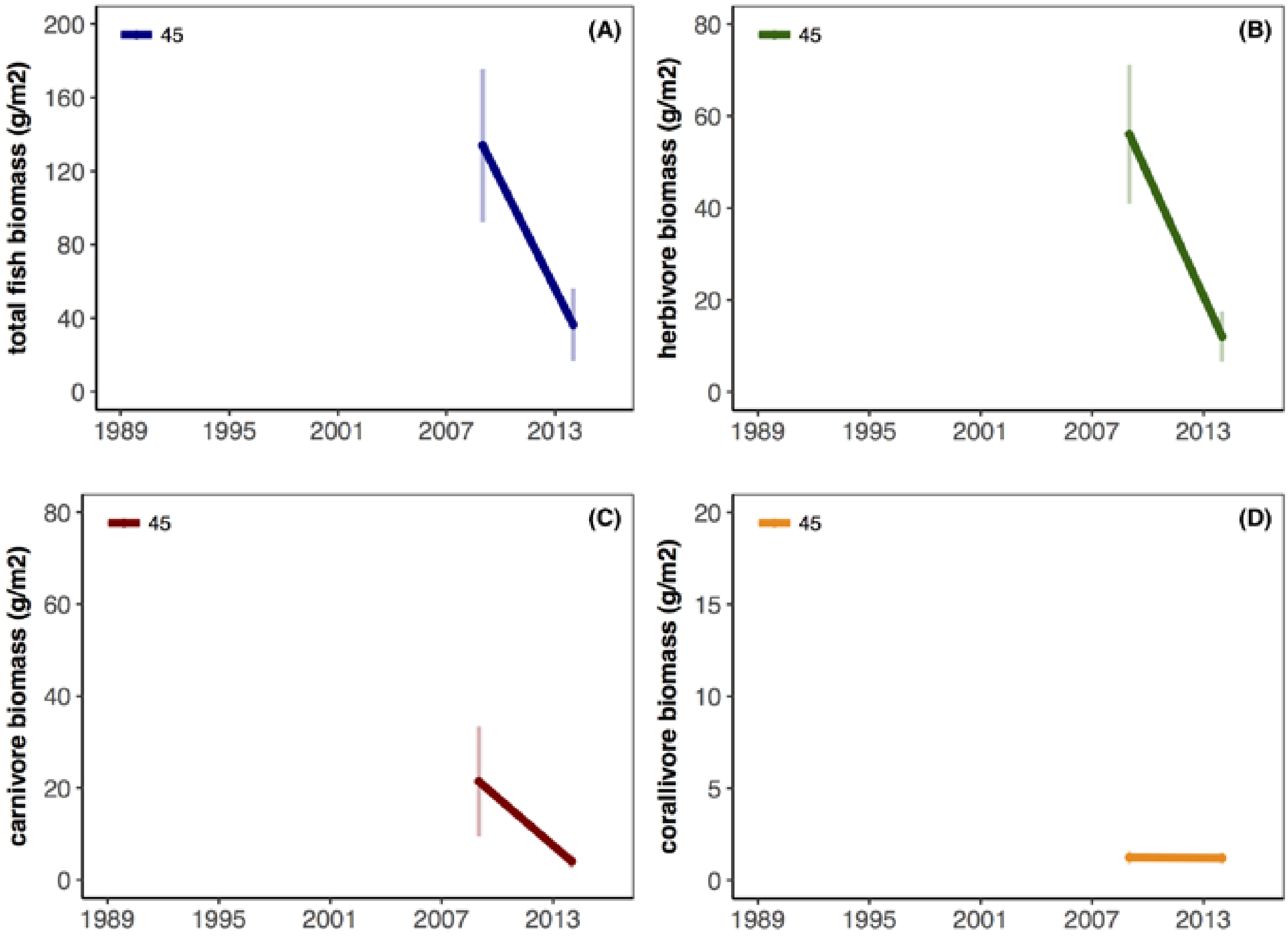

FIGURE 2.2
Average fish biomass in Pitcairn: (A) Total; (B) Herbivore; (C) Carnivore; (D) Corallivore.

General Literature

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Western Samoa

Collaborators: Yannick Chancerelle, Vetea Liao, Serge Planes and Gilles Siu

Geographic information

Maritime area: 120 000 km²	Reef area: 490 km²
Land area: 2 934 km²	Coastal length: 403 km
Number of islands: 2	Distance to nearest continent: 3 800 km to Australia
Island type: volcanic	Island age: 23 million years
Population: 192 342	Number of uninhabited island: 0
Climate: equatorial	Major wind regime: Southeast trade winds
Total MPAs: > 20	GDP's/CAP: $4 496

Overview

Samoa (also know as the Western Samoa) is an independent state of Polynesia with a parliamentary democracy and is a member of the Commonwealth of Nations and United Nations. The two large main islands are Savai'I and Upolu and account for 99% of the total land area, surrounded by eight islets.

The economy is based on agricultural production (copra, cacao, banana, coconut, etc.) but subsistence fishing in inshore areas is an important activity.

Timeline of major events

1970's	COTS outbreaks
1987	Hurricanes Tusi
1990	Hurricanes Ofa
1991	Hurricanes Val
1994	Mass coral bleaching
2004	Cyclone Heta
2009	Tsunami hit Upolu's shore
2012	Cyclone Evan

Maps of individual surveys of substrate

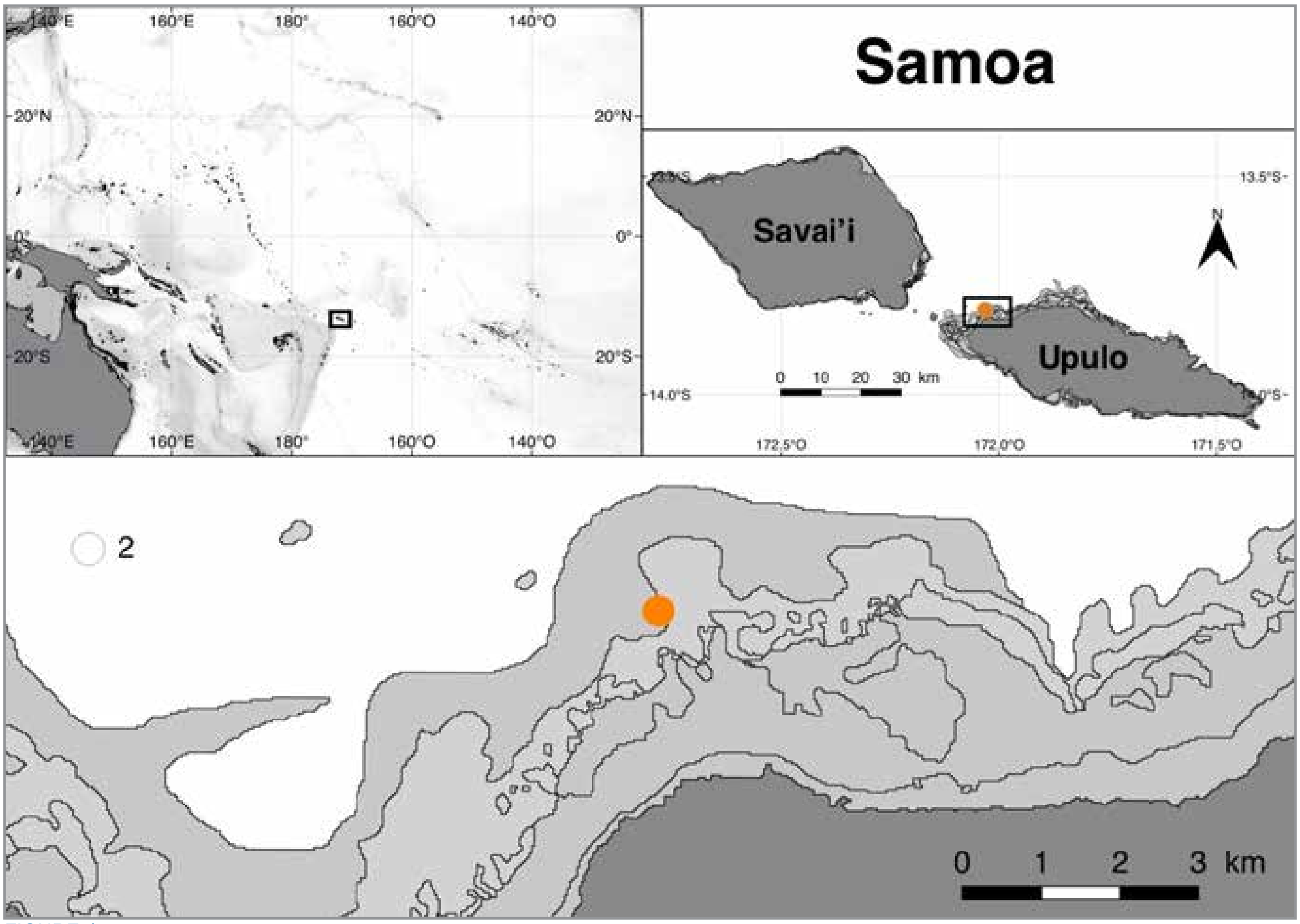

FIGURE 1
Map of the Samoa. Each colour represents a different dataset (orange: dataset n°44). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from the Samoa used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
44	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	1993 - 2016	1	X		
45	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	2004 - 2016	2			X

Trends

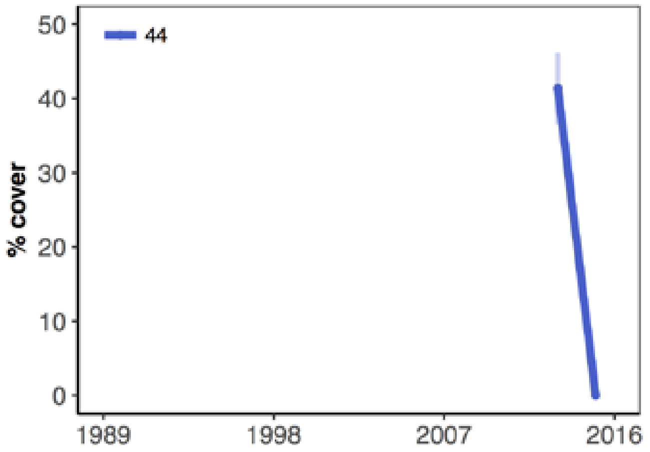

FIGURE 2.1
Average percent of live hard coral cover in Samoa.

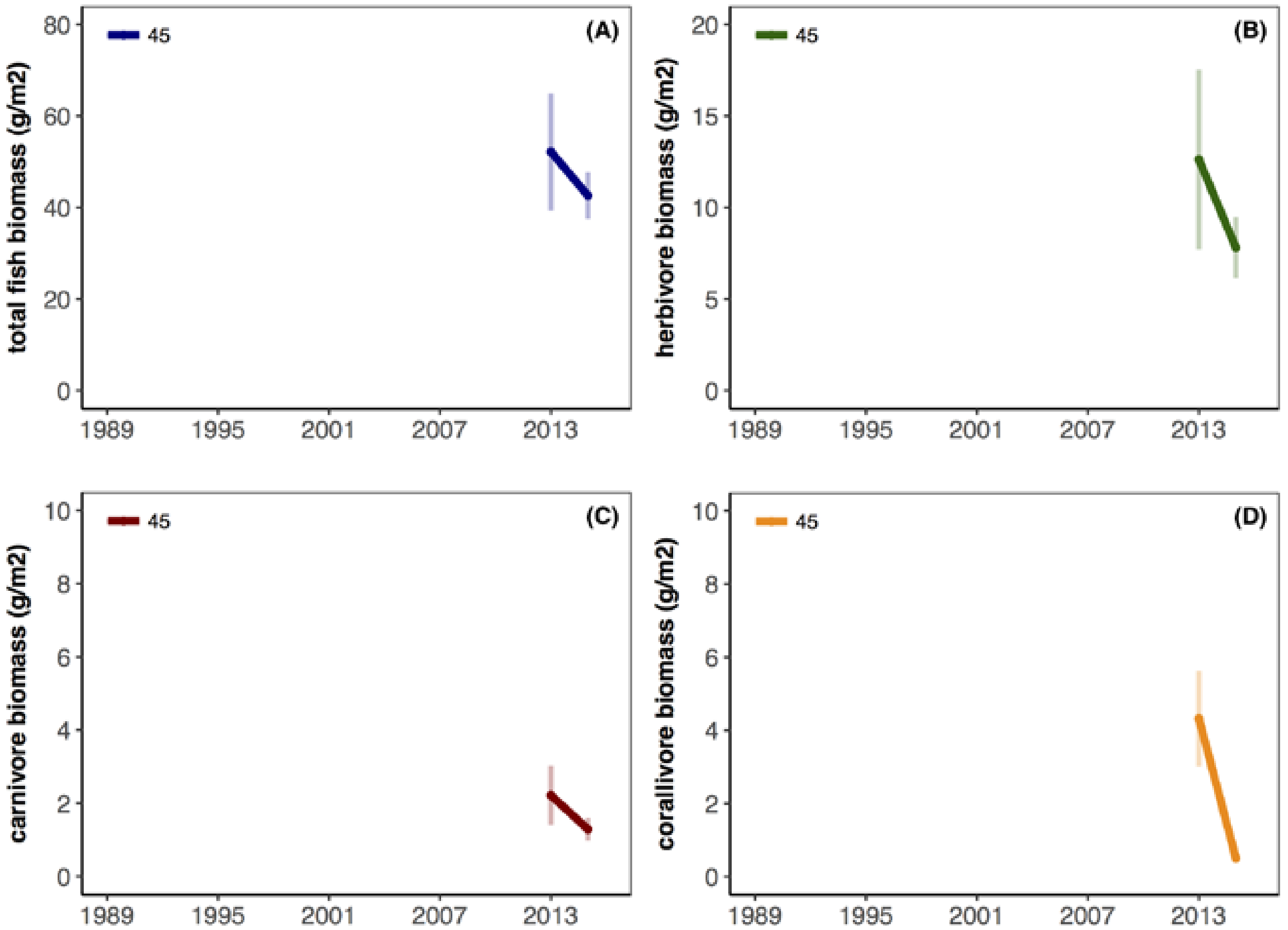

FIGURE 2.2
Average fish biomass in Samoa: (A) Total; (B) Herbivore; (C) Carnivore; (D) Corallivore.

General Literature

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The Kingdom of Tonga

Collaborators: Yannick Chancerelle, Vetea Liao, Serge Planes and Gilles Siu

Geographic information

Maritime area: 700 000 km²	**Reef area: 1 500 km²**
Land area: 718 km²	**Coastal length: 419 km**
Number of islands: 176	**Distance to nearest continent: 3 000 km to Australia**
Island type: volcanic, limestone coral and low-lying coral atolls	**Island age: 45 million years**
Population: 103 000	**Number of uninhabited islands: > 130**
Climate: tropical	**Major wind regime: trade winds**
Total MPAs: 6	**GDP's/CAP: $4 220**

Overview

The Kingdom of Tonga is divided into three main groups: Tongatapu, Vava'u and Ha'apai. Coral reef resources are very important to the Kingdom of Tonga for income and food security. The population is comprised largely comprised of subsistence farmers and fishermen.

Timeline of major events

1970's	COTS outbreaks
1982	Cyclone
1992	COTS outbreaks
1995	Cyclone
1997	Cyclone
1999	Cyclone
2000	Bleaching event in Tongatapu and cyclone
2009	Tsunami; volcanic eruption around Hunga Tonga
2018	Cyclone Gita (category 4)

Maps of individual surveys of substrate

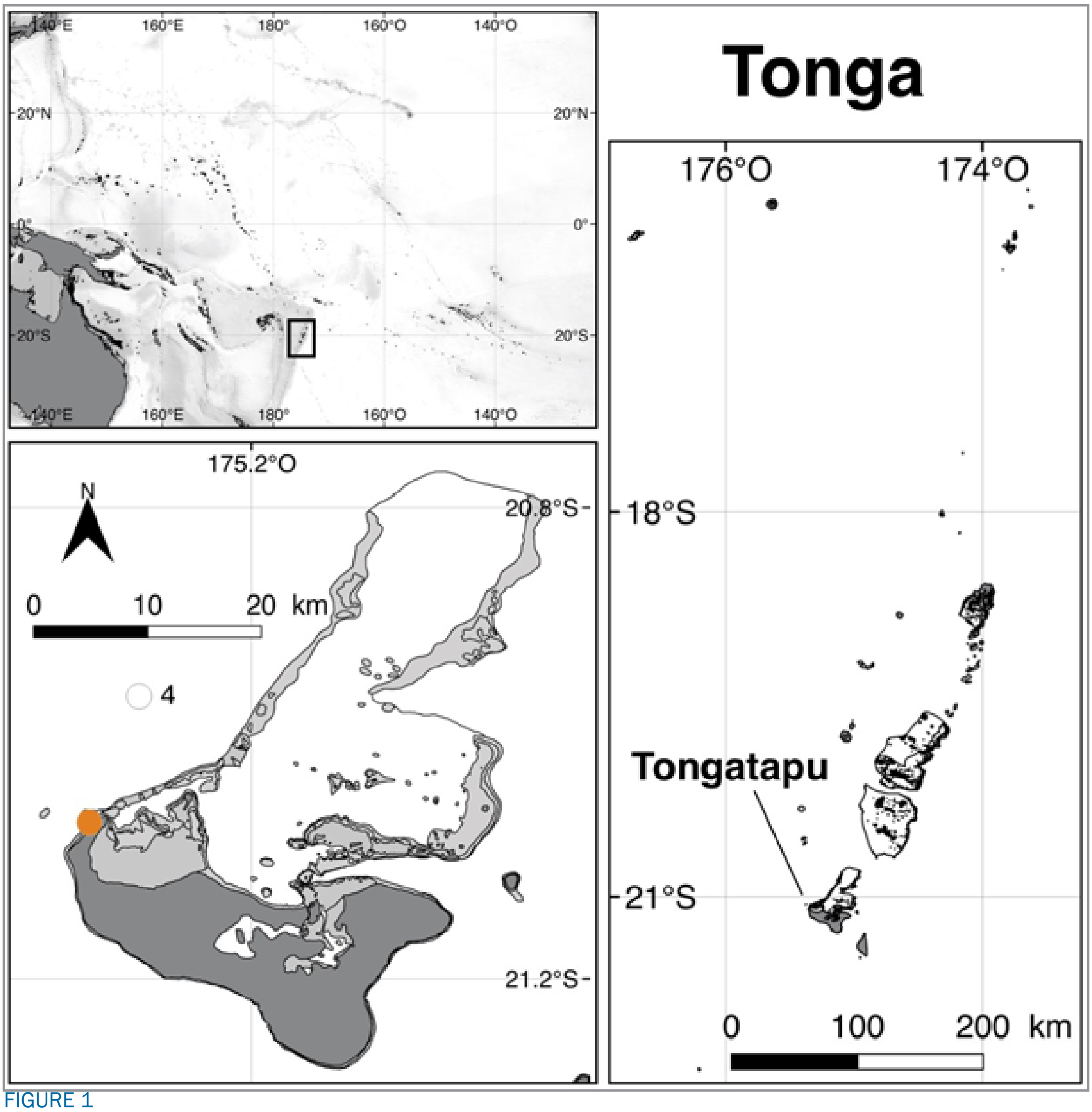

FIGURE 1
Map of the Tonga. Each colour represents a different dataset (orange: dataset n°44). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from the Tonga used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
44	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	1993 - 2016	4	X		
45	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	2004 - 2016	4			X

Trends

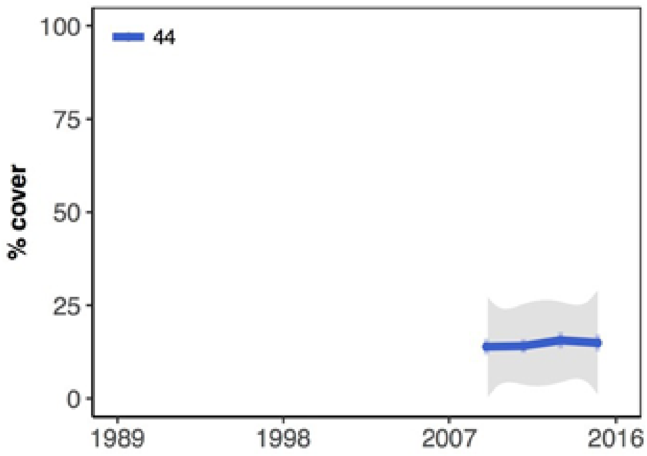

FIGURE 2.1
Average percent of live hard coral cover in Tonga. The grey area represents the average loess trend in coral cover.

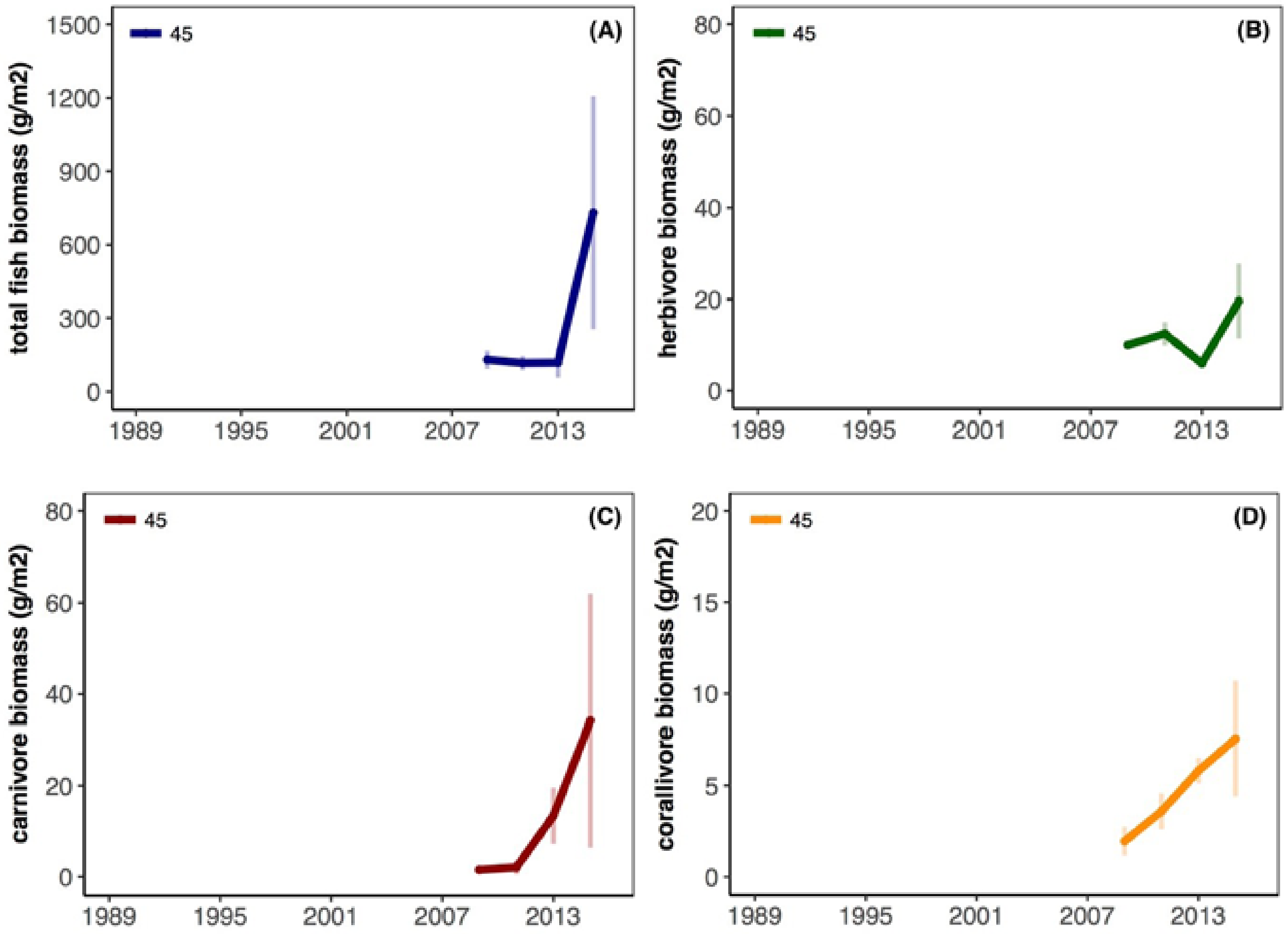

FIGURE 2.2
Average fish biomass in Tonga: (A) Total; (B) Herbivore; (C) Carnivore; (D) Corallivore.

General Literature

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Republic of Vanuatu

Collaborators: Johanna Johnson, Eryn Hooper, Sarah Dwyer,
Jane Waterhouse and Jeremie Kaltavara

Geographic information

Maritime area: 680 220 km²	Reef area: 4 110 km²
Land area: 11 880 km²	Coastal length: 2 528 km
Number of islands: 83	Distance to nearest continent: 1750 km to Australia
Island type: volcanic, atoll	Island age: 153 – 2 million years
Population: 264 652	Number of uninhabited islands: 16
Climate: tropical	Major wind regime: Southeast trade winds
Total MPAs: 55	GDP's/CAP: $3036

Overview

The 83 islands of Vanuatu are divided into six provinces. Vanuatu has one of the highest population growth rates in the Pacific at 2.6% in 2010 (Bell et al. 2011, Pacific Community [SPC] Statistics 2011). Around 80% of the population relies heavily on marine resources and agriculture for subsistence and local income. The domestic coastal fishery is very important to food security, supplying protein to 60% of households (Bell et al. 2017). Tourism is also an important source of income for Vanuatu (ca. 40% of the GDP).

Vanuatu has different reef types including fringing, platform and oceanic ribbon reefs, and atolls. The reefs contain significant biodiversity with records of 295 hard corals, 469 reef fishes, and 18 species of sea cucumbers. However, seismic events and cyclones periodically cause significant damage to Vanuatu's coral reefs. This is due to Vanuatu's location on the western margins of the Pacific plate. Of Vanuatu's 16 volcanoes, 9 are active, and earthquakes and eruptions occur regularly. Vanuatu also lies within the tropical cyclone belt and is affected by an average of two cyclones per year.

Timeline of major events

1999	10-metre-high tsunami impacts Pentecost Island (Penama Province)
2001-2002	Bleaching event on several reefs around Efate Island (Shefa Province)
2003	Tropical Cyclone Danny damaged 80% of corals on exposed reefs in southwest Efate Island (Shefa Province)
2004	Bleaching event and Tropical Cyclone Ivy (Category 4)
2006-2008	Crown-of-Thorns Starfish (COTS) outbreak. Significant impacts on some reefs with high coral predation in Shefa Province (Efate, Emau, Nguna, Pele, Moso, Lelepa and Mele islands)
2014	COTS outbreaks in Shefa Province with significant impacts on some reefs with high coral predation
2015	Tropical Cyclone Pam (Category 5) with significant impacts on reefs on Epi Island, Shepherd Islands, northeast Efate, and the Tafea islands of Erromango and Tanna
2016	El Niño drought, very low rainfall throughout Vanuatu (improved water quality on reefs)
2016	Spatially variable bleaching event on reefs in Efate (5–70% corals affected); very high recovery (low mortality) on all reefs surveyed
2017	Cyclone Donna (Category 4) impacting Gaua and Vanua Lava (Torba Province)

Maps of individual surveys of substrate

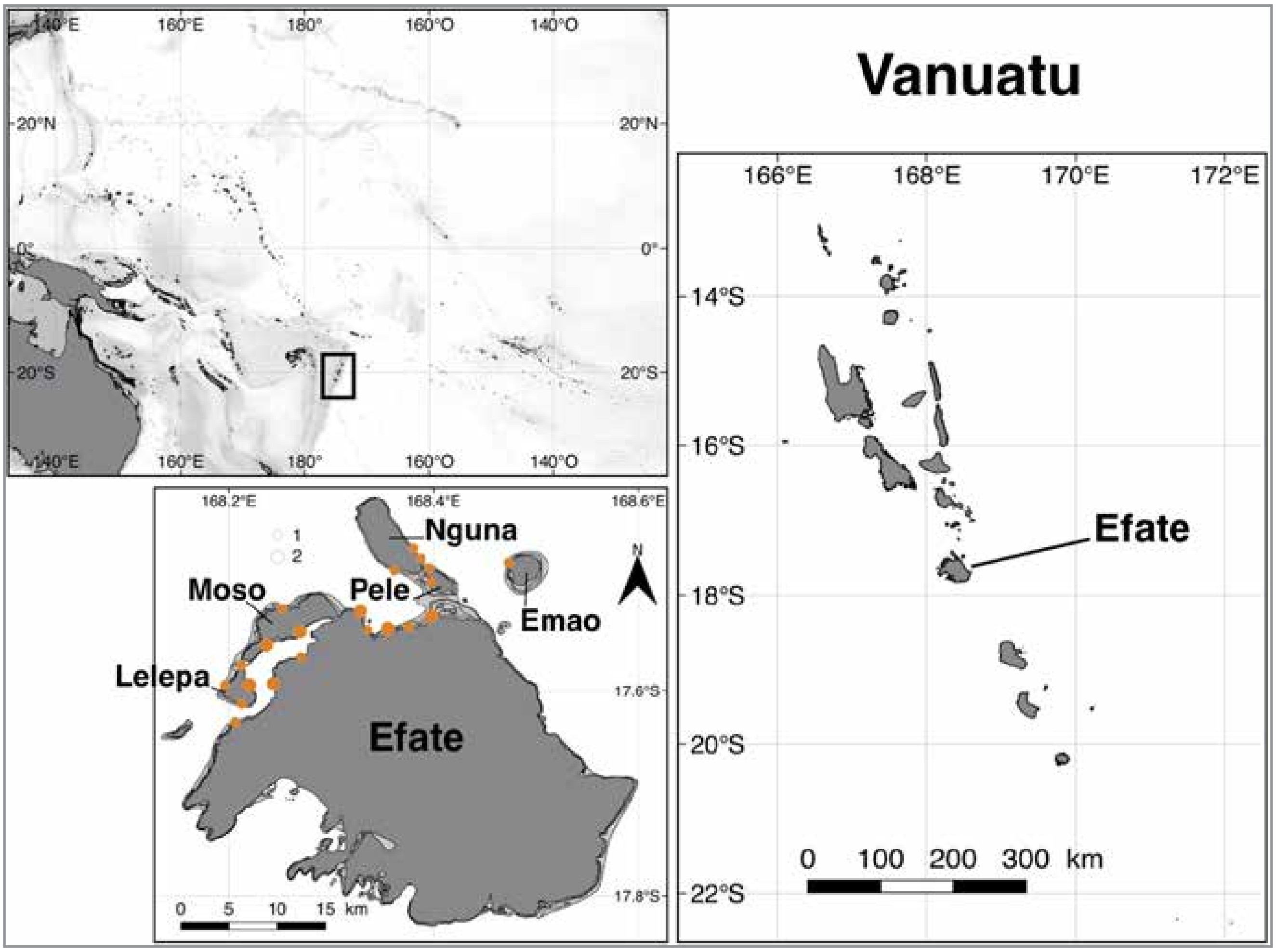

FIGURE 1
Map of Vanuatu. Each colour represents a different dataset (orange: dataset n°12). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from Vanuatu used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
12	Johanna Johnson – C2O Pacific – Data collection funded by RESCCUE SPC	2015 – 2016	4	X	X	

Trends

Consistently, communities, government and NGOs report that the greatest threats to the marine and coastal environments of Vanuatu are tropical cyclones, overexploitation of fisheries, coral predation and bleaching, land-based pollution, and coastal development for tourism purposes (Raubani 2009, Pakoa 2007). Recent reef surveys documented relatively high hard coral cover and low macroalgae cover in the northwest of Efate, around Moso and Lelepa islands, and at Emao Island, while reefs in Undine Bay and around Nguna-Pele islands had low coral cover and high macroalgae cover (Johnson et al. 2016).

Reef surveys at 16 sites in North Efate in 2015 and 2016 recorded reef condition after Tropical Cyclone (TC) Pam, as well as during the 2016 coral bleaching event (Johnson et al. 2016). The surveys documented spatially variable cyclone impacts with significant coral damage on northeast reefs and less damage as distance increased away from the cyclone path. Results also showed greatest damage in shallow areas. Many reefs impacted by TC Pam were showing signs of recovery in May 2016, with coral growth and juvenile corals documented.

Coral bleaching rapid surveys in 2016 recorded spatially variable coral bleaching, with reefs in sheltered bays being moderately to severely bleached, while other reefs experienced minor to no bleaching. This is most likely a consequence of local environmental conditions, such as depth, currents and tides, thermal history and species composition, that are known to influence response and resistance to thermal stress. Most reef sites were showing signs of recovery within two weeks of the surveys, once water temperatures began to cool.

Significant longer-term reef degradation was evident at some coastal sites, most likely due to coral predation by crown-of-thorns starfish (COTS) outbreaks between 2006 and 2008. A control program lead by the Vanuatu Government and tourism operators has been operational since 2006 and has so far been successful in keeping the COTS population low. However, reef sites severely impacted by previous COTS outbreaks appear to be showing very little recovery, which may be due to the fact that these reefs have very low coral cover (< 5%) and high macroalgae cover, which may be hindering coral recruitment.

There were no patterns evident in reef response to disturbances or reef impacts between protected "tabu" areas and open areas. While reefs in Efate have experienced multiple disturbances of tropical cyclones, coral predation, coral bleaching and heavy fishing pressure, they generally show a high capacity for recovery. However, some locations have experienced significant coral declines in recent years and surveys in 2016 documented low abundance of some key fish groups (e.g. piscivores and scarids; Welch and Moore 2016). Recovery at these sites may take decades or the reefs may never return to a coral dominated state. Reducing anthropogenic pressures on reefs, particularly overfishing, will be important to the future recovery and ultimately condition of these reef. Ongoing monitoring and assessment of reef condition is important to inform effective management, using community-based and innovative techniques to measure coral reef status and trends, as well as fish populations.

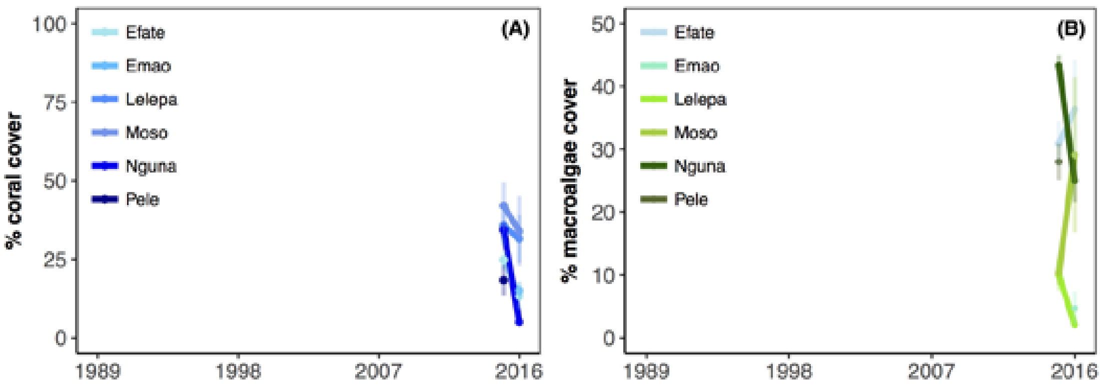

FIGURE 2
Average percent of (A) live hard coral cover and (B) macroalgae cover for the Vanuatu.

General Literature

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Welch D, 2016. Broadscale assessment of the status of coastal finfish in North Efate, Vanuatu. Report to the Pacific Community (SPC), Noumea, New Caledonia, and Agence Française de Developpement, Paris, France. Vanuatu RESCCUE project, 31 pp.

WALLIS & FUTUNA

Collaborators: Yannick Chancerelle, Vetea Liao, Serge Planes and Gilles Siu

Geographic information

Maritime area: 300 000 km^2	Reef area: 940 km^2
Land area: 274 km^2	Coastal length: 129 km
Number of islands: 3	Distance to nearest continent: 4 327 km to Australia
Island type: volcanic	Island age: 1 to 2 million years
Population: 13 000	Number of uninhabited islands: 0
Climate: tropical	Major wind regime: Southeast trade winds
Total MPAs: 0	GDP's/CAP: $12 640

Overview

The overseas territory, Wallis and Futuna, is a French collectivity of 3 high main volcanic islands, into two island groups that lie about 260 km apart: Wallis (Uvea) island in the northeast, and the Hoorn Islands compose by Futuna and Alofi in the southwest. Subsistence agriculture is the main economic activity but coral reef resources with coastal fishing are an important part of the diet.

Timeline of major events

2000	Protection of reefs in Wallis and Futuna is supported by national French legisla-tion
2009	Creation of the 'Plan de Gestion de l'Espace Maritime' (PGEM)
2010	Cyclone Tomas struck Futuna

Maps of individual surveys of substrate

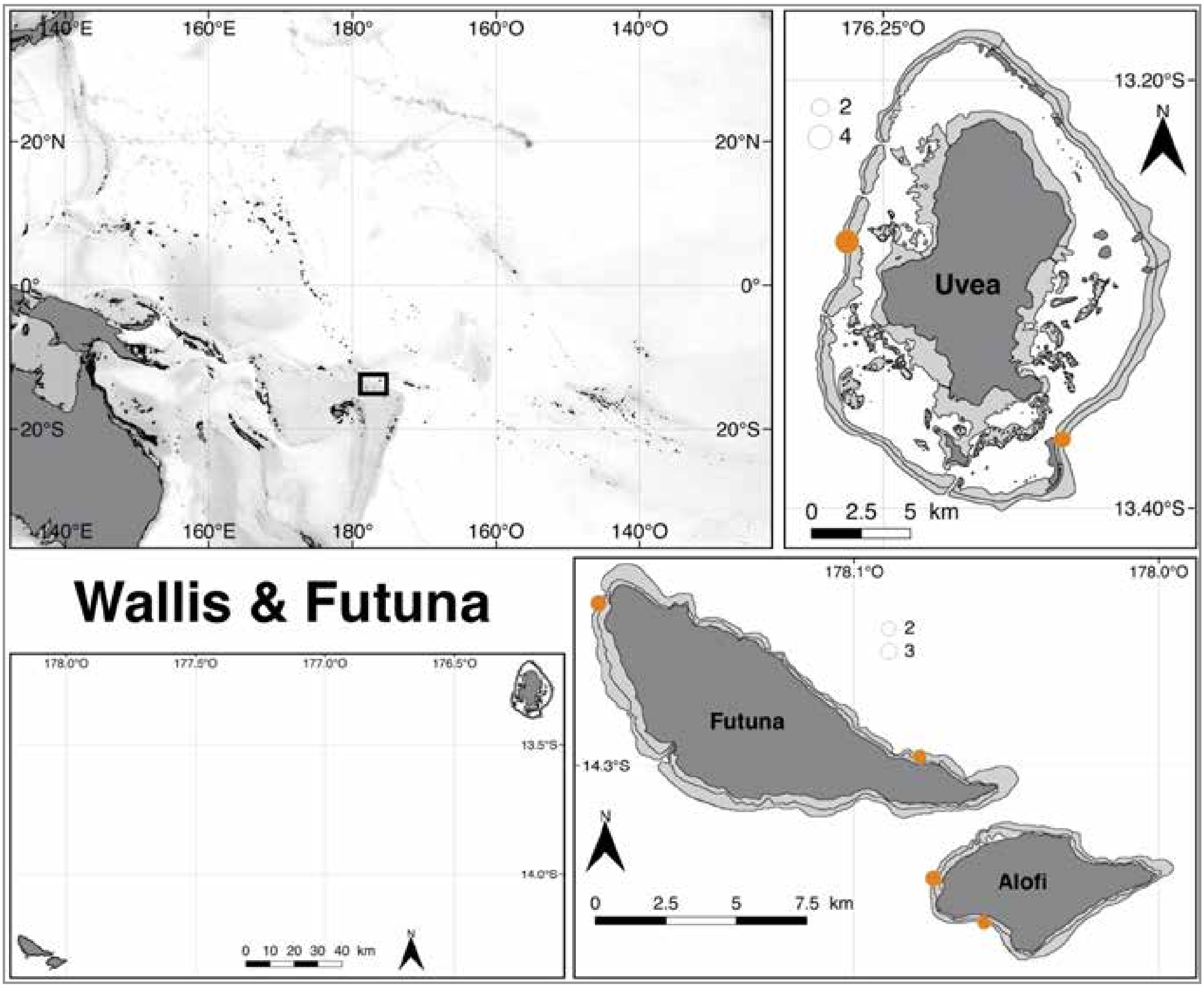

FIGURE 1
Map of Wallis and Futuna. Each colour represents a different dataset (orange: dataset n°50). Circle size represents the total number of times the site was sampled. Only sites where substrate was sampled are represented.

Table of data sources

TABLE 1
Data sources from Wallis and Futuna used in the report. Datasets represent individual monitoring programs.

Dataset N°	Contributor	Time period	Year count	Coral	Macroalgae	Fish
50	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	1999 - 2005	4	X		
51	Polynesia Mana - CRIOBE SO CORAIL, French Polynesia	2010 - 2011	2			X

Trends

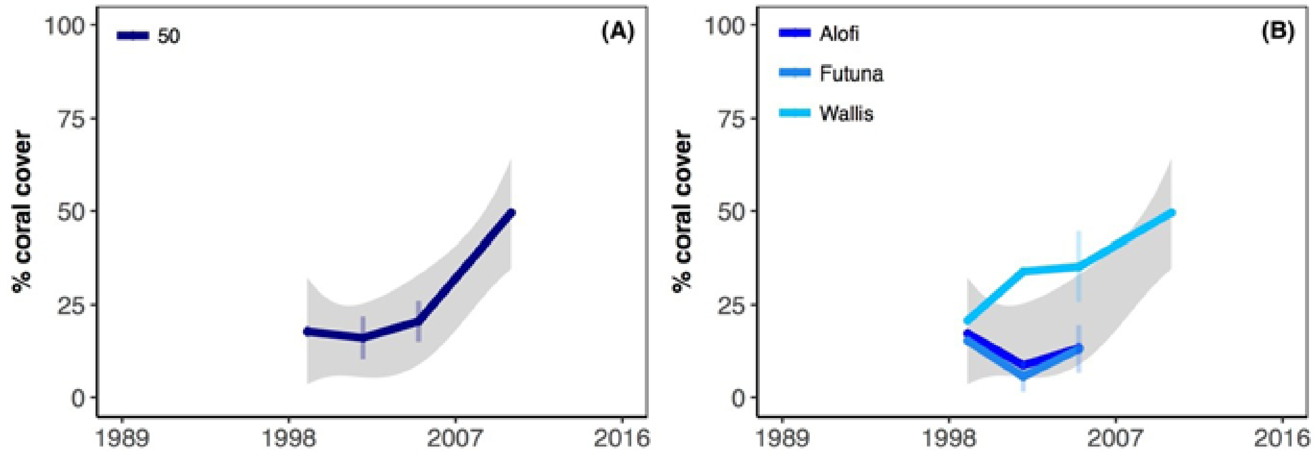

FIGURE 2.1
Average percent of live hard coral cover in Wallis and Futuna: (A) All islands combined; (B) Alofi, Futuna, and Wallis. The grey area represents the average loess trend in coral cover when islands are combined.

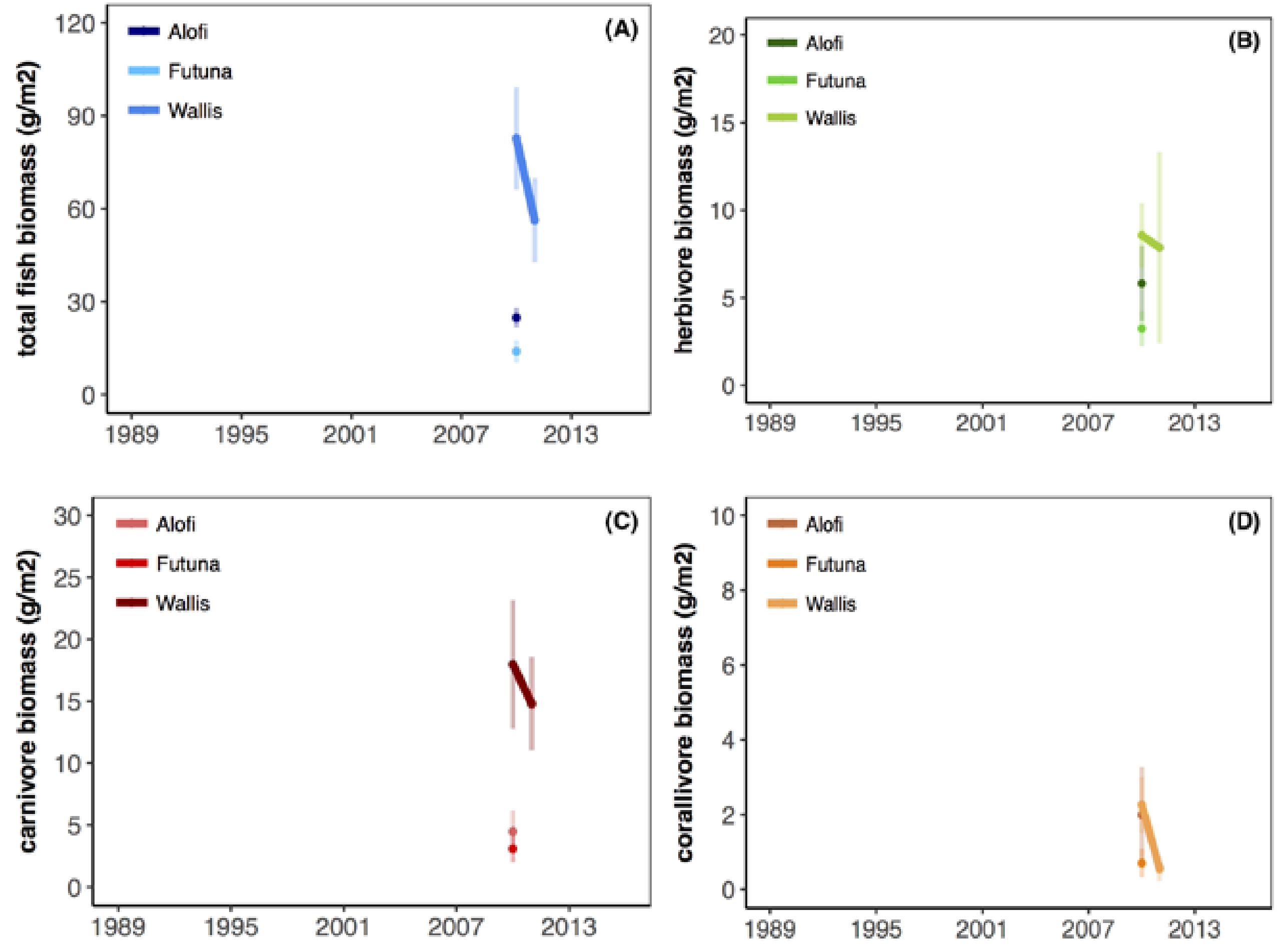

FIGURE 2.2
Average fish biomass in Wallis and Futuna: (A) Total; (B) Herbivore; (C) Carnivore; (D) Corallivore.

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