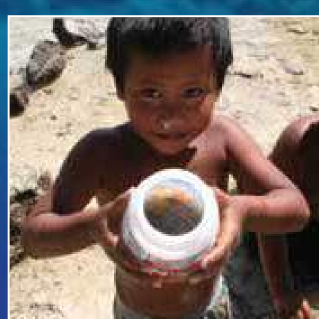
Towards Reef Resilience and Sustainable Livelihoods



A HANDBOOK FOR CARIBBEAN CORAL REEF MANAGERS

Citation:
Peter J Mumby, Jason Flower, Iliana Chollett, Stephen J Box, Yves-Marie Bozec, Clare Fitzsimmons, Johanna Forster, David Gill, Rosanna Griffith-Mumby, Hazel A Oxenford, Angelie M Peterson, Selina M Stead, Rachel A Turner, Philip Townsley, Pieter J H van Beukering, Francesca Booker, Hannah J Brocke, Nancy Cabañillas-Terán, Steven W J Canty, Juan P Carricart-Ganivet, John Charlery, Charlie Dryden, Fleur C van Duyl, Susana Enríquez, Joost den Haan, Roberto Iglesias-Prieto, Emma V Kennedy, Robin Mahon, Benjamin Mueller, Steven P Newman, Maggy M Nugues, Jorge Cortés Núñez, Leonard Nurse, Ronald Osinga, Claire B Paris, Dirk Petersen, Nicholas V C Polunin, Cristina Sánchez, Stijn Schep, Jamie R Stevens, Henri Vallès, Mark J A Vermeij, Petra M Visser, Emma Whittingham, Stacey M Williams (2014) Towards Reef Resilience and Sustainable Livelihoods: A handbook for Caribbean coral reef managers. University of Exeter, Exeter. 172 pages.

Design and production: Diana Kleine
Published 2014, University of Exeter, Exeter, Devon, UK
Printed by the University of Queensland Press, Brisbane, Australia
ISBN 978 0 902746 31 2

This book and further information is available from:
FORCE project, University of Exeter, Marine Spatial Ecology Lab,
College of Life and Environmental Sciences, Exeter, Devon, UK
www.force-project.eu

Towards Reef Resilience and Sustainable Livelihoods

A HANDBOOK FOR CARIBBEAN CORAL REEF MANAGERS

Peter J Mumby, Jason Flower, Iliana Chollett, Stephen J Box, Yves-Marie Bozec, Clare Fitzsimmons, Johanna Forster, David Gill, Rosanna Griffith-Mumby, Hazel A Oxenford, Angelie M Peterson, Selina M Stead, Rachel A Turner, Philip Townsley, Pieter J H van Beukering, Francesca Booker, Hannah J Brocke, Nancy Cabañillas-Terán, Steven W J Canty, Juan P Carricart-Ganivet, John Charlery, Charlie Dryden, Fleur C van Duyl, Susana Enríquez, Joost den Haan, Roberto Iglesias-Prieto, Emma V Kennedy, Robin Mahon, Benjamin Mueller, Steven P Newman, Maggy M Nugues, Jorge Cortés Núñez, Leonard Nurse, Ronald Osinga, Claire B Paris, Dirk Petersen, Nicholas V C Polunin, Cristina Sánchez, Stijn Schep, Jamie R Stevens, Henri Vallès, Mark J A Vermeij, Petra M Visser, Emma Whittingham, Stacey M Williams

FORCE

Future of Reefs in a Changing Environment

nagers.

s for
lains why
vels of

ey
.

nce
t

cts

n Group

PREFACE

fs

ics

ms.

ef

e

ls

Sincerely

Caribbean

xico

),

ls

),

ınds

UK

ment Ltd, UK

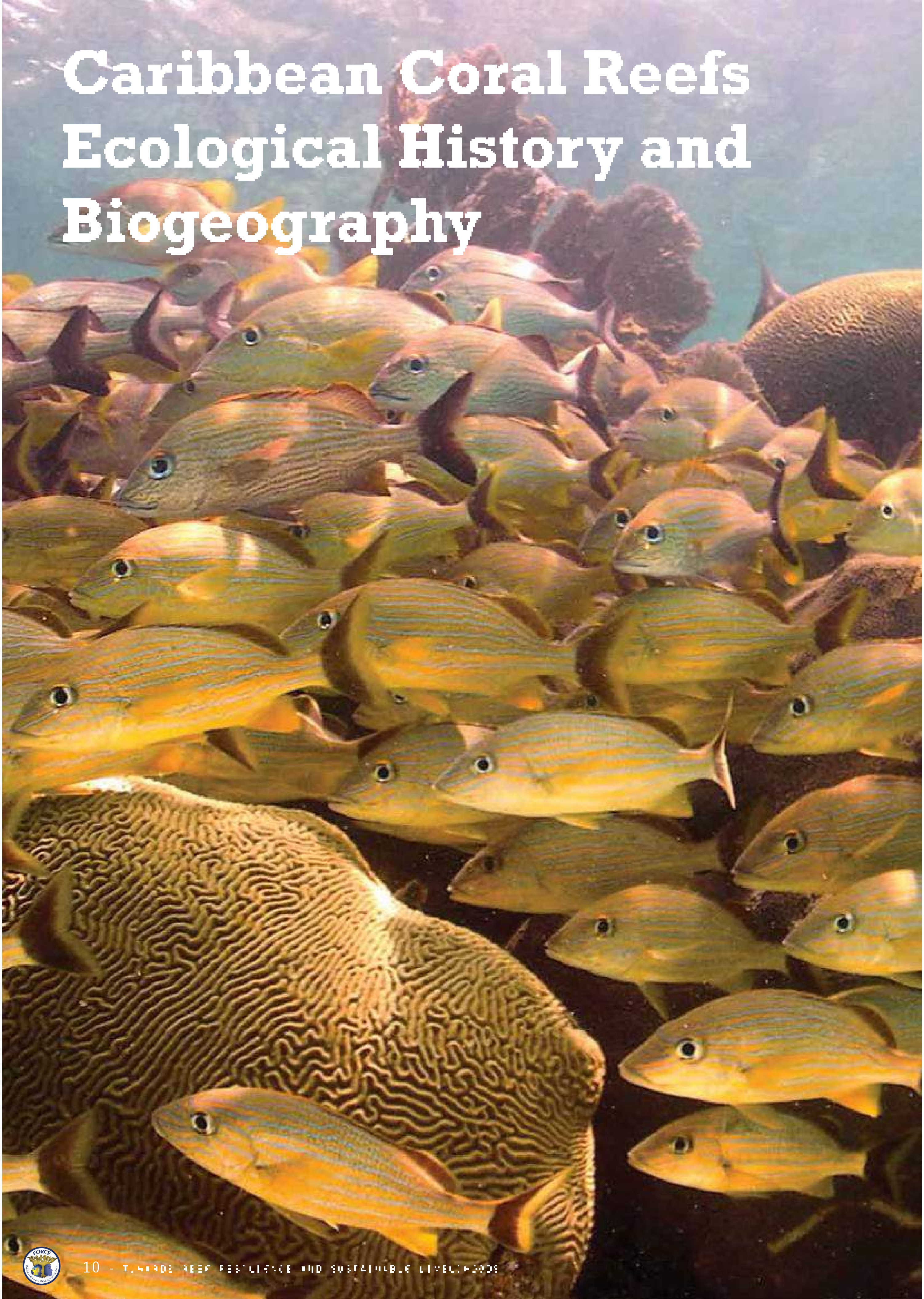
CONTENTS

FISHERIES

SERVICES

es

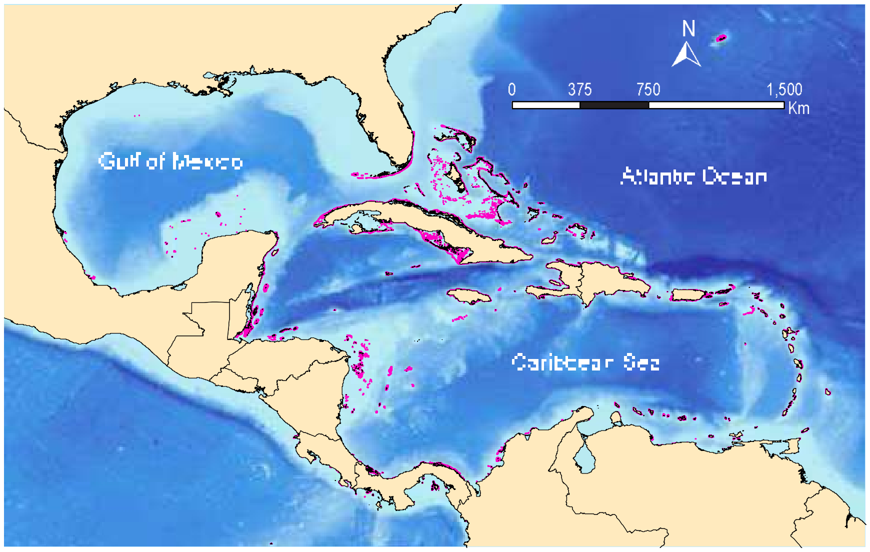
Caribbean Coral Reefs Ecological History and Biogeography



Caribbean coral reefs account for only 7% of the world total coral reef area but play a vital role in the economy of the region and the livelihoods of millions of people who depend upon the reefs for income and employment.

Coral cover has declined from 50% in the 1970s to less than 20% today, potentially reducing the ability of the reefs to provide the ecosystem services that many people rely upon, including habitat for reef fisheries, tourism appeal and coastal defense from storms. Coral loss has been accompanied by an increase in fleshy macroalgae (seaweed) across much – though not all – of the region. Many impacts have contributed to this shift from coral to macroalgal dominated reefs including disease, coral bleaching, hurricanes, overfishing, and land-based run-off (bringing sediment, pollution and nutrients).

Human impacts on reefs in the Caribbean predate the arrival of European settlers in the 15th century, but it is only since the 1970s that large declines in coral cover across the region have occurred. These declines were in part due to outbreaks of disease which wiped-out much of the branching acroporid corals and long-spined sea urchins during the late 70s and early 80s. Overfishing and land-based run-off due to human development fundamentally weakened the ability of the reefs to recover from these impacts. Since the 1980s, many reefs have declined further because of hurricanes, major bleaching events in 1995, 1998, 2005 and 2010, and coral diseases. There is considerable variation in the state of reefs across the region. A few reefs still have coral cover above 50% but others have slipped below 10%. Deep coral reefs (those greater than 30 m depth) may provide a refuge to corals from some of the impacts that have affected shallower reefs. However, reducing local human impacts, which have been affecting many reefs for decades if not centuries, is vital to enable coral reefs to withstand the worsening impacts of climate change. While climate change is already impacting coral reefs, reef management is by no means futile and more important than ever.



Geological time-scale development of Caribbean reefs

ty
l
y
ie
ow
v
ig
ic
gh
fs
ee
ty
Jackson 2006).
al
fic

A. cervicornis.

Agaricia spp.

Before Columbus

es

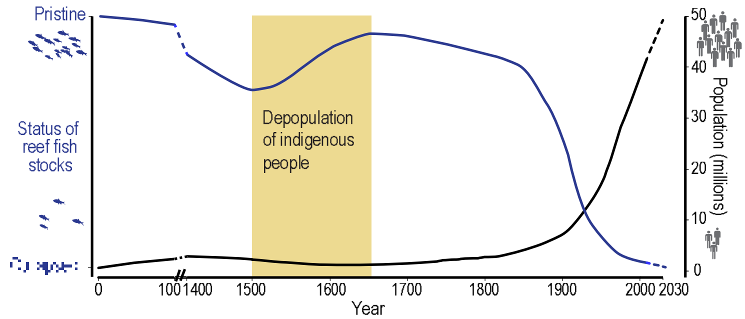
d

f

Wing 2001).

l

an



oil,

a

em

ands

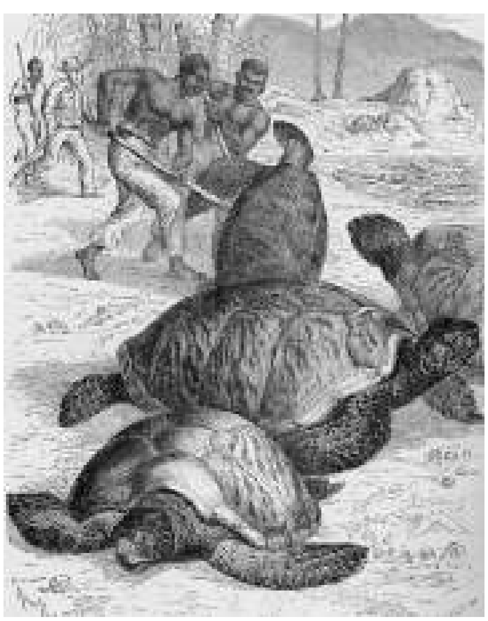
ng

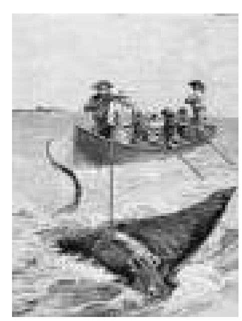
bers

Columbus and colonization

ish

).





g

rilli

s

984;

cha
F.

n

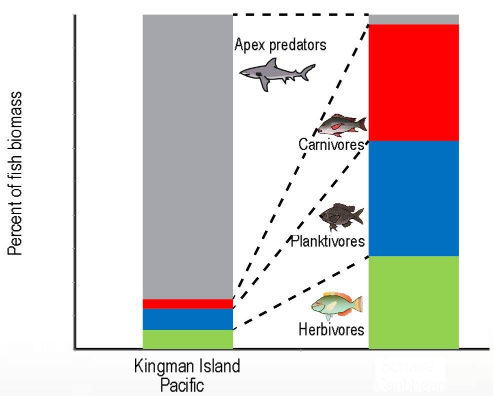
ı

ve

ted
an
ly
m

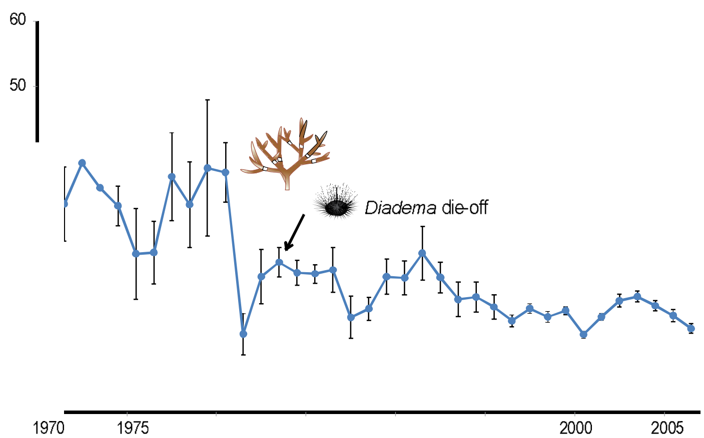
al.

of
r
uch
fish



seen quite dramatically in the falling size of fish caught by sport fishermen in the Florida Keys (McClenachan 2009).

ly
or
it



te

tal

over
n

t

2).

e

n

nd

d

ad

es

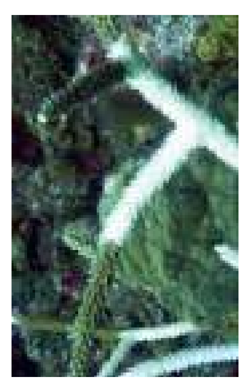
&

Mumby 2012).

e

l

Lionfish.



White-band disease.

et al. in prep).

Orbicella reef.

orne

test

s

cal

-

me

s

at

') in

nts

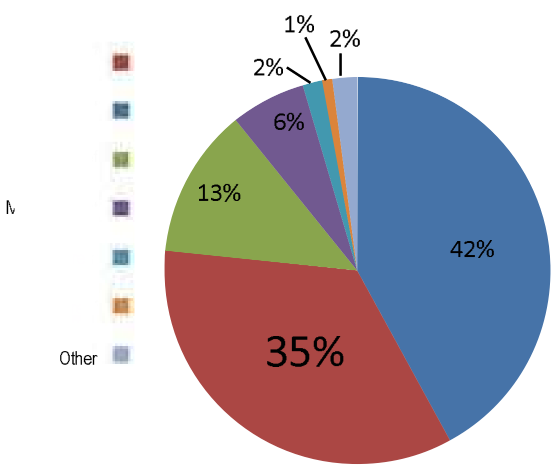
ugh

as

a

s

d



MESOPHOTIC CORAL REEFS

Discarded/lost fishing gear on a mesophotic reef at [illegible] m photographed in Curaçao from a submarine

Mesophotic reef at [illegible] m in Bonaire

Deep coral refuges

One area of coral reefs that goes largely unnoticed by many people are deep reefs. Deep reefs, or mesophotic coral reef ecosystems (MCEs), are defined as any reef beyond 30 m to a depth of approximately 150 m where the corals are still light dependent (Lesser et al. 2009). They can be divided into two general categories: (1) sections of reef slopes beyond 30 m; and (2) submerged offshore banks. From 30 – 60 m the benthic communities of the reefs are similar to those in shallower reefs, but beyond 60 m they tend to be dominated by sponges and algae (Slattery et al. 2011).

Their depth means that not only are MCEs beyond the view of many scuba divers, but they also frequently escape many of the disturbances that affect shallower reefs such as bleaching, hurricanes, sedimentation and disease. They can therefore act as a natural refuge for corals against both human impacts and the predicted impacts of climate change (Bridge et al. 2013). In the Caribbean approximately a quarter of corals are found on both deep and shallow reefs, with just a few species (e.g. *Agaricia grahamae*, *Madracis formosa*), observed exclusively on mesophotic reefs (Bongaerts et al. 2010). MCEs offer a refuge not just for their own unique biodiversity but also to some corals that may eventually become locally extinct in shallower waters. However it is still debated to what extent larval movement occurs between deep and shallow reefs, and to what extent deep reefs can act as a source of reproduction (Bongaerts et al. 2010).

It might appear that deep reefs are naturally well protected from impacts and therefore don't need further protection, however mesophotic corals are highly vulnerable to sedimentation and physical damage. Most deep corals have plate-like growth forms; the most common species within the Caribbean are *Agaricia grahamae* and *A. lamarcki*, which are fragile and therefore easily broken by fishing gear and anchors. These growth forms are also prone to collecting sediment hence most mesophotic reefs are found in areas of low sedimentation and poor coastal development practices that increase sediment flows to the ocean risk smothering mesophotic corals. A further threat within the Caribbean are invasive lionfish which are found at depths greater than 100 m and consume important herbivorous fish (Lesser & Slattery 2011). Evidence from the Bahamas suggests lionfish may have already contributed to declines in coral populations at mesophotic depths (Lesser & Slattery 2011).

Protecting deep, mesophotic, reefs could therefore be included in reef management plans and marine parks might endeavor to extend beyond the easily accessible and well known shallow reefs and include MCEs. Beyond preserving coral biodiversity, protection of MCEs is important for some commercial fish species. Fishing on deep reef banks for species such as grouper and snapper is common in many areas of the Caribbean and some fish species, including groupers, migrate to mesophotic reefs to spawn (Bridge et al. 2013). Protection of MCEs present a new challenge to reef managers as many of these areas are still being discovered and may be far offshore. Nonetheless, reef management plans could aim to include MCEs or risk losing areas of coral reef that we have only just begun to understand.

Different changes for different reefs

km² of

Map p.12

Porites astreoides.

am

oides

l,

oss

ess

us

er

s

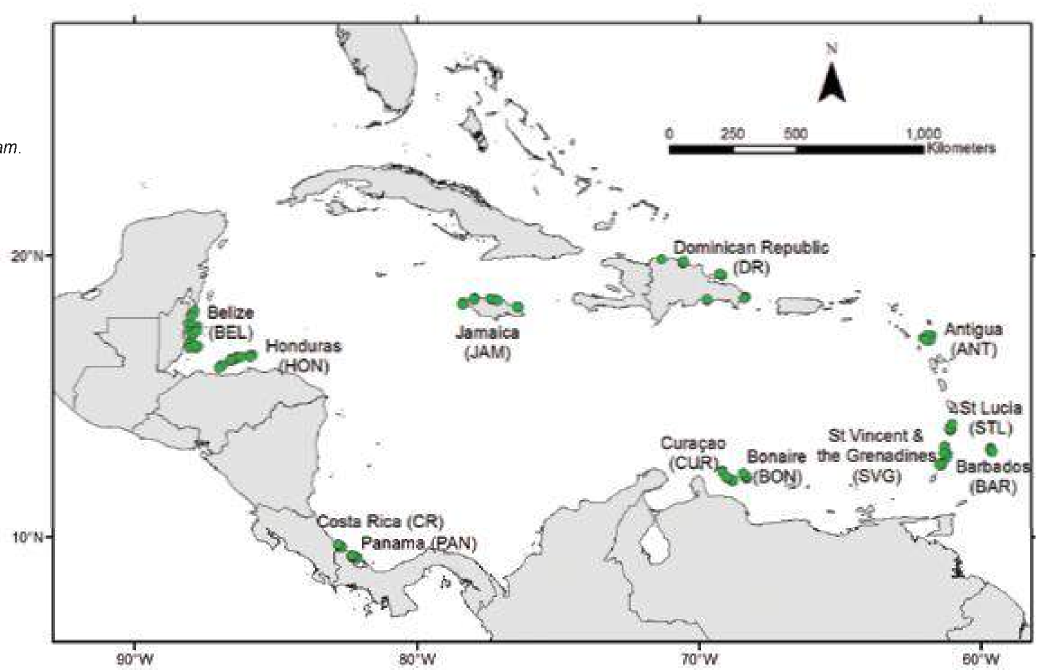
of

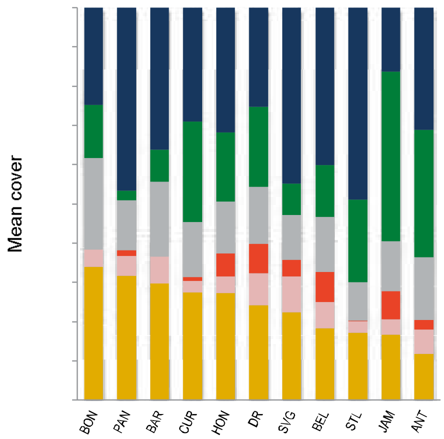
t

for

s,

FORCE team.





f

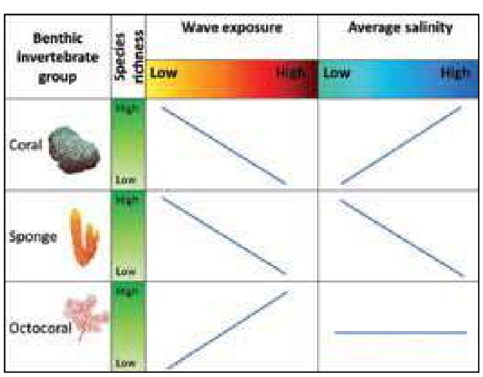
st
e)

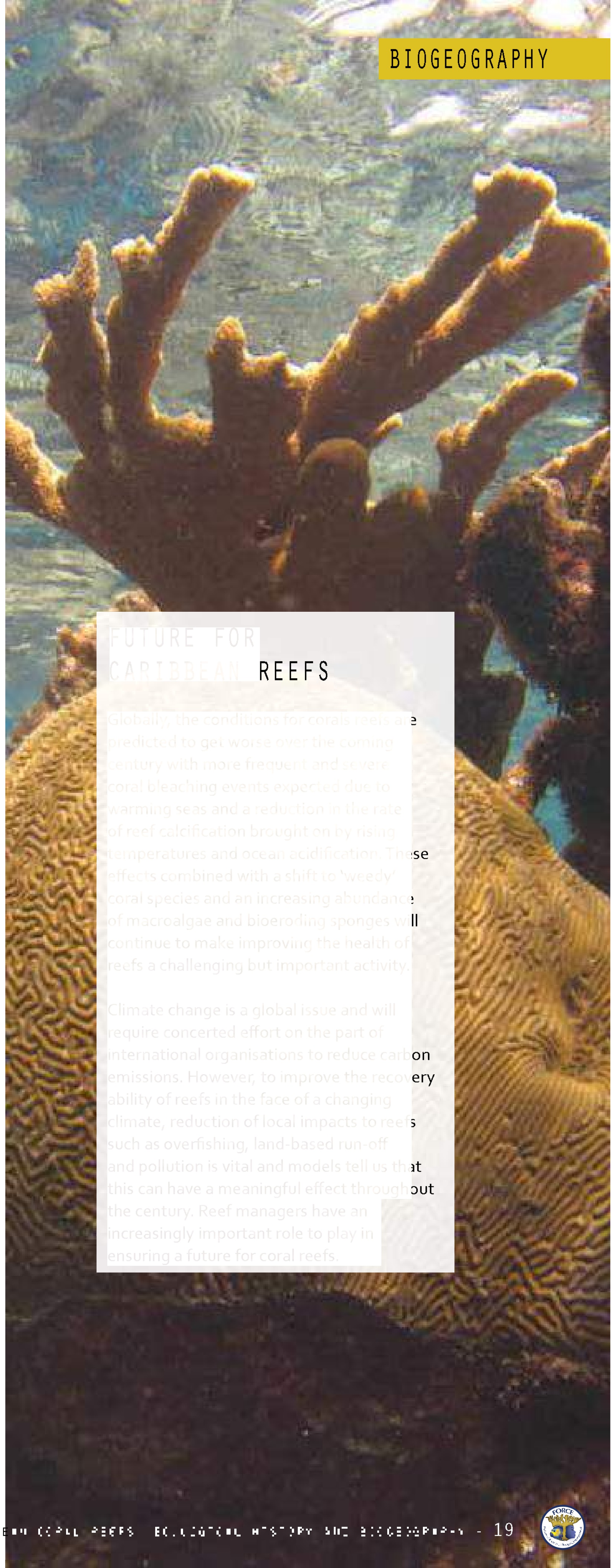
wave exposure.

ys

a.
,

( ).





FUTURE FOR CARIBBEAN REEFS

Globally, the conditions for corals reefs are predicted to get worse over the coming century with more frequent and severe coral bleaching events expected due to warming seas and a reduction in the rate of reef calcification brought on by rising temperatures and ocean acidification. These effects combined with a shift to 'weedy' coral species and an increasing abundance of macroalgae and bioeroding sponges will continue to make improving the health of reefs a challenging but important activity.

Climate change is a global issue and will require concerted effort on the part of international organisations to reduce carbon emissions. However, to improve the recovery ability of reefs in the face of a changing climate, reduction of local impacts to reefs such as overfishing, land-based run-off and pollution is vital and models tell us that this can have a meaningful effect throughout the century. Reef managers have an increasingly important role to play in ensuring a future for coral reefs.

Juan Pablo Carricart-Ganivet

Universidad Autónoma de México

OUR RESEARCH

We are looking at the effect of temperature on rates of calcification in corals that form reefs.

In terms of ecological importance there is a replacement of species ...

l

e
:
e
ne

e
o

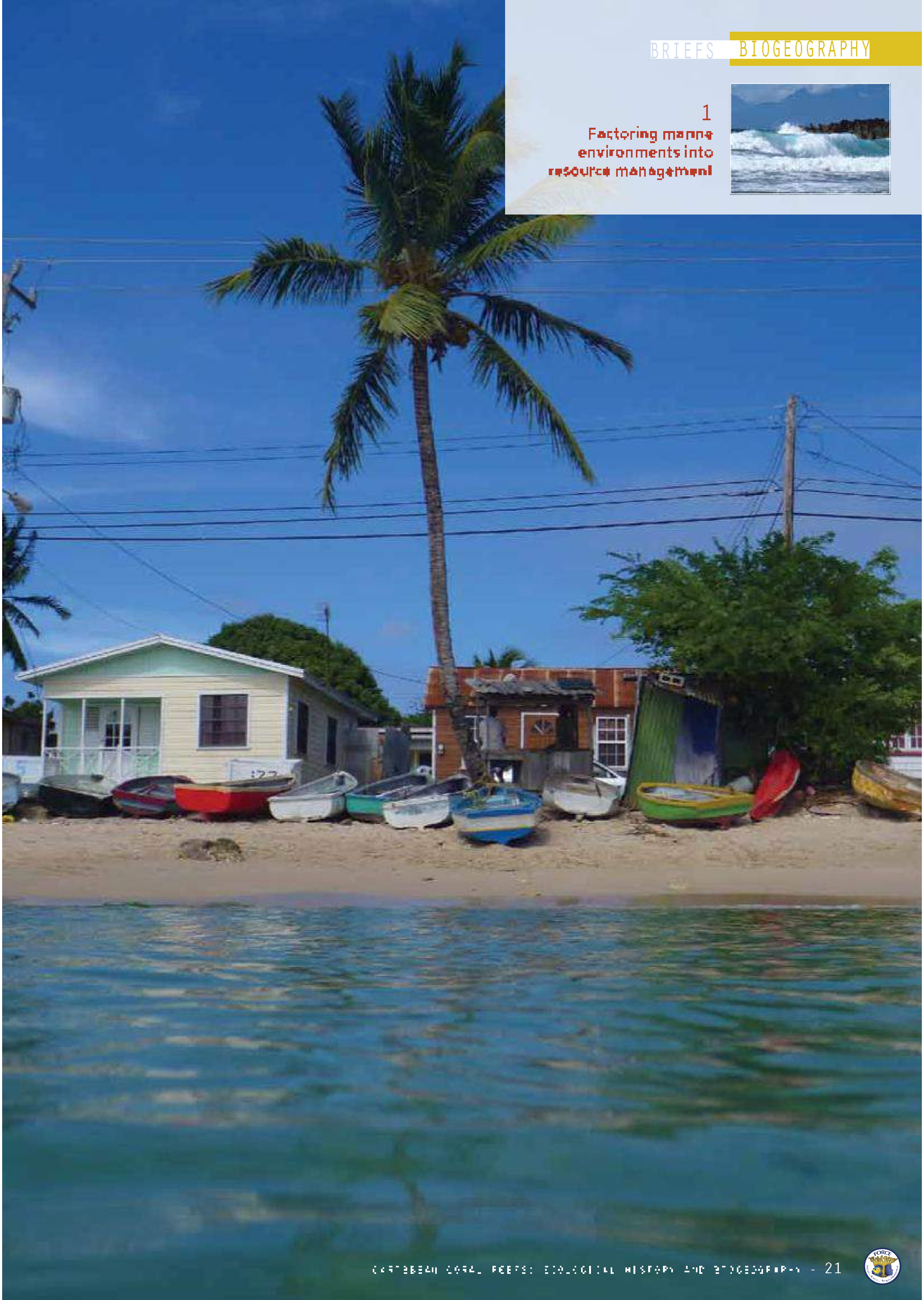
ng

,

d

s
nt

orse.



1
Factoring marine environments into resource management

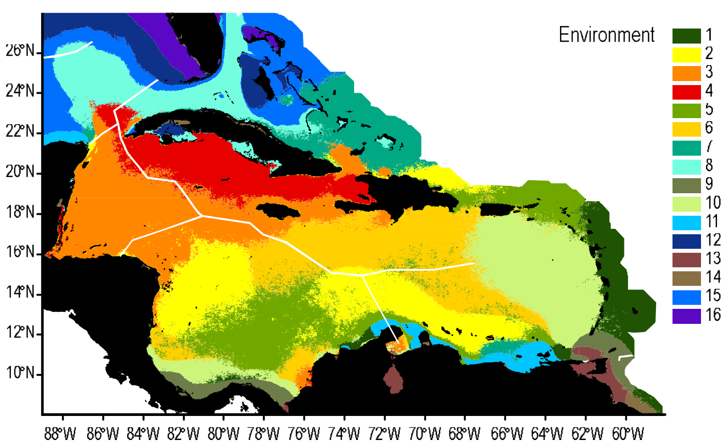
THE ISSUE

Factoring marine environments into resource management

THE EVIDENCE

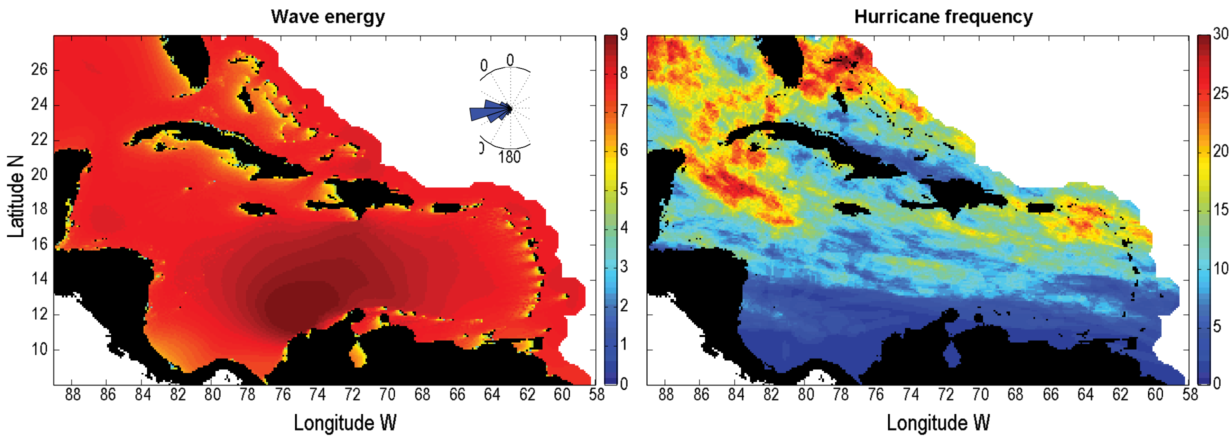
Marine ecosystems have long been exposed to the influence of diverse environmental forces such as extreme temperatures, upwelling, storms, river and runoff inputs, wave energy and hurricanes. These physical factors strongly influence reef biodiversity, the impact of disturbance, and recovery of marine ecosystems. However, data on physical environments have been difficult to acquire.

Recently, we used a wide range of satellite and field data to create the most detailed characterization of Caribbean environments to date. These maps, called Physical Environments of the Caribbean Sea (PECS), categorise the basin into distinct environmental provinces based on the characteristics of their waters at a spatial detail of 1 km². As many organisms, particularly those living in shallow coastal habitats, are strongly influenced by mechanical forces of wave action and hurricanes, we also mapped average wave energy and the number of hurricanes that have impacted each site. These maps are available free online and will help managers plan their interventions and monitor their impacts.



ıct

et al. 2007,



MANAGEMENT IMPLICATIONS

By defining physical environments, PECS can be used for a variety of purposes within resource management:

- **Mapping biodiversity proxies**
  Good-quality data on marine biodiversity are scarce. Habitat maps are a common proxy for biodiversity assessments; however, they assume that species living in each habitat are the same everywhere. In reality, marine communities vary according to the physical environment even within a single habitat type. Habitat maps can now be stratified by physical environment to provide better proxies of biodiversity.

- **Building ecologically representative marine protected area (MPA) networks**
  The Convention on Biological Diversity emphasizes importance of including a representative range of diversity within an MPA network. A good way to do this is attempt to represent each habitat type in each of its physical environments.

- **Assessing transferability of management approaches and setting realistic expectations for management outcomes**
  Areas of the same environment are likely to respond similarly to management interventions (e.g., reserve impacts should be similar in comparable environments). PECS can help explain why some areas respond well to management and other areas (in different environments) respond differently.

- **Setting priorities for rapid assessment/monitoring activities**
  Stratifying field surveys by physical environment would facilitate a cost-effective, comprehensive appraisal of biodiversity within an area.

- **Identifying potentially valuable or vulnerable marine ecosystems**
  PECS can be used, for example, to identify areas where upwelling occurs, which might be particularly productive and valuable from a fisheries perspective. PECS can also identify areas under river influences, which might be heavily impacted by pollution.

- **Mapping potential fishing access**
  Areas with high wave energy tend to be too rough so receive less fishing.

- **Mapping potential algal growth**
  Much of the Caribbean has very weak tides and wind-driven waves play an important role in delivering fresh nutrients to algae which help them grow. Areas of high wave exposure tend to have faster-growing algae than sheltered areas. This information might identify areas that are more susceptible to algal overgrowth if herbivores are heavily depleted. Essentially, if parrotfish are removed, an algal bloom is more likely in exposed areas rather than in sheltered areas.

FURTHER INFORMATION

Coral Reef State and Resilience

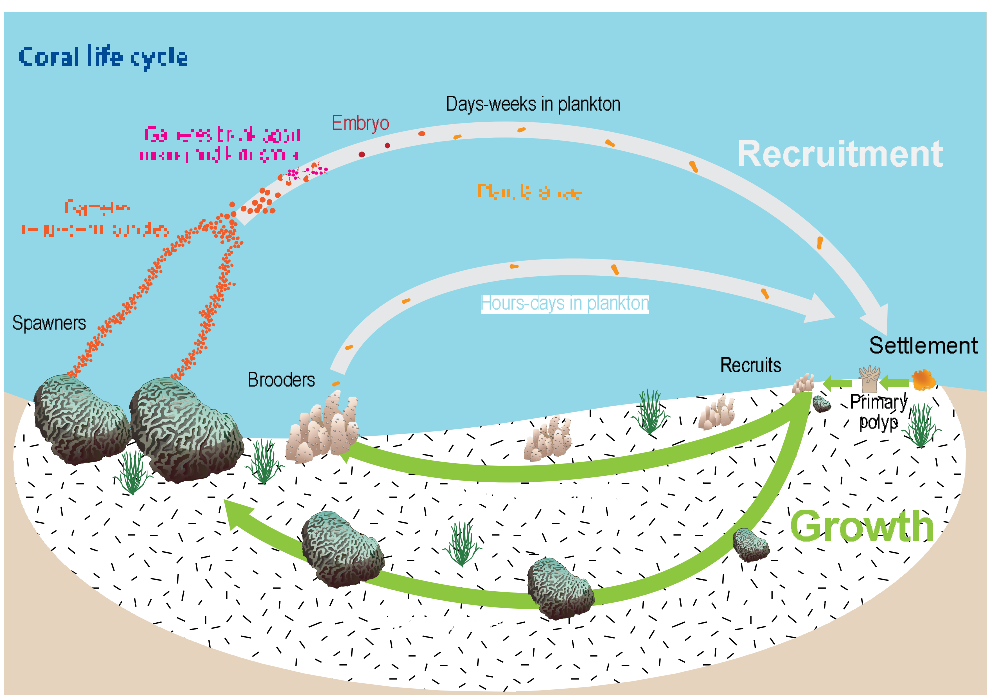
Corals have evolved and adapted over millions of years, having survived major changes in the Earth's climate and ocean circulation patterns. At the regional and local scale corals are impacted by natural events such as hurricanes and sediment outflows from rivers. Coral reefs can recover naturally from such impacts and this ability to recover towards a coral dominated state is termed reef resilience. Overfishing of herbivores, increased nutrient flows onto reefs from sewage and agricultural run-off, and the effects of climate change are all reducing reef resilience. On some Caribbean reefs, this has resulted in a change from reefs dominated by corals to reefs dominated by fleshy macroalgae. Such reefs do not provide the same quantity and quality of ecosystem services, such as coastal defence, tourism and fisheries, which millions of people are dependent upon. It is worthwhile prioritising the enhancement of reef resilience as part of any reef management programme.

Elkhorn coral on a shallow reef

Recruitment

:e

1).



during
the recruitment process.

Growth

ss

.

ors
w
r
nes

().

ral

Mortality

ls

ıls
ıic

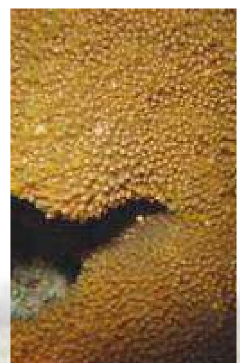
y

ıls
g

k

et al. 2005). These processes are natural causes of coral mortality. Mortality can involve the death of the whole coral colony or just part of the colony. However, mortality of corals worldwide

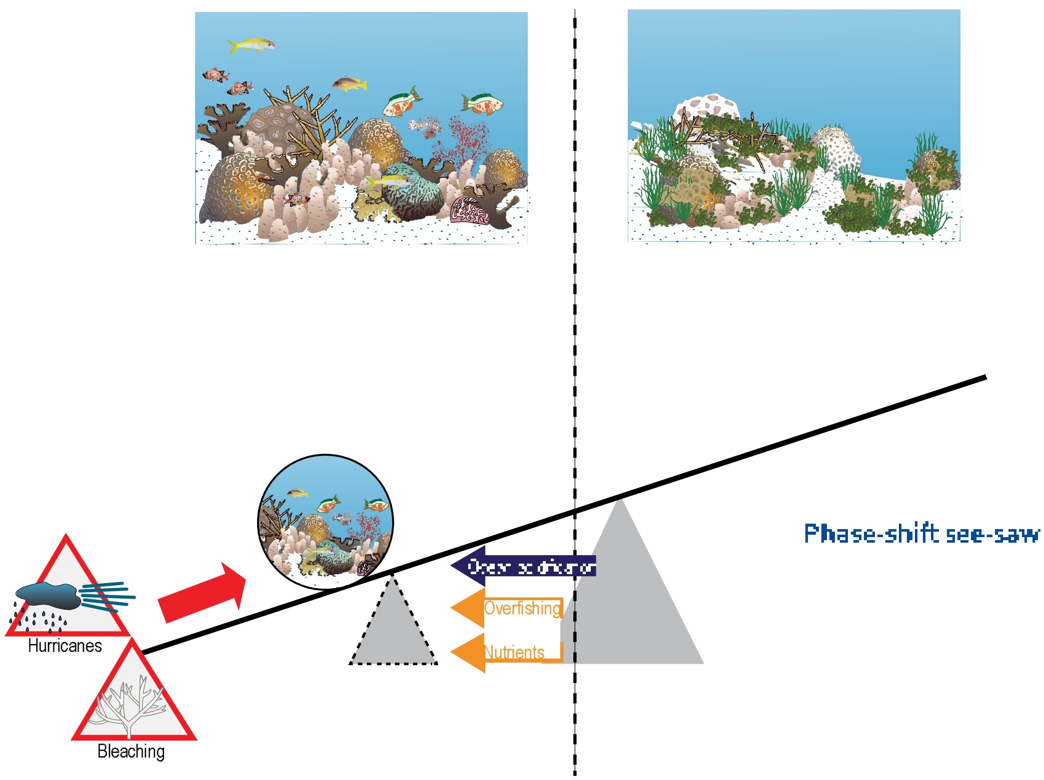
long lasting effects, such as bleaching which reduces coral growth for several years after the bleaching event and also reduces coral reproductive ability (Baker et al. 2008).



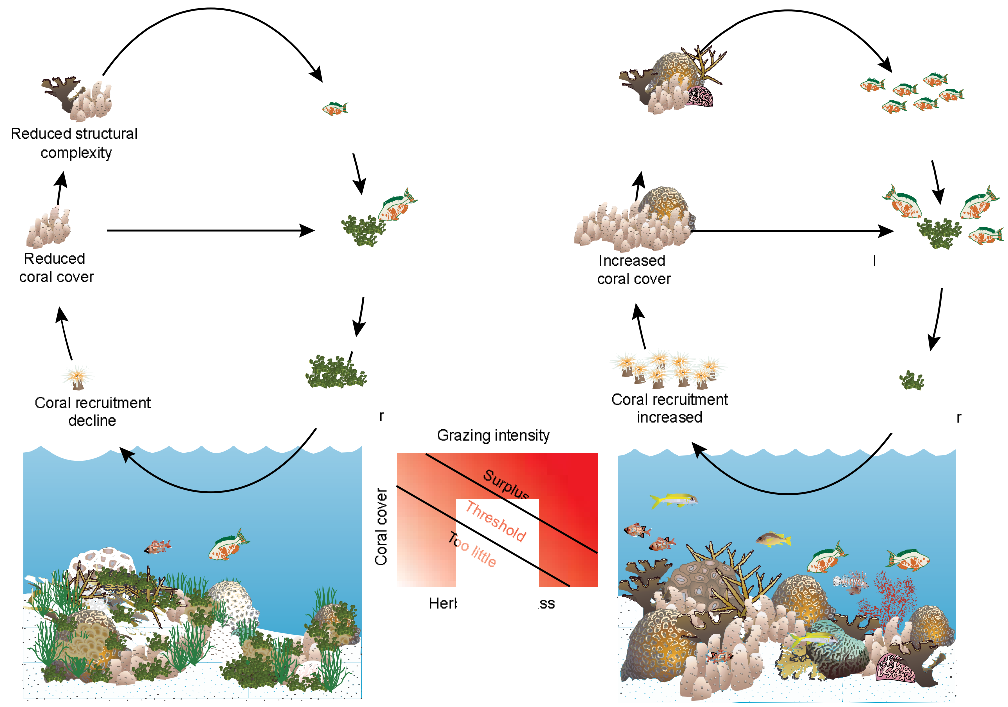
Coral spawning.

Process	What affects the process?	Proximate effects on process	Anthropogenic influences on process	Resulting change in process (+ or -)*	References
RECRUITMENT	e	ıostil nhibi	ıd ivores dance	–	
	y	substrate ff	's	+	
			ty	–	
	ıls			–	rowth in this
			,	–	les &
GROWTH	Substrate available for growth	Macroalgae and other sessile reef organisms compete with coral for space, often using chemical methods	Excess nutrients and overfishing of herbivores can increase abundance of macroalgae and other coral competitors	–	(Rasher & Hay 2010; Chadwick & Morrow 2011)
	Light	Reduced light reduces growth rate	Increased sediment from land use change (e.g. deforestation) blocks light from reaching corals	–	(Fabricius 2005)
	Sea surface temperature	Abnormally high or low temperatures can reduce growth rate	Climate change is increasing sea surface temperature	–	(De'ath et al. 2009; Carricart-Ganivet et al. 2013)
	Acidity of the oceans (pH)	More acidic oceans lead to lower calcification rates of corals, which can reduce growth rate	Increasing CO_2 in the atmosphere is increasing the acidity of the oceans	–	(Doney et al. 2009)
MORTALITY	Hurricanes			–	
	ıg		es ity	–	3)
			s e r	–	&
	Coral disease		ly on ınd	–	
	Bioerosion	ins l	.g. 's, of bioeroders	–	(Hutchings 2011)

e
,
d,
ed
d
le


Hurricanes
Bleaching
Overfishing
Nutrients
Phase-shift see-saw

Grazing feedback loop



algal bloom.

e

nt

oes

ng.

s

s

e

s

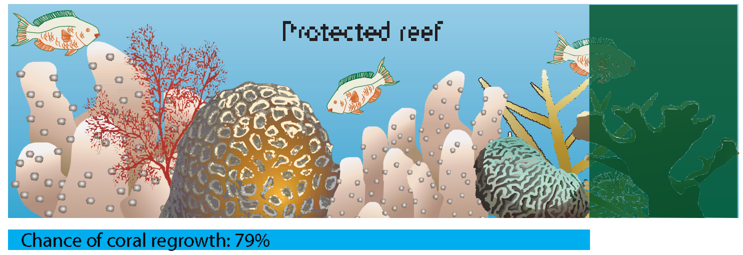
ral

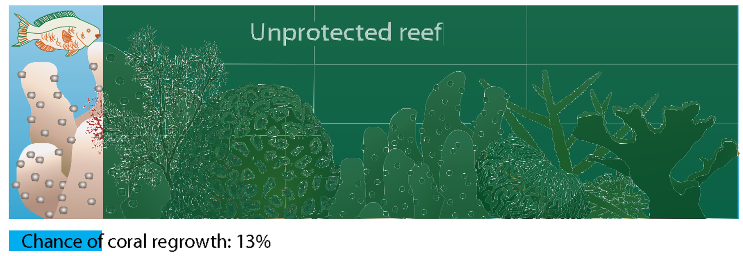
ealistic

der

ice

o





e

ected

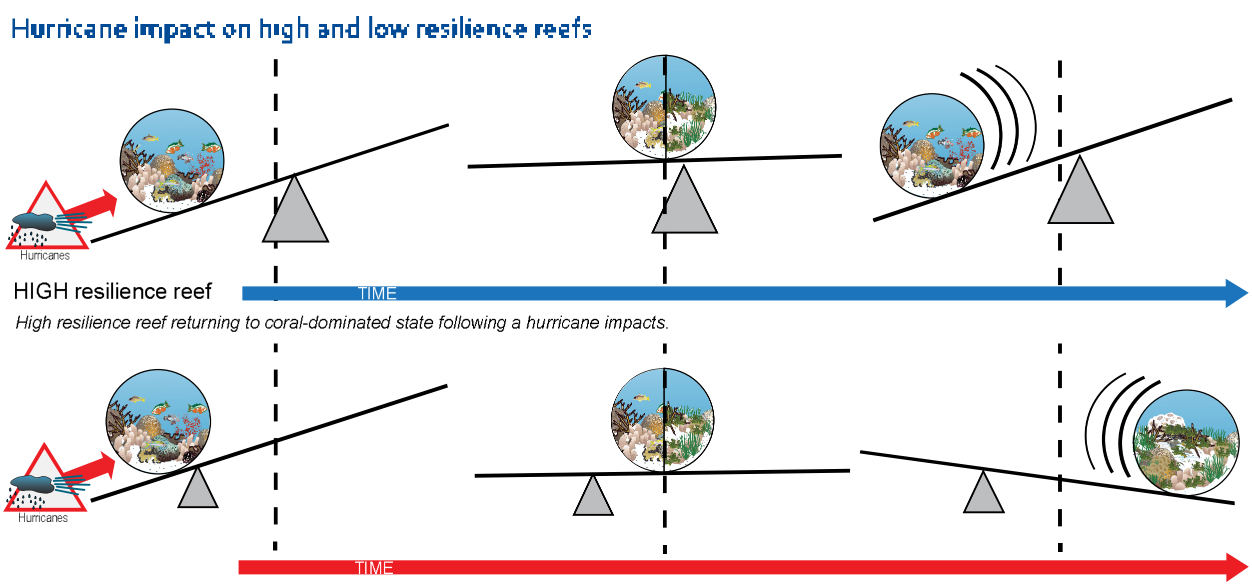
t

a

st
h
e

n

in



High resilience reef returning to coral-dominated state following a hurricane impacts.

Key events reducing reef resilience in the Caribbean:

Loss of branching *Acropora* corals

These corals are important for reef resilience as they are the fastest growing corals in the Caribbean and they provide important structural habitat for fishes. Much of the *Acropora* cover was lost in the 1980s due to white-band disease.

Loss of *Diadema* sea urchins

Along with parrotfish, *Diadema* are the key herbivores on Caribbean reefs. Mass die-off of *Diadema* due to disease has removed this important herbivore from many reefs, reducing the amount of algal grazing on the reefs.

Chronic overfishing

This has reduced the abundance of herbivorous fish, principally parrotfish, which play an important role on reefs as grazers of algae.

FURTHER INFORMATION

resources for managers: [illegible]

BRIEFS **RESILIENCE**

1
Preventing blooms of cyanobacterial mats

2
Reducing nutrients to restore the coral-algal balance

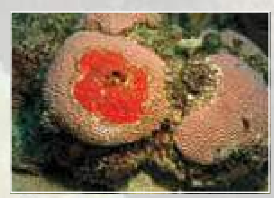
3
Seagrass meadows as bioindicators of increases in nutrient levels

4
Influences of seasonality and herbivores on macroalgal growth

5
Thinking in 3D: integrating habitat complexity into reef management

6
Conservation of parrotfishes to aid reef recovery

7
Bioerosion on coral reefs and monitoring its effects



8
The use of sexual coral reproduction in reef restoration

Preventing blooms of cyanobacterial mats

THE ISSUE

Cyanobacteria, also called blue green algae, are a type of bacteria found in both aquatic and terrestrial environments. In the sea they occur as cells floating in the water column, as well as mats largely composed of intertwined cyanobacterial filaments covering the seafloor. On coral reefs cyanobacterial mats are normally rare. However, in recent years they have increased in abundance on many Caribbean reefs, sometimes reaching close to 50% cover in some areas.

Their increase can have a variety of negative consequences for the reef and the benefits that people derive from reefs. These go well beyond the simple loss of reef 'attractiveness' to divers. Cyanobacterial mats can grow quickly over the reef. They can prevent coral larvae from settling on reefs, can overgrow juvenile and adult corals and can act as coral pathogens. Furthermore, they can produce chemicals which deter the grazing of fishes and urchins and have been linked to mass reef fish die-offs.

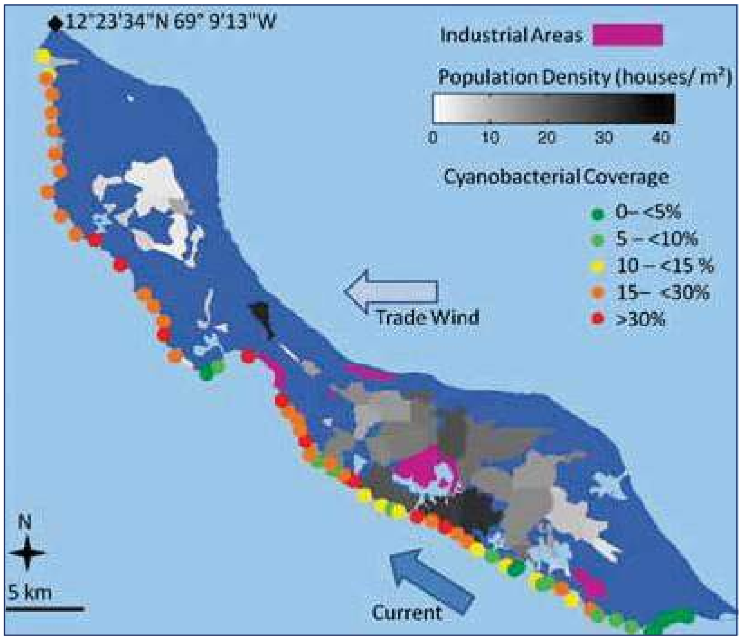
THE EVIDENCE

red
land

ted

ter
sites
ganic
matter compared to sites harboring few mats.
Sediments are known to be a sink of organic matter. Researchers found that organic matter added to sediments can fuel the growth of cyanobacterial mats.

Diver checking cyanobacteria.



MANAGEMENT IMPLICATIONS

High coverage of cyanobacterial mats on a reef indicates an increase in nutrients and organic matter which principally come from land-based run-off and pollution. Septic tanks, landfills and waste dumping areas leak nutrients into groundwater which can subsequently flow out onto reefs. Efforts could be made to reduce or stop untreated waste water and run-off from agricultural land reaching the reef.

Bays and other partially enclosed coastal areas have narrow or shallow openings towards the sea, naturally preventing nutrients from reaching the reefs. **Dredging and other activities that change water flow and increase flushing effects can lead to higher nutrient levels and, potentially, more cyanobacteria.**

Reducing nutrient inputs will not only reduce the abundance of cyanobacterial mats, it can also decrease the growth of macroalgae and bioeroders and slow down the spread of coral diseases.

FREQUENTLY ASKED QUESTIONS

Cyanobacteria.

FURTHER INFORMATION

Reducing nutrients to restore the coral-algal balance

THE ISSUE

On coral reefs, there is constant competition for space among benthic organisms such as corals, algae and cyanobacteria. Macroalgae are seaweeds that can overgrow neighbouring corals. Turf algae are diminutive mixed algal communities composed of small macroalgae and cyanobacteria. It has been shown that turf algae reduce the recruitment of new corals and can also overgrow existing corals. Cyanobacterial mats can overgrow both macroalgae and corals.

Recent human activities (e.g. coastal development and the use of fertiliser on agricultural land) have caused an unnaturally high flow of nutrients such as nitrogen and phosphorus onto many reefs. It is hypothesized that this causes macroalgae, turf algae and cyanobacteria to grow faster and overgrow corals. If nutrient influxes persist, coral reefs could turn into ecosystems dominated by algae and cyanobacteria, which decreases their ecological, economic and aesthetic value.

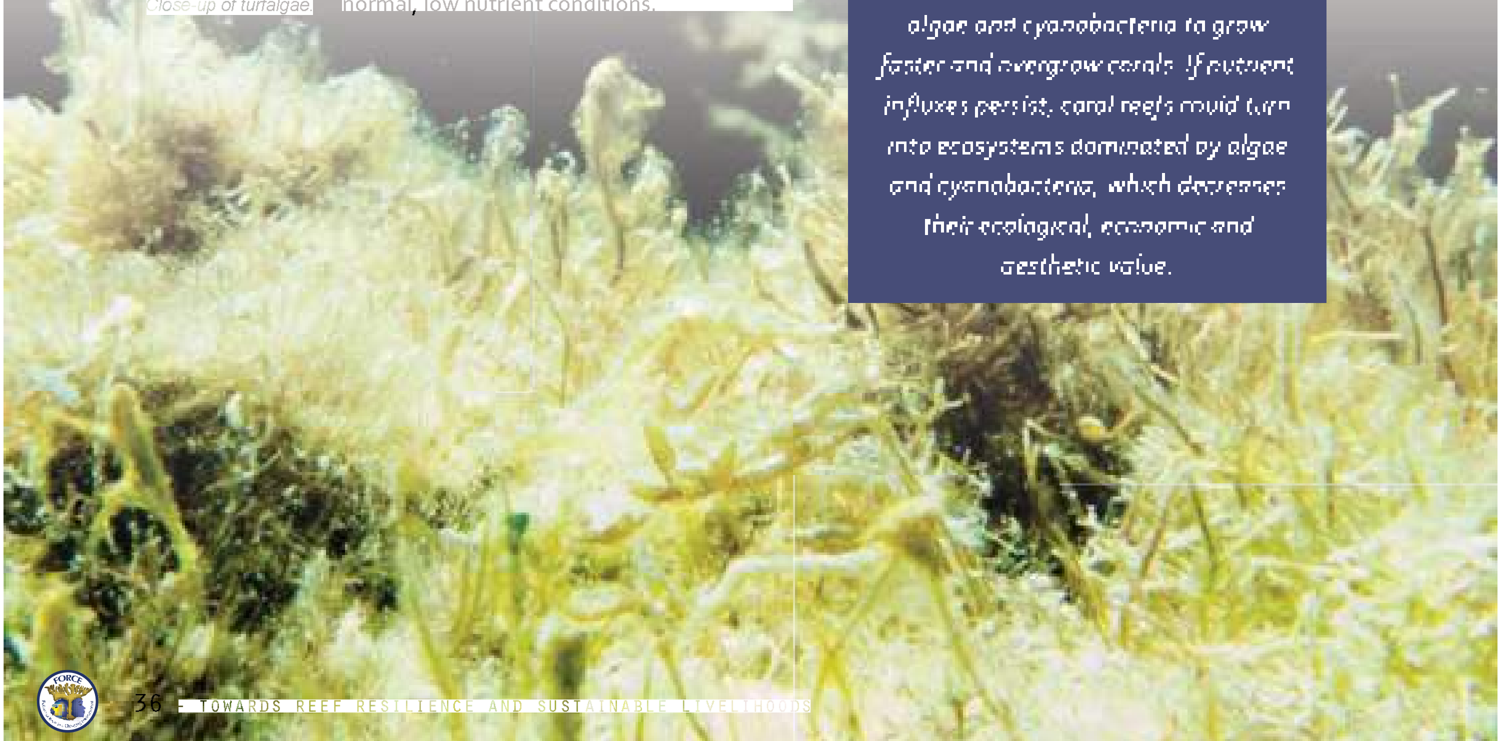
Cyan

THE EVIDENCE

ed

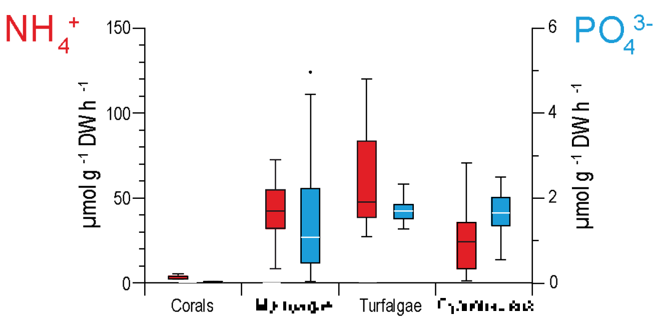
ns

sources of nitrogen entering the reef. However, increases in external sources of both nitrogen and phosphorus can increase their growth rate as these nutrients often limit their growth under normal, low nutrient conditions.



Close-up of turfalgae.

Temporary nutrient enrichment events entering coral reefs from land as seen from the surface and under water.



...nt of

FREQUENTLY ASKED QUESTIONS

eliminate the

...ducing
...'s?

...ch

...nts

and the ocean.

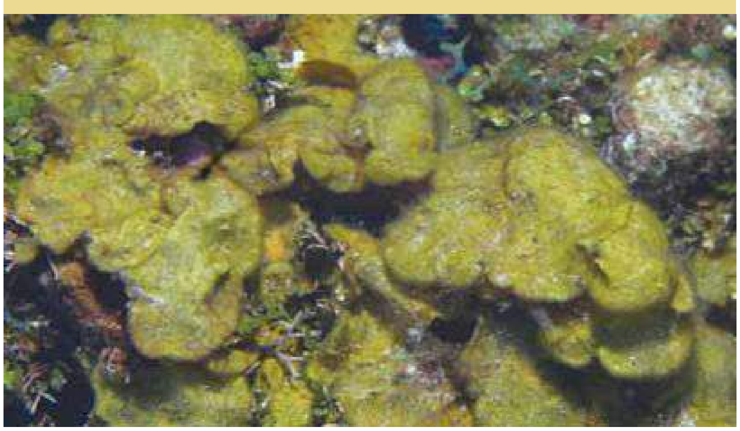
FURTHER INFORMATION

Available free online:

MANAGEMENT IMPLICATIONS

Reduce nutrient input to reefs, with a focus on sources of phosphate. Since macroalgae, turf algae and cyanobacteria all take up nutrients, reductions in nutrient flows onto reefs will help reduce the growth potential of these algae and cyanobacteria. Reducing the phosphate inflow will specifically decrease the growth of turf algae and cyanobacteria since they are less dependent on external nitrogen as they can fix otherwise unavailable nitrogen (N_2). In particular, sources of phosphate, such as raw sewage outfalls, should be reduced.

Reducing nutrient flow onto reefs will ultimately benefit corals as they compete for space with algae and cyanobacteria.



Macroalgae (Lobophora sp.).

Seagrass meadows as bioindicators of increases in nutrient levels

THE ISSUE

Coral reefs are naturally low nutrient environments. Corals are adapted to survive in such conditions, therefore large inputs of nutrients into the waters surrounding a reef can have negative effects on corals. It is normally algae that benefit from this nutrient enrichment, as relative to corals, they have higher growth rates and greater ability to take up nutrients. This allows algae to overgrow parts of coral colonies and reduce the space available for the recruitment of new corals.

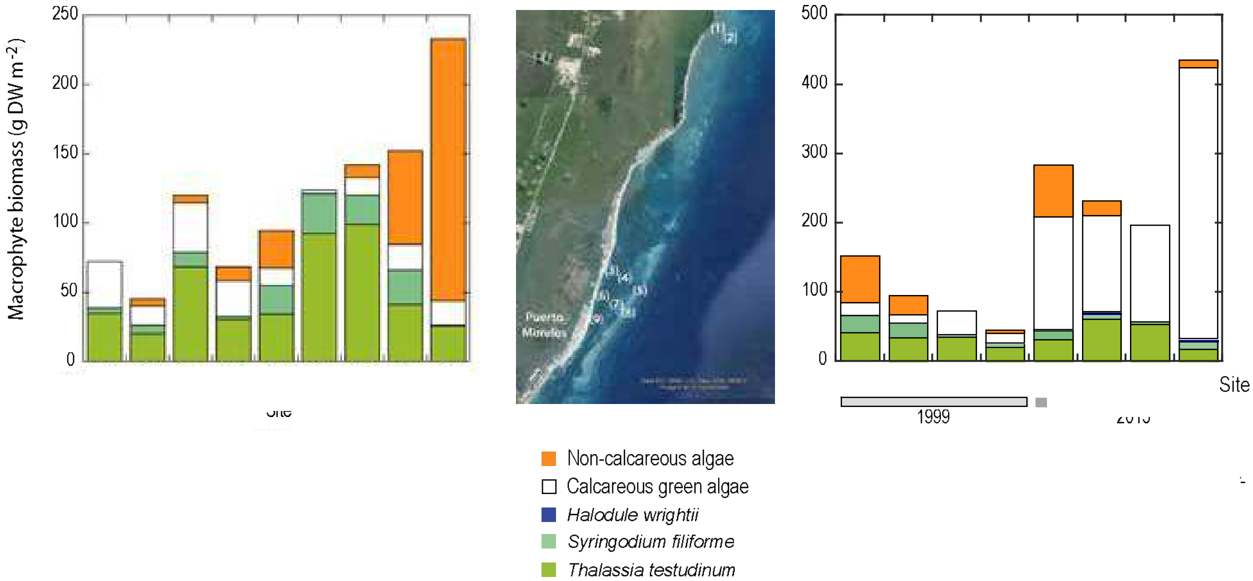
Detecting changes in nutrient levels on reefs is therefore key for managers so that they can reduce or remove sources of excess nutrients, hopefully before severe changes in the coral community become apparent.

Biological indicators (bioindicators) are used to assess the health of the environment and detect changes early, before damage to a habitat becomes irreversible. Seagrass meadows respond faster than corals to nutrient enrichment, and when they are located close to the reef, they act as a biological sink for nutrients, buffering the coral reef. Nutrient enrichment of seagrass meadows is visible as changes in the extent of the meadow and in community composition. These changes can be useful bioindicators, providing an early warning of nutrient enrichment in the water that may eventually impact the health of nearby reefs.

THE EVIDENCE

meadow located at the shore.

availability.



:

he

es.

Calcareous algae: Halimeda.

FURTHER INFORMATION

(3):

293-310.

MANAGEMENT IMPLICATIONS

There are three possible bioindicators in seagrass meadows of trophic changes in the coral reef habitat due to nutrient enrichment:

- Increases in the abundance (cover and/or biomass density) of the dominant seagrass
- Increases in the presence of fleshy algae
- Increases in calcareous algae relative to the total mass of the seagrass community.

Changes should be significant and sustained, but will vary depending on the magnitude of the environmental disturbance, i.e. amount of nutrients being added to the water. Although large scale changes in the seagrass community can be seen on satellite or aerial photos, local monitoring of the seagrass meadow through measurement of shoot density, shoot size and leaf biomass of the dominant seagrass, provides a more sensitive method of detecting changes. Suitable data are collected in CARICOMP surveys which include measurements of seagrass biomass.

Importantly these bioindicators are helpful for detecting changes in the reef environment before serious impacts are observed in the coral community.

However, some care needs to be taken in interpreting environmental changes because cover and biomass of seagrasses and algae varies both spatially and seasonally and changes in the abundance of herbivores can also have a strong effect. Monitoring programs should therefore compare the same sites at the same times of the year (same seasons). Sites selected should aim to include the natural variability in conditions present in the area, but it is useful to include sites with low changes in sediment accretion and movement which are less prone to large changes in the seagrass meadow community. As seagrass meadow sites closest to the coast are the most disturbed ones, preferable sites for monitoring are closer to the reef community (i.e., back-reef).

Influences of seasonality and herbivores on macroalgal growth

THE ISSUE

Macroalgae are a natural part of the reef community but on many Caribbean coral reefs they are becoming the dominant species as the cover of hard corals declines. Macroalgae compete with corals for space and reduce the space available for juvenile corals to settle on the reef. Herbivores and nutrients are known to play an important role in controlling algal growth but changes in water temperature and light are also important. In most reef environments changes in temperature and light are mainly due to the change in seasons, i.e. lower light levels and temperature in the winter compared to the summer. Understanding the relative importance of seasonality and herbivory on the abundance of algae on reefs is important for managers who might be monitoring reefs at different times of the year and in areas with different levels of herbivory, e.g. inside and outside a marine park.

Dictyota.

THE APPROACH

a

d

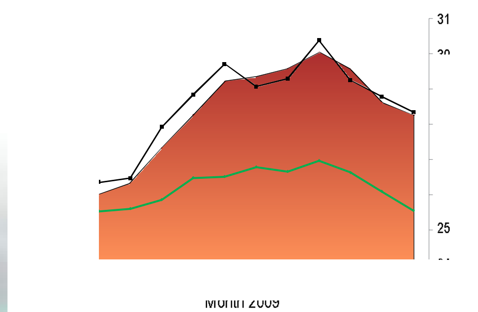
THE EVIDENCE

t.

els.

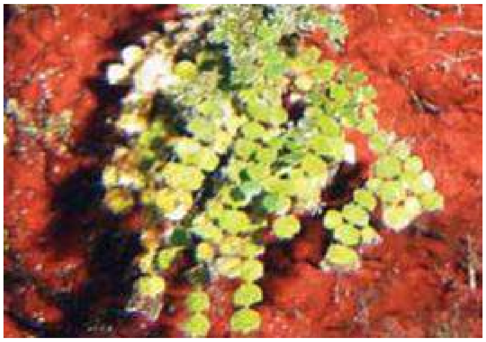
en

temperature.



Lobophora variegata and halimeda.

Influences on abundance of algae



ıs reduced by

g

s

abundant.

MANAGEMENT IMPLICATIONS

- **Consider the effect of seasonal changes in reef surveys.** Even on healthy reefs there are changes in the cover of macroalgae and the abundance of macroalgae species throughout the year. If reef surveys are conducted on the same reefs at more than one time during the year, managers should expect to see some variation in macroalgae, even if there are no disturbances (e.g. bleaching events, hurricanes) or other changes on the reef. To avoid the complicating factor of seasonal changes in macroalgae, it is best to compare data that was collected at the same time (month) each year.

- **Herbivores are an important control on macroalgae.** Without herbivores present, macroalgae can dominate the reef, squeezing out corals and reducing the chances of reefs recovering from disturbances such as hurricanes and bleaching events. Parrotfish are the main herbivore on most Caribbean reefs, though the *Diadema* sea urchin can be a very important herbivore if present in sufficient numbers (typically 1 or more per square metre).

It is advisable to protect both parrotfish and *Diadema* from overharvesting.

FURTHER INFORMATION

raction

Thinking in 3D: integrating habitat complexity into reef management

Bo

THE EVIDENCE

s

ed

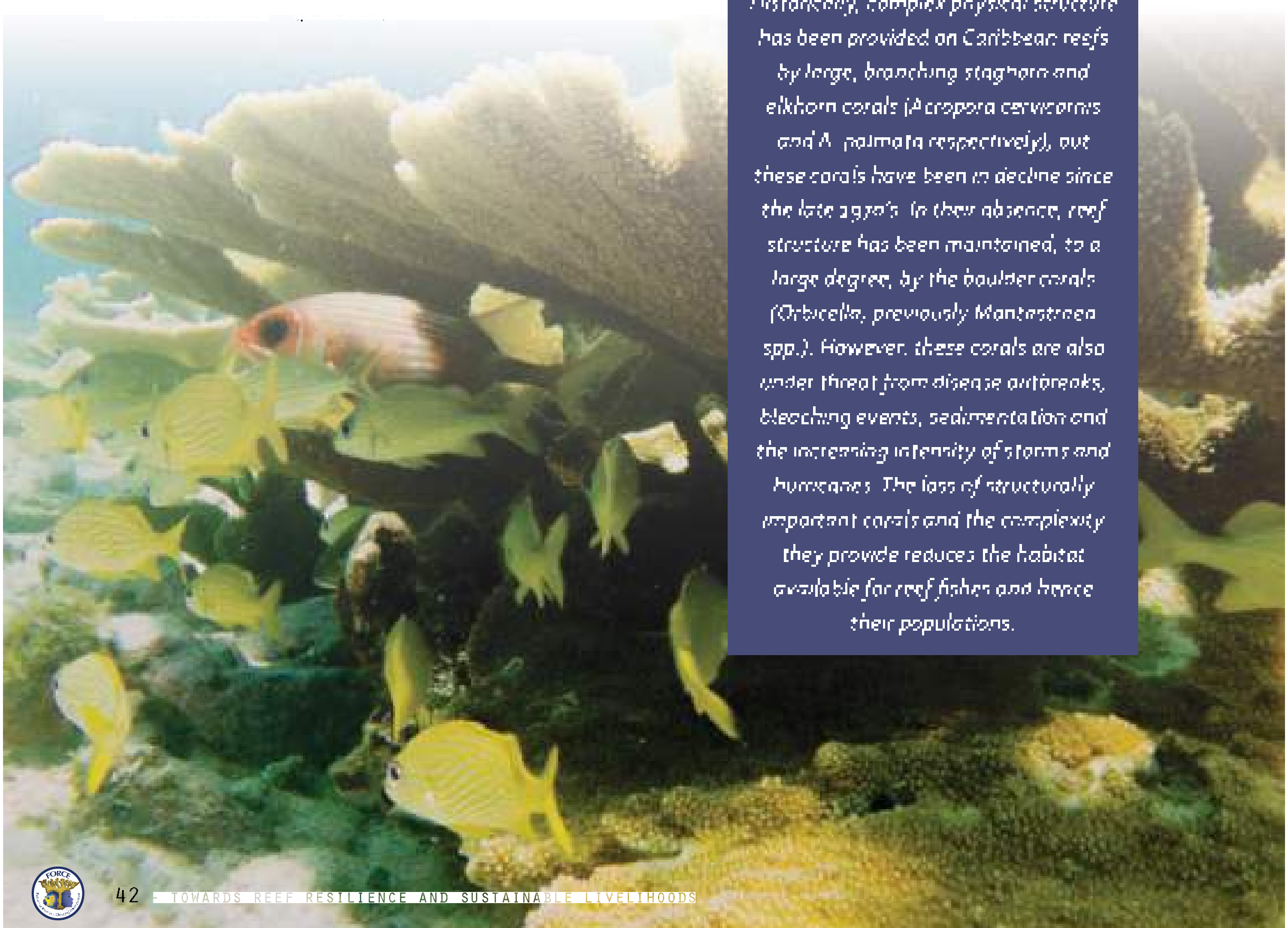
ity

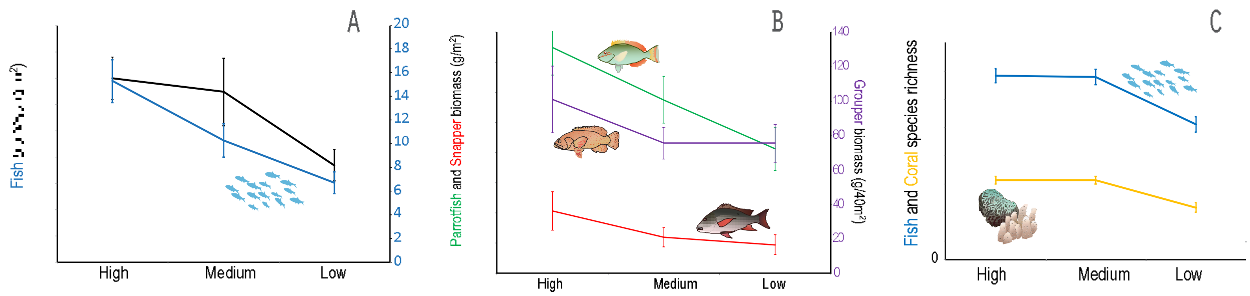
fs:

THE ISSUE

From rainforest to reefs, physical structure created by organisms (e.g. trees, corals) provides habitat for plants and animals. Structurally complex habitats support a greater diversity and abundance of life, resulting in healthier ecosystems which are typically more resilient to environmental change. Coral reef habitat complexity is especially important for fishes, thus directly supporting valuable reef fisheries, diving and tourism.

Historically, complex physical structure has been provided on Caribbean reefs by large, branching staghorn and elkhorn corals (Acropora cervicornis and A. palmata respectively), but these corals have been in decline since the late 1970's. In their absence, reef structure has been maintained, to a large degree, by the boulder corals (Orbicella, previously Montastraea spp.). However, these corals are also under threat from disease outbreaks, bleaching events, sedimentation and the increasing intensity of storms and hurricanes. The loss of structurally important corals and the complexity they provide reduces the habitat available for reef fishes and hence their populations.





Relationship between reef complexity and biomass (A and B) or species richness (C) (mean values with standard error).

MANAGEMENT IMPLICATIONS

- **Protecting reef complexity**
  It is worth considering prioritising the protection of reefs with high and medium complexity. Management efforts could focus on human impacts such as sediment and nutrient run-off, overfishing and physical damage to the reef from anchoring and tourist activities.

- **Restoring habitat complexity**
  It is hard to create the naturally-occurring complex reef structure using artificial means so it is more cost-effective to prevent decline of existing habitat structure than attempt to restore it. The prevention of decline is achieved by managing the processes that drive coral reefs such as coral recruitment and growth. However, at small scales, reefs that have lost complexity may benefit from the addition of artificial structures to provide habitat and shelter for fish and help accelerate recovery. These reefs will need protection from fishing if long term recovery is to be achieved.
  Introducing artificial structures into naturally low complexity reef areas creates habitat that was not necessarily there before: 'habitat creation', not 'habitat restoration'. Conditions for the development of corals are unlikely to be favourable (e.g. low-recruitment of new corals, high growth rates of macroalgae), limiting the long-term construction of natural complexity.

- **Measuring reef complexity**
  Reef monitoring protocols often use the chain method to quantitatively assess reef complexity, providing a useful measure of ecosystem health. Visual assessment of reefs using a simple 3 or 5 point qualitative scale can also be useful for categorising reefs for prioritisation in spatial management.

FREQUENTLY ASKED QUESTIONS

ity

sh.

nt

ar

vn
ry
ny
kly

THREE POINT QUALITATIVE SCALE FOR MEASURING COMPLEXITY ON REEFS

Conservation of parrotfishes to aid reef recovery

THE ISSUE

The coral on many Caribbean reefs is currently in a degraded state, often being below 10% cover whereas it should ideally exceed 40-50%. If corals remain in this degraded state for long periods of time then the benefits that people derive from reefs will be threatened. It is the corals that build the reef structure needed to provide habitat for reef fisheries, generate sand for beaches, and protect coastal areas from wave erosion.

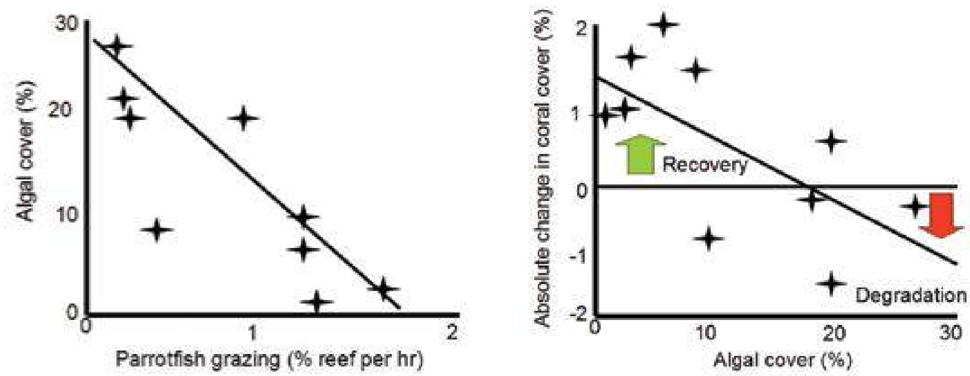
There are many causes of this decline which include mass coral bleaching events, outbreaks of coral disease, hurricanes, mass regional decline of long-spined sea urchins, overfishing, and eutrophication. The precise causes will vary from place to place.

It has recently been shown that coral recovery can be helped by taking practical steps to manage parrotfishes. Parrotfishes are the main grazers of algae and high levels of parrotfishes are able to reduce the amount of algae on reefs. Algae can interfere with coral recovery in two ways. Firstly, by taking up space, algae prevent larval corals finding a place to settle on the reef and this effectively cuts off the supply of new corals. Secondly, algae smother established corals, which either stunts their growth or reduces their size.

Quee

THE EVIDENCE

Algae control coral recovery



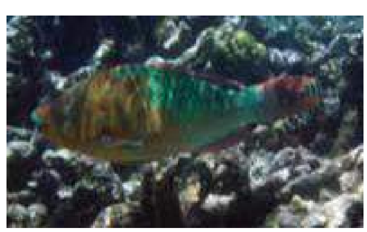
MANAGEMENT IMPLICATIONS

Policy Options

- **Most conservative**
  Draft legislation to outlaw the catch or selling of parrotfish as has been done in Belize. This policy may help sustain the long-term livelihoods of fishermen by helping to preserve the reef habitat needed by their target species.
- **Less conservative**
  Vastly reduce the use of fish traps which cause much parrotfish bycatch. Educate fishers to retrieve the traps regularly, haul them to the surface slowly, and return surviving parrotfishes.
- **Least conservative**
  Educate fishers to reduce their impact on parrotfishes and try to reduce fishing effort. The most important parrotfishes are the larger-bodied individuals. The most important species are the stoplight (*Sparisoma viride*), rainbow (*Scarus guacamaia*), queen (*Scarus vetula*), and princess (*Scarus taeniopterus*).

Management expectations

Protecting parrotfishes will not return reefs back to their former, pristine states: there is simply too much stress on corals for a full recovery to take place in most locations. However, protecting parrotfishes is a concrete step that will help recovery and help stem the loss of reef services such as fisheries productivity.



FREQUENTLY ASKED QUESTIONS

If** … **al do I still
ne

Th
re

nains.

Pe … ***so***
sh

s

A
co

FURTHER INFORMATION

www.pl…

Bioerosion on coral reefs and monitoring its impact

THE EVIDENCE

he
s
ly

Cross-section view of sponge excavation and infiltration of limestone rock

THE ISSUE

Bioerosion is the destruction and removal of substrate by the action of organisms. On coral reefs bioerosion plays a major role in the balance between constructive (calcification and cementation) and destructive forces (physical erosion, chemical dissolution and bioerosion). Bioeroders create suitable surfaces for corals to settle, increase habitat complexity and provide food for numerous reef-associated organisms enhancing biodiversity. Bioerosion is crucial for maintenance of coral reefs as long as it is in balance with calcification. Bioeroders create suitable surfaces for corals to settle, increase habitat complexity and provide food for numerous reef-associated organisms enhancing biodiversity. Bioerosion is crucial for maintenance of coral reefs as long as it is in balance with calcification.

This balance is now at stake. Coral reefs are declining worldwide and their calcification rates are being reduced due to factors such as eutrophication, coastal run-off and the effects of global warming and acidification. Worryingly, many bioeroders are less sensitive to these stressors than corals and are therefore colonizing newly available space on reefs. Bioeroders might even benefit from local and global anthropogenic disturbances. Consequently the balance is tipping in favour of bioerosion leading to a flattening of reefs and the loss of fisheries, biodiversity, and aesthetic beauty of coral reefs.

MANAGEMENT IMPLICATIONS

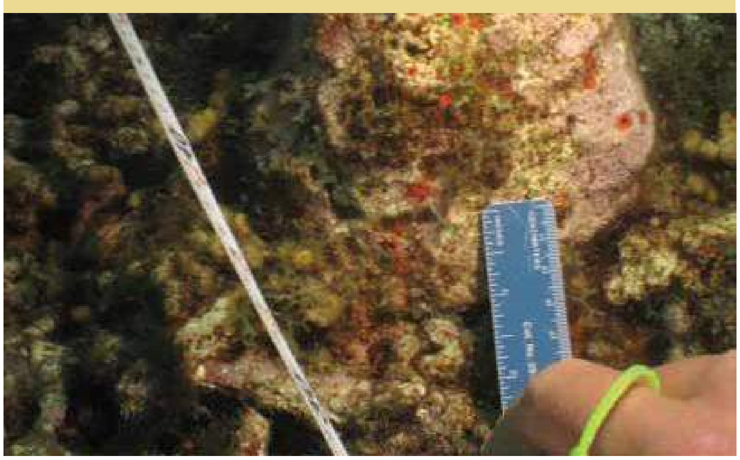
Reducing waste water and land based run-off will help to reduce the supply of nutrients to the filter-feeding bioeroders. This will not immediately result in a change from net loss to net growth of reef structure but will help improve reef resilience.

To assess whether the reef is growing or losing structure, monitoring of bioerosion should be conducted. Several methods can be used to monitor bioerosion:

- Belt or line transects in which the cover and abundance of different functional groups of bioeroders is determined. The cover of bioeroding organisms (e.g. coral excavating sponges, sea urchins) is compared with that of benthic calcifying organisms (e.g. corals) giving an indication of the balance between calcifying and bioeroding organisms on the reef . The full methodology, including Excel data entry spreadsheets is available free online: www.geography.exeter.ac.uk/reefbudget/

- To assess relative differences in bioeroding organisms between sites, coral rubble and/or live coral colonies are collected and inspected for abundance, cover and composition of the bioeroding community and the abundance and size of the bore holes relative to the surface of the coral rubble piece.

The first method suggested can be integrated into existing reef monitoring protocols which measure benthic cover, e.g. AGRRA.



Measuring coral excavating sponge cover on a transect.

FREQUENTLY ASKED QUESTIONS

...roders on

...d in two ... h

... rs ... e ... k ... v

...rs?

... ar.

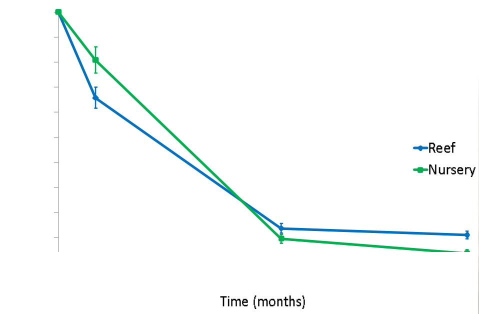
... region.

... ng ... rs ... ct

... es ... es ... te ... ely

... future.

The use of sexual coral reproduction in reef restoration



(blue line) compared to settlers kept in land-based aquaria (green line)

THE ISSUE

Besides reducing local stresses on coral reefs from overfishing, sewage, coastal run off and eutrophication, active reef restoration has recently become a popular management tool. In order to succeed in any effort, it is essential to realize that restoration is not an ultimate cure to stop reef degradation; however, when used in the right circumstances, it may support the natural reef recovery process. Restoration is only useful if the stressors causing degradation are significantly reduced or ideally eliminated before any restoration attempt is undertaken. In many cases, stress elimination alone will lead to successful recovery. However, if recovery is not expected to occur without active measures, restoration could be considered as a management option.

Elkhorn coral (Acropora palmata).

THE EVIDENCE

en

ed

ss

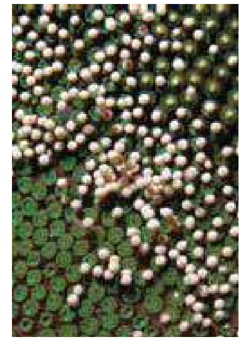
ıt.

n,

r

:

-



Orbicella coral spawning.

HOW IS IT DONE?

s

restoration site.

s.

e

ao,

lers

er

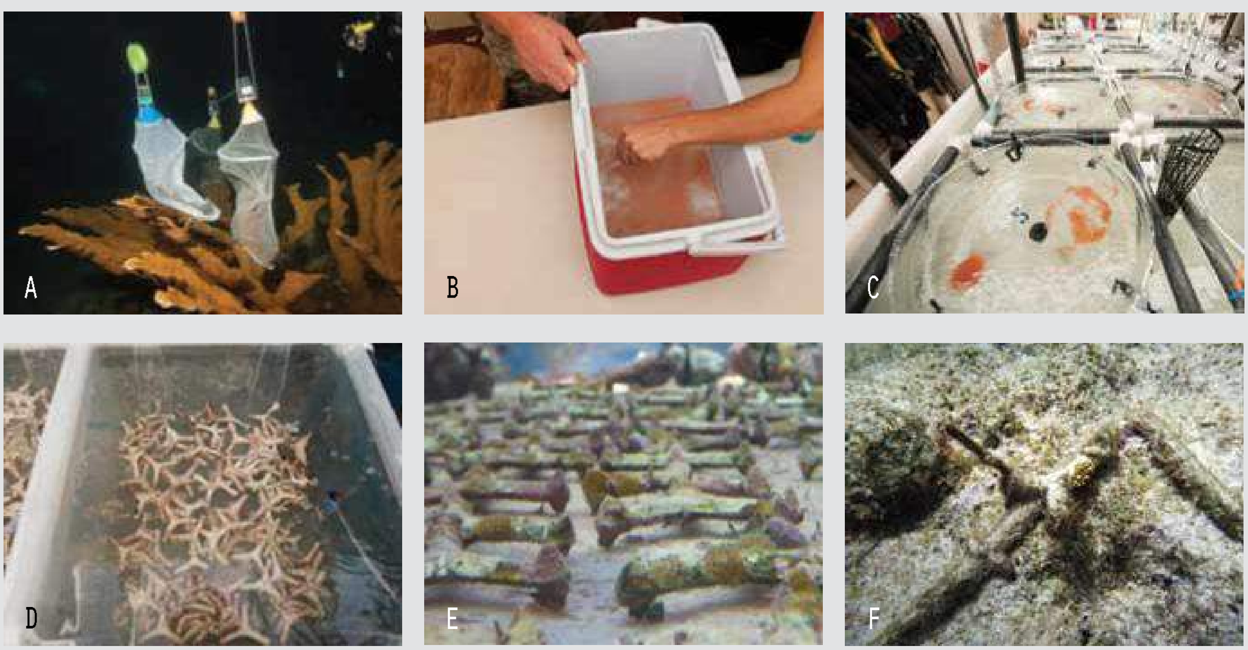
ıs

on

lly,

ctor

n



FROM GAMETES TO RECRUITS

(A) Plankton nets are put above a spawning elkhorn coral to collect egg-sperm bundles in the plastic cups at top. A plastic-foam float keeps the nets in position. (B) Here, a regular cooler is used for batch fertilization. (C) The developing larvae are cultured for several days in flow-through devices to maintain high water quality. (D) Once settlement competent, larvae are transferred to bins with fresh seawater and pre-conditioned settlement tiles. The ceramic tiles have a diameter of approx. 7 cm (E) 6-month old elkhorn coral cultured in a land-based aquarium. (F) When outplanted on the reef directly after larvae settlement, settlement tiles may be fixed to rods which are fixed to the reef substrate using u-shaped stainless steel nails; Elkhorn coral, age: 12 months.

TIME SERIES OF AN ELKHORN CORAL RECRUIT OUTPLANTED AT AN AGE OF ONE YEAR

1 week | 2 months (scale bar = 1 cm) | 6 months | 12 months after outplanting

g
; to
of

REQUIREMENTS

The use of sexual coral reproduction in restoration requires more knowledge and experience than other practices (i.e. fragmentation). Here are some logistical recommendations:

- **Spawning times**
  The precise spawning times of the target species have to be identified. They may vary between different geographical regions. Plan to dive more nights than just the predicted one since spawning dates may shift between years and on a local scale (between neighboring reefs)
- **Gamete collection**
  - Target populations need to be easily and safely accessible by boat or from shore (night diving!).
  - Although fertilization work can be carried out directly on the boat or at the beach, the culture facilities must be reached within two hours of fertilization being initiated to allow safe transfer of eggs to static culture bins.
  - Collect from as many colonies as possible to enhance genetic diversity. Avoid sampling of neighbors. As a result of asexual fragmentation they might be identical genotypes.
  - Work on a local scale. Do not use genetic material (gametes, larvae, settlers) from other regions (i.e. islands) to avoid the introduction of non-native genotypes.
- **Larvae culture**
  Use low rather than high egg/embryo concentrations to avoid total collapse of the culture. It is best to use more culture bins to spread the eggs.
- **Model species**
  Get a feeling for larvae behaviour, settlement and recruitment using brooding species which are much easier to work with compared to broadcast spawners. Ideal model species are the golfball coral *(Favia fragum)* and the low-relief lettuce coral *(Agaricia humilis)* which release larvae all year long and adult corals of these species can be easily kept in aquaria.
- **Outreach**
  Coral spawning is a fascinating natural event. Make it a public event and invite locals to visit you at the culture facilities (not while working on the reef!). This helps raise awareness of reef conservation.

FURTHER INFORMATION

SECORE Foundation
[illegible]
home.html

Nancy Cabañillas-Terán

El Colegio de la Frontera Sur

OUR RESEARCH

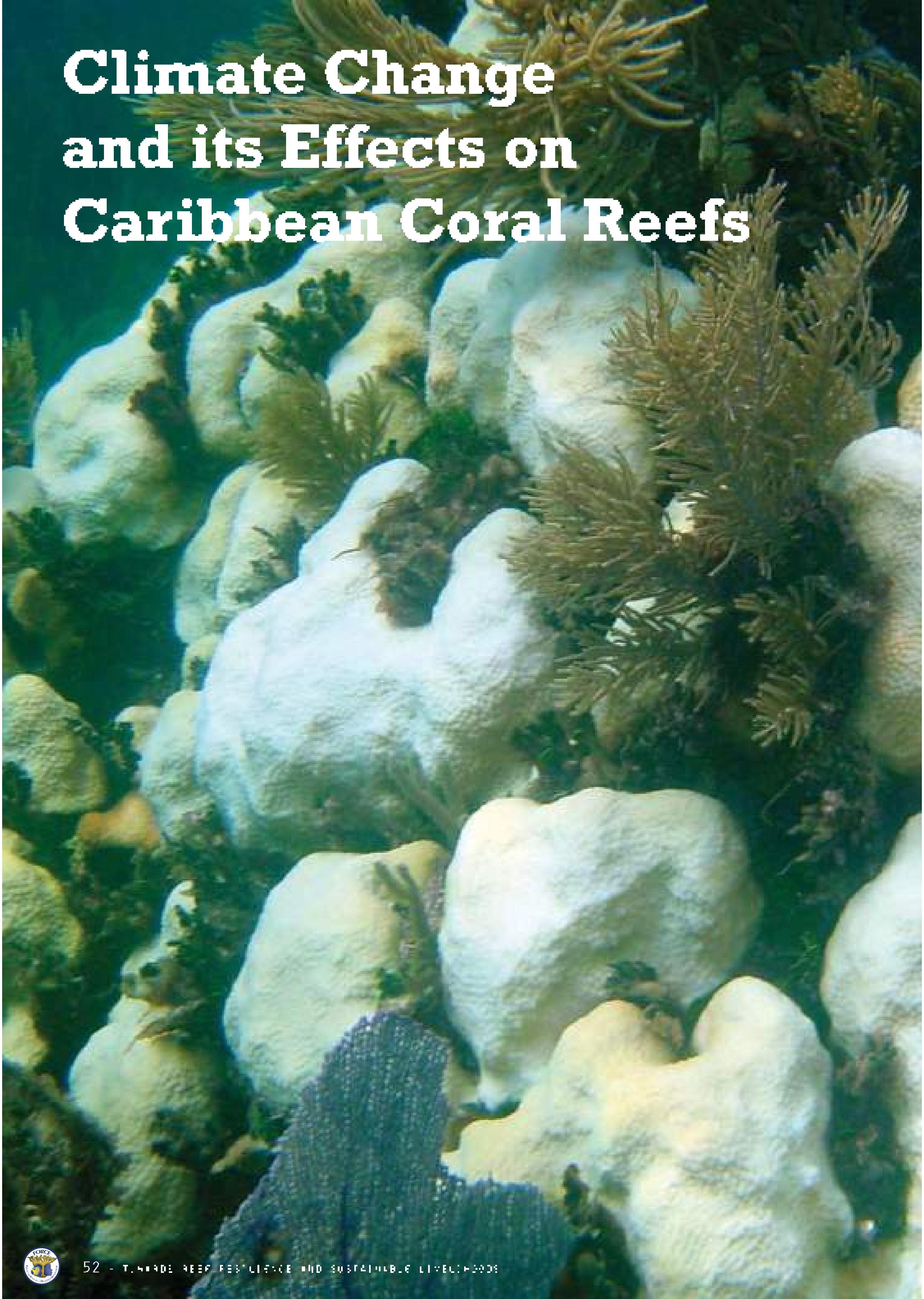
We are investigating how the rates of calcification have changed throughout the last decades. Using x-ray technology we look at the growth rings of reef-building corals to calculate the rates of expansion, density. We evaluate how the rate of calcification has changed in these reef builders and how these rates vary along the Caribbean, studying the aragonite saturation gradient.

... and we would swim up to the reef where there were a variety of breathtaking coral especially acroporas

d

ch

Climate Change and its Effects on Caribbean Coral Reefs



The effects of climate change are being felt across the world, with warming of the atmosphere, increases in sea level and reductions in the amounts of snow and ice. The oceans are changing too; not only are their temperatures rising, but ocean chemistry is changing due to increased amounts of carbon dioxide dissolving into the water resulting in ocean acidification. Both of these changes have important consequences for coral reefs. Higher ocean temperatures are linked to increased frequency of coral bleaching and increased prevalence of coral diseases. Ocean acidification will combine with elevated temperature to reduce the ability of corals to produce their calcium carbonate skeletons, which may lead to reefs that erode faster than they can accrete. Additionally, continued increases in the intensity of hurricanes in the Caribbean, linked to ocean warming, could hinder recovery of corals. Although the causes of climate change need to be tackled at a global level, this does not mean that local reef management is futile. Mitigating local stressors to reefs, such as overfishing of herbivores and sediment and nutrient run-off onto reefs, can greatly improve coral reef resilience in the face of climate change. A new method for factoring coral bleaching vulnerability into the design of MPA networks offers managers a further tool for planning for a changing climate.

Freighter enters Willemstad, Curacao.

"Warming of the climate system is unequivocal". "The atmosphere and oceans have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased." (IPCC 2013)

n

g

al.
ns
r
gh-

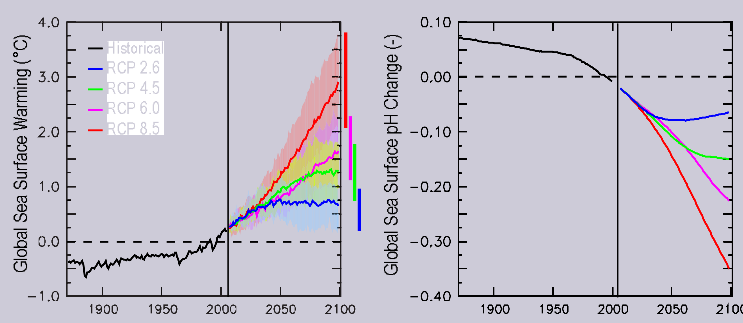
Monitoring climate change in the Caribbean

o
hange
of
ugh
www.
coralreefwatch.noaa.gov/satellite/index.php

e Change
des
h
ol
r

Modelled time series of global sea surface warming and pH change

Future projections use the four scenarios defined by the IPCC. RCP 2.6 represents an aggressive policy of greenhouse gas emissions reduction and RCP 8.5 represents a 'business-as-usual' scenario. RCP 4.5 and 6.0 represent scenarios in between these two extremes. Vertical line at 2005 shows the end of the historical simulation and start of climate change scenario models. Shading indicates one inter-modal standard deviation.



ce.

Coral bleaching

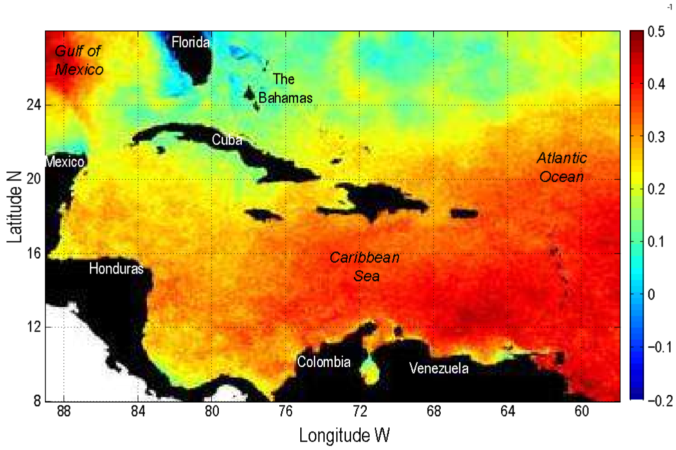
Non-bleached porites.

Ocean acidification

(Fine & Tchernov 2007).

Climate change effect	Global observations (IPCC 2013)	Effect on corals	References
Ocean acidification	pH of the sea surface has decreased by 0.1 pH units since 1750	Less calcification – weaker skeletal structure and less reef-building	(Doney et al. 2009)
		Increase in bioerosion and dissolution of the reef framework	(Andersson & Gledhill 2013)

CC terminology)



Increasing sea-surface temperature

ne

ne

e

do et

ed

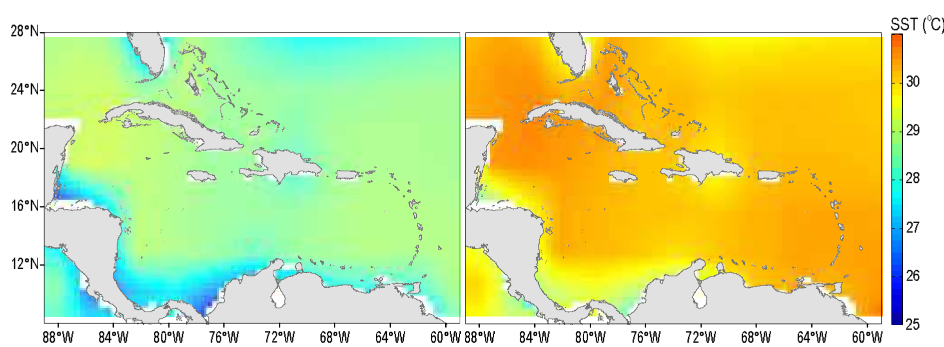
is

cal

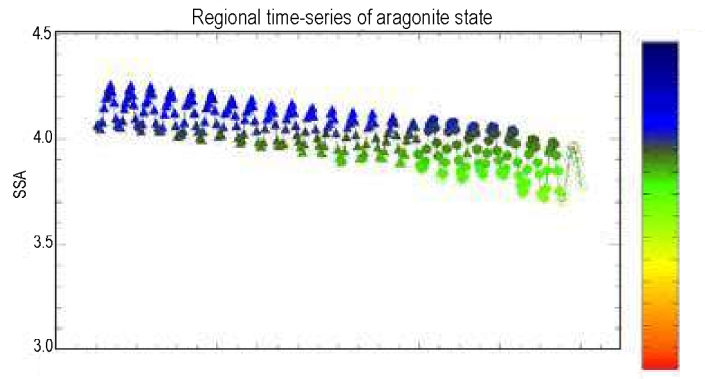
ng

rd reduce pollution ([illegible]).

White plague disease.



Ocean acidification



e
ir
H
d
od

in

een
n
t

Hurricanes and tropical storms

es

re

a

MANAGING FOR CLIMATE CHANGE

Although reef managers can do little to directly reduce the greenhouse gas emissions that are causing climate change, there are some management actions that can help improve the future for coral reefs:

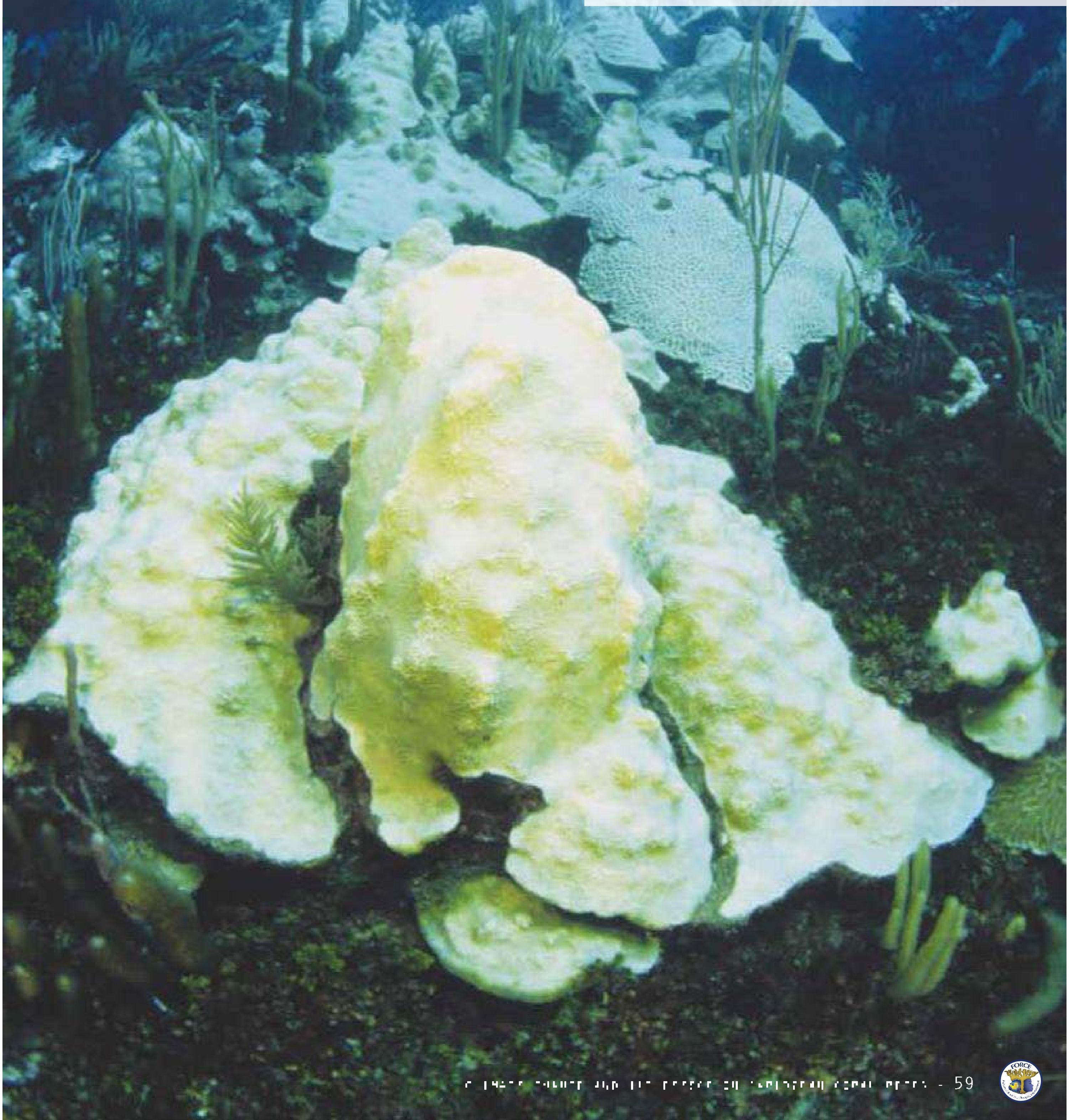
- **Marine reserves designed for climate change.** Reef sites have different exposure to bleaching risk. Using satellite data on the temperatures reef areas are used to and how intensively they are impacted during extreme heating events, reef sites that are less likely to bleach or where corals are better prepared to cope with bleaching can be identified. This information can be used to aid in the design of marine reserve networks to maximize the probability of persistence of the entire network under a changing climate (Mumby, Elliott, et al.2011).
- **Reduce local stressors on reefs.** Management actions such as decreasing land-based sources of nutrients and reducing herbivore overfishing can help improve reef health and increase reef resilience (Edwards et al. 2011; Kennedy et al. 2013). This will improve the ability of reefs to recover after bleaching events and hurricanes.

Roberto Iglesias-Prieto

Universidad Autónoma de México

OUR RESEARCH is trying to understand the effect that temperature has on the aragonite saturation state and the rates at which corals calcify. The goal is the construction of a global model that will predict how the ability of corals to form reefs will change in the future.

People in the Caribbean are dependent on the services that the reefs provide



BRIEFS

CLIMATE CHANGE

1
Managing for climate change: incorporating bleaching vulnerability into MPA planning

2
Buying time for coral reefs by reducing local threats

Managing for climate change: incorporating bleaching vulnerability into MPA planning

THE APPROACH

impacts will likely fare worst by climate change.

Coral bleaching in La Bocana, Puerto Morelos, Mexico

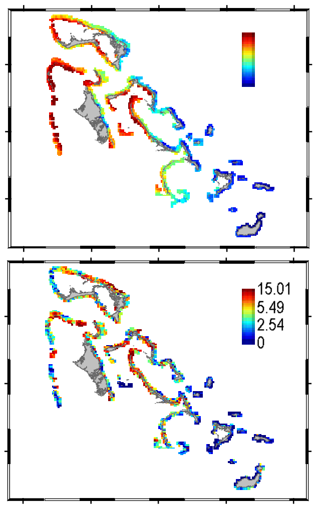
Aerial view of cays in Los Roques, Venezuela.

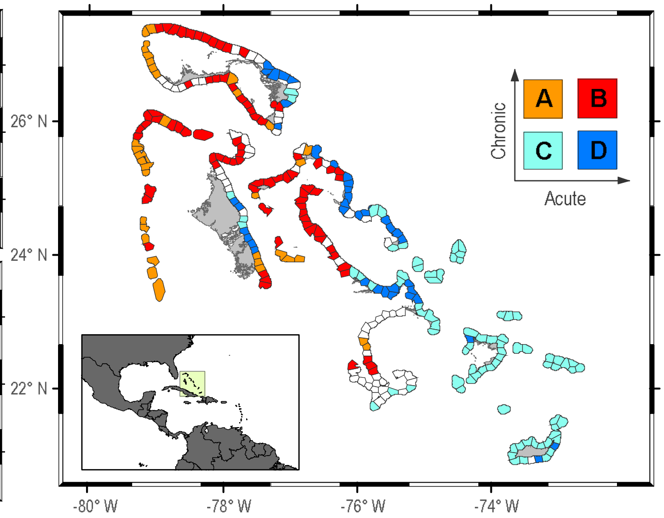
THE ISSUE

Coral bleaching, a stress condition in corals, happens when the algae that live in the coral's tissue, providing food and its normal healthy colour, are expelled. When bleached, corals starve, weaken and become more vulnerable to diseases and death. In some parts of the Caribbean, 80% of corals bleached and 40% died after the 2005 mass bleaching event. Since mass coral bleaching occurs when water temperatures increase, bleaching events will become more common and intense as the world's oceans become warmer.

In the long term it is clear that decreasing greenhouse gas emissions is the appropriate course of action to reduce the impacts of warming temperatures in corals. But what can we do at local levels?

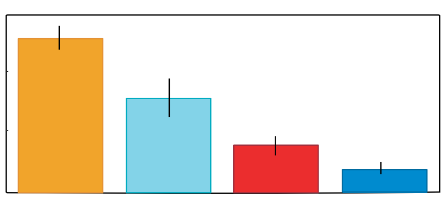
When looking across reefs within a single country, there is large variability in where bleaching occurs. Reefs differ in their preparedness (acclimation) to bleaching and how intensively they are impacted by warming events. This variability can be harnessed by local managers by protecting reefs that are more prepared and have been less impacted by sea warming.





s
erature
ture

THE EVIDENCE



HOW IS IT DONE?

ted locations
http://msel.

s

www.nodc.noaa.gov/

98

l

,

d

ng

be
ot
e,

MANAGEMENT IMPLICATIONS

To maximize chances of success, we recommend managers focus protection on areas that are predicted to cope better with climate change (regimes A and C). If feasible, also including areas that offer the greatest potential for acclimation (regime B) could serve to hedge your bets. This information can be factored in with other relevant layers (e.g. habitat maps, maps of current uses) to prioritize conservation actions.

FURTHER INFORMATION

Bilko lesson on how to calculate thermal stress from satellite data:

Prieto

Buying time for coral reefs by reducing local threats

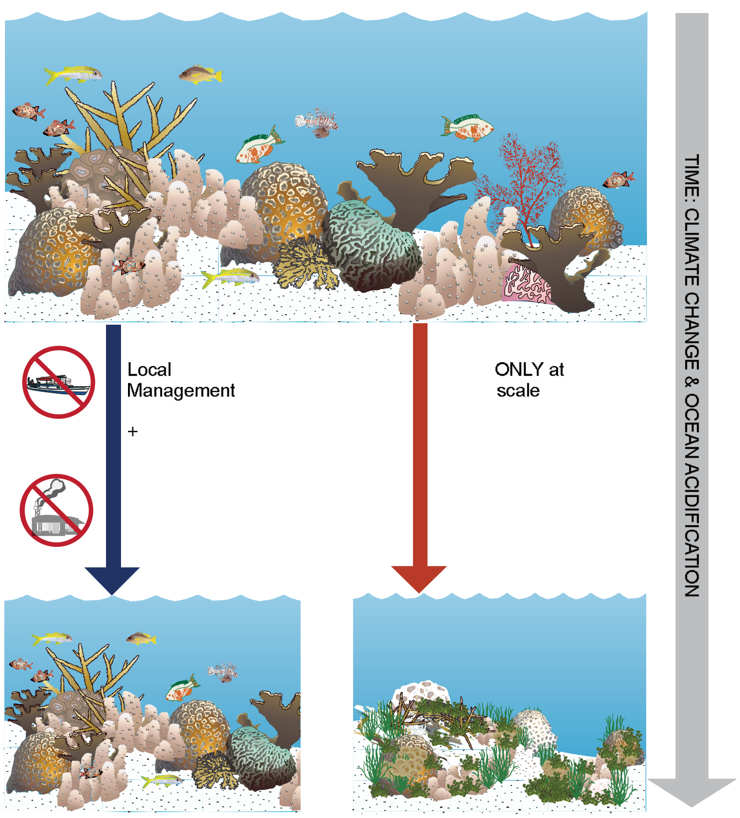
THE ISSUE

Local efforts on mangrove conservation.

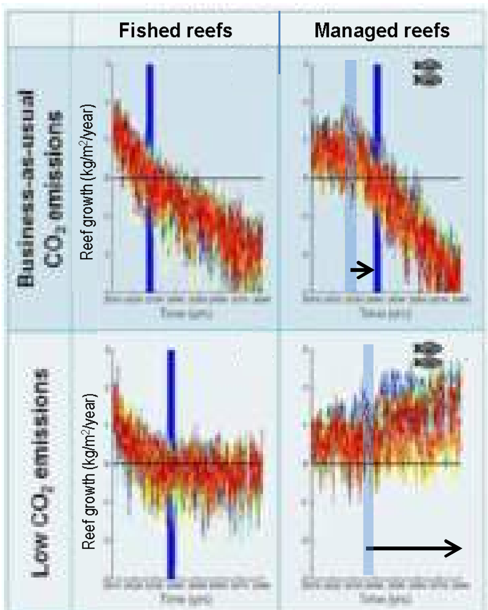
Coral reefs provide ecosystem services, such as coastal protection, fisheries and tourism that are vital to the livelihoods of millions of people. These services are dependent upon healthy living corals and the structure they create. Corals generate skeletons of calcium carbonate (limestone) as they grow which provide a natural breakwater and the complex three dimensional habitat that is essential to support the high biodiversity of coral reefs. Other processes (e.g., cementation by coralline algae) also add to the growth of reef structure, while bioerosion helps further create complexity and is essential in determining the balance between reef growth and disintegration.

Climate change is expected to reduce the ability of corals to form reef structure. Rising ocean temperatures are projected to disrupt growth rates for many corals and increase the frequency of coral bleaching. Ocean acidification will also slow coral growth and weaken reefs, at the same time as increasing the rate of bioerosion. In the face of such impacts, local efforts to improve reef health might seem hopeless. However, recent research has shown that local management of reefs is vital to maintain the continued net production of reef structure, and therefore the provision of the important ecosystem services that reefs provide.

THE EVIDENCE



Caribbean reef growth



MANAGEMENT IMPLICATIONS

Effective local management is essential

Protection of herbivores is vital for reefs to withstand predicted impacts of climate change. Although global action to reduce greenhouse gas emissions is essential to ease the effects of climate change on reefs, such efforts are not sufficient on their own to ensure reefs continue to exhibit net production of three dimensional structure.

Unprotected reefs will degrade quickly due to reduced coral growth and cover, and increased bioerosion. Although improved local management measures alone may not be sufficient to ensure continued growth of reef structure, such measures are vital for buying time for reefs while global action on climate change is negotiated. Local management efforts that protect herbivores and reduce nutrient run-off onto reefs will maximise the chances that healthy reefs and the services they provide are maintained in the future.

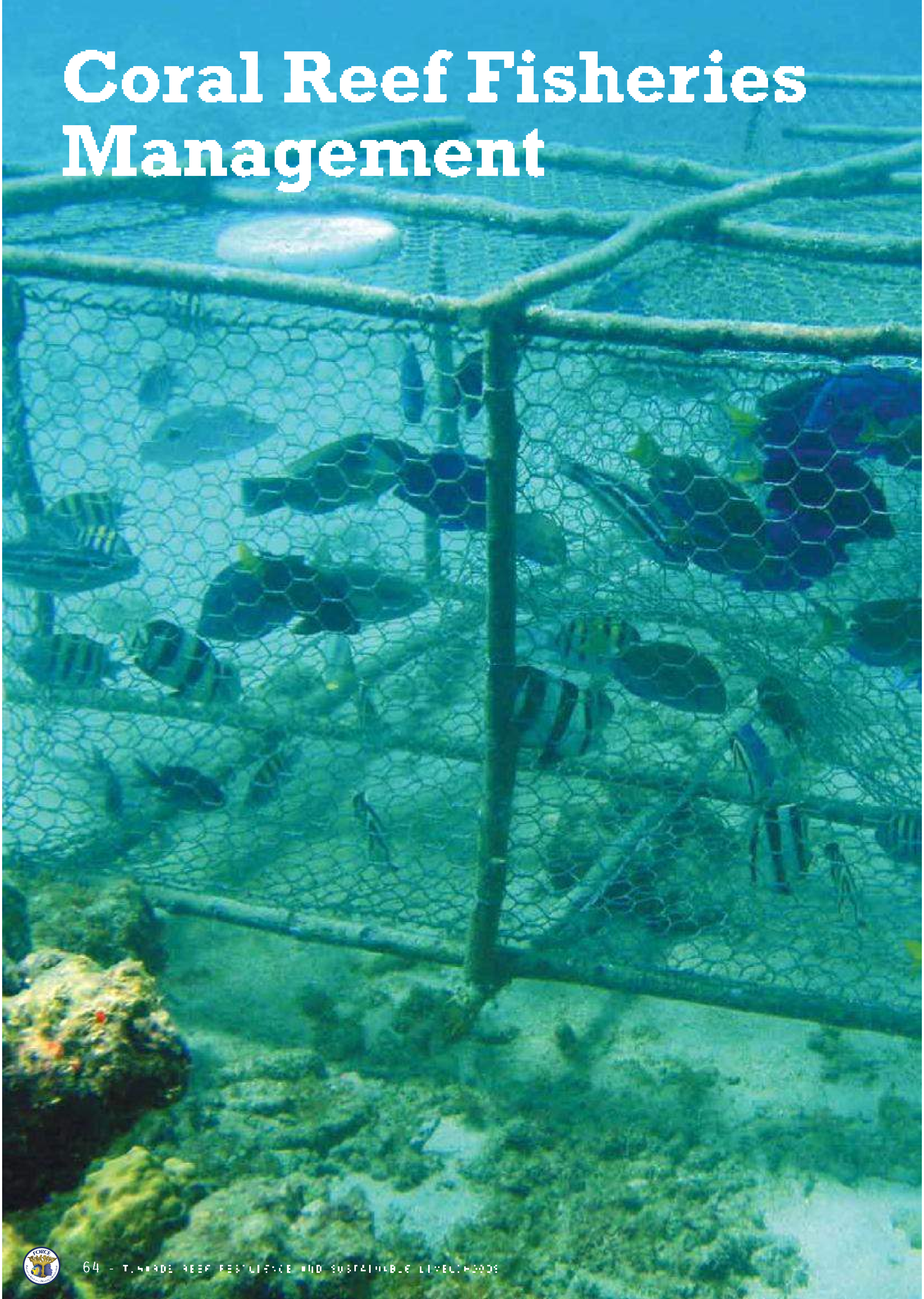
FURTHER INFORMATION

[illegible], Brief 6 p.44, [illegible]

Kennedy EV et al. 2013. Avoiding Coral Reef Functional Collapse Requires Local and Global Action. Current Biology 23 (10): 912 – 918.

Dredging and landfill activities can increase sediment loads and nutrient levels on reefs.

Coral Reef Fisheries Management



Caribbean reef fisheries are a vital source of income and food for thousands of people in the region, with annual net benefits estimated at US $395 million. Reef fisheries also provide an important social safety-net for people when other sources of employment are unavailable. Populations of reef fishes and other important fishery species such as queen conch (Strombus gigas) and spiny lobster (Panulirus argus) have been severely reduced across the region due to a combination of overfishing and habitat degradation. Management of coral reef fisheries has to take into account the diverse nature of the fishery including factors such as multiple species harvested with multiple different gears, geographically dispersed fishing and landing sites and the variable nature of the fishers' dependency on the fishery. Resources available for the monitoring and control of coral reef fisheries are often limited, but good management is vital for ensuring the long-term viability of the fisheries. Ecosystem-based fisheries management (EBFM) is suggested as a better alternative to conventional fisheries management practices and is particularly appropriate for coral reef fisheries. The focus is on maintaining the health of the coral reef to ensure sustainable fishery yields and other critical ecosystem services of reefs. EBFM is being promoted throughout the region and new tools are being developed to help managers introduce EBFM measures. Existing fisheries management tools, such as no-take areas and catch quotas, will continue to be used alongside new and improved tools, such as habitat protection zones and vessel monitoring systems (VMS), which will expand the range of fisheries management measures available. Only by understanding and managing the effects of fishing as well as other impacts on the ecosystem can managers ensure sustainable use of coral reef fisheries.

Parrotfish catch.

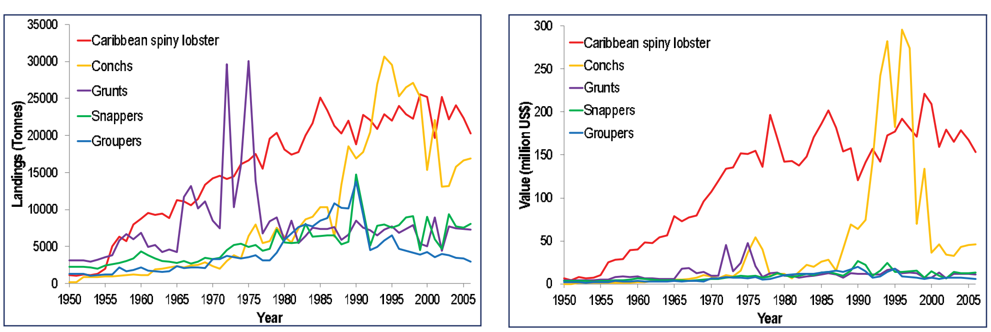
"Generally, a fishery is an activity leading to harvesting of fish. It may involve capture of wild fish or raising of fish through aquaculture."

Reef fish catch being sorted at a dock in Honduras.

only

(Jackson 1997; [illegible]).

Queen conch.



Catch value of main Caribbean reef fishery species.

ill

of
sharks
around

d

e

in

ainability

tat

in

Spawning aggregation protection in Belize

*Fish spawning aggregations are temporary, high-density groupings of single species of fish that come together at a fixed location, often converging from distant places, for the specific purpose of reproducing. Spawning aggregations are particularly vulnerable to overfishing as they occur at predictable locations and times, meaning that fishers can target the aggregations and rapidly reduce the population size of a species normally distributed across a wide area. Throughout the Caribbean, Nassau grouper (*Epinephelus striatus*) spawning aggregations have been decimated by fishing and the species is now listed as endangered by the IUCN* (Sadovy De Mitcheson et al. 2008). *In Belize, about one-third of grouper spawning aggregations had disappeared by early 2000* (Sala et al. 2001). *In response to this a National Spawning Aggregations Working Group was formed to monitor and validate the status of spawning aggregations. Support for protection of aggregation sites was gained by involving a wide range of stakeholders in the work, including local fishers, NGOs and government departments. Fishers were involved in research activities, being paid for their work, and training in alternative livelihoods such as SCUBA dive guiding, kayaking and fly fishing was provided. Following confirmation of broad support from fishers, the Minister of Fisheries signed legislation in November 2002 that created a closed season for Nassau grouper from December to March, and fully protected 11 spawning aggregation sites in new marine reserves. Belize now has four of the last few known Nassau grouper spawning aggregations of over 100 individuals* (Sadovy De Mitcheson et al. 2008) *and their successful protection should help ensure their long-term persistence.*

For more information on Belize spawning aggregation protection:
http://www.reefresilience.org/case-studies/belize-mpa-design/

it

[illegible]).

r

es

Fisheries, Brief 1 p.78).

nd

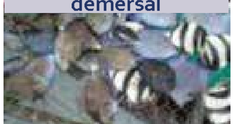
nery
bus

ate

al

value in local markets.

Reef fisher emptying his multispecies catch from a fish trap.

Category	Qualifications
Reef (shallow-shelf) demersal 	nidae), ail s, nets
Deep slope demersal 	;
Nearshore pelagics 	*us*
Conch 	g.
Lobster 	deep slope environments.
Other shellfish/ molluscs 	chins). ving or

REEF FISHING GEAR

ent
e

g
as
nt

bends').

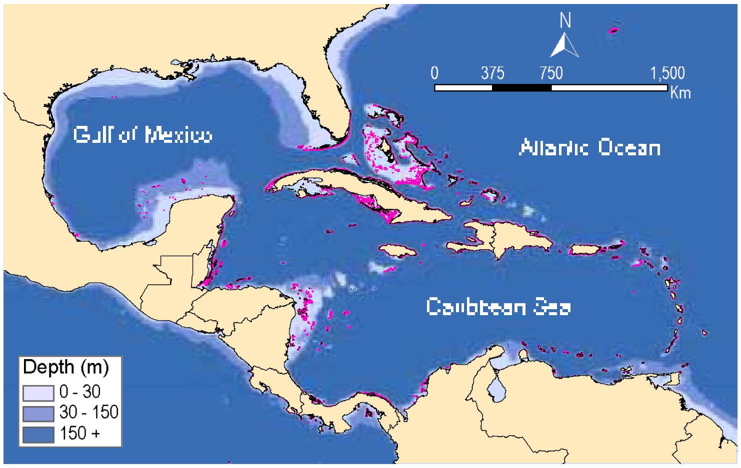
d

om

lly

ed
ry

Fishing activity	Description of fishing activity/gear/ target species
Diving (free)	
Diving (compressed air)	Compressed air diving includes SCUBA-diving with tanks as well as the use of compressed air supplied from the surface through a tube (Hookah diving). As with free diving, harvesting may take place by hand (for species such as conch, whelks and urchins) or with the use of a handheld prying device, spear or sling, or a speargun (for species such as reef fish, lobster, crabs and octopus).
Line fishing	
Trolling	Trolling refers to fishing with a baited hook and line towed behind a moving boat so that the line remains close to the surface and targets epipelagic reef-associated species.
Netting	
Trapping	Trapping refers to the method of fishing with some form of cage structure. These may be made of wire mesh (or cane) with a wooden or metal frame and a specially shaped entrance funnel, and are commonly referred to as 'fish pots'. They are used baited or unbaited to target reef fishes and lobsters. Lobster-specific traps, made of slatted wood with a specialised entrance funnel are also used, as are open, lobster-attracting artificial habitats, commonly known as casitas. These may comprise a variety of materials such as wooden pallets, a collection of short pipe lengths, shelves of galvanised sheeting, or piles of cement blocks, placed on the bottom near reef habitat to aggregate lobsters for easy harvesting by hand or net.



Challenges of managing reef fisheries

Reef fishers

A further challenge to managing reef fisheries in the Caribbean is the diverse nature of reef fishers themselves and their varying dependence on the reef resources for livelihood support. Reef fishers often remain unregistered and may have multiple, dynamic sources of income besides reef fishing, including income from alternative fisheries as well as from agricultural, construction or tourism sectors. Research from nine study sites in Belize, Honduras and St Kitts and Nevis found that reef fishers' dependency on income from reef fishing ranged from 31 – 69% and the number of other occupations held by the average fisher ranged from 1.5 – 2.6 occupations per fisher (Gill 2014). As such, reef fishers may be able to maximize their income and minimize livelihood risk by switching between full and part-time reef fishing, depending upon personal circumstances, changes in the seasonal availability of other fishery species, and the availability of work in other sectors.

The movement of fishers in and out of the reef fishery and seasonal changes in availability of fish can complicate any efforts to manage fisheries. An understanding of how fishing forms a part of many people's livelihoods is therefore necessary for any effective management measure ([illegible]).

Some fishers are becoming involved in the lionfish fishery.

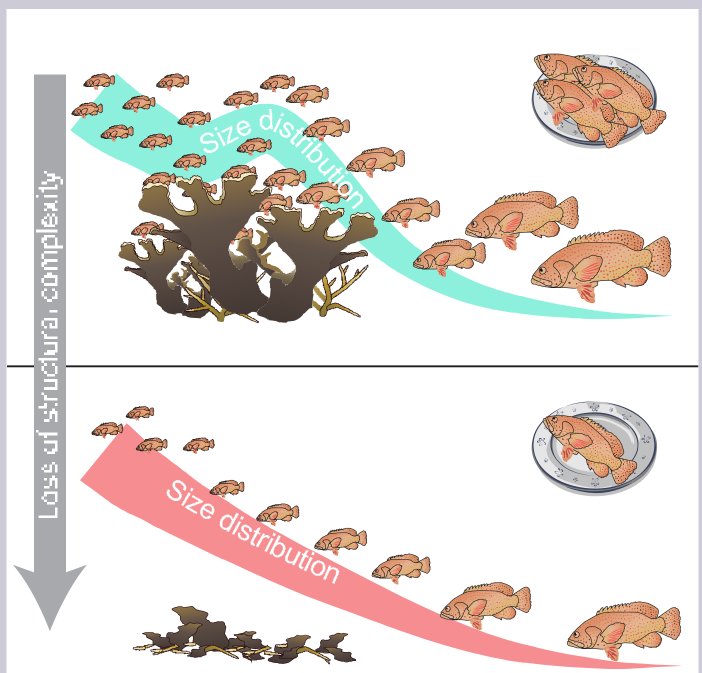
fish stocks.

Linking coral reef complexity and fisheries productivity

Corals create an amazingly complex habitat made up of lots of holes, cracks and crevices that serve as hiding places and homes for a huge abundance and diversity of organisms. This structural complexity is vital for the productivity of reef fisheries. Using data from coral reefs in the Exuma Cays Land and Sea park in the Bahamas, researchers created a food web model to understand the effects of reduced structural complexity on fisheries productivity. Initial results from the model suggest that a complete loss of structural complexity may reduce fisheries productivity 3-fold, i.e. three-times less potential catch.

Reefs with high structural complexity provide lots of predation refugia for vulnerable organisms, including juvenile and small-bodied fish. When this complexity is lost however, the dynamics of the reef community change. Increased mortality results in fewer small and medium-bodied fish, and in turn results in fewer fish overall. There is an associated decline in the rate that energy is transferred up the food web meaning less food is available for large-bodied fish that are valuable to reef fisheries.

Maintaining a structurally complex reef is therefore important for the thousands of people who rely on reef fisheries for food and livelihoods.



Structurally complex reefs have more fish and higher fishery productivity than low complexity reefs.

FURTHER INFORMATION

Rogers A, Blanchard JL, Mumby PJ. 2014. Vulnerability of coral reef fisheries to a loss of structural complexity. Current Biology 24 (9) pp. 1000 - 1005

e

rge

ne

(see [illegible]).

"The key management goal is not to maximize fisheries catch, but to maintain the ecosystem in a state that will lead to sustained production." [illegible]

t

ls

y

e

down control.

are listed below.

Rigorously protect structural habitat

ial

[illegible] ([illegible]).

Protect water quality

[illegible] and [illegible])

Maintain ecosystem integrity and function

n

function ( ).

Select reference points and indicators for monitoring

Employ a precautionary approach at all times

Parrotfisl

Recognize limits to production and control rates of extraction

h ıg

d

fic ch

can be easily targeted by fishers (Protection of [illegible]).

e1
t
susta

[illegible]).

e)

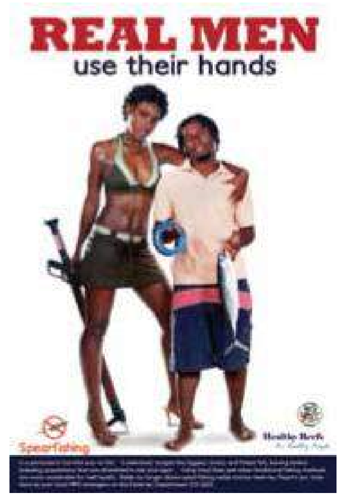
he

lly

w

individual growth rates but large maximum sizes (e.g. large snappers and groupers). These measures, combined with marine reserves, which would allow individuals to reach their maximum size, could help increase populations of important fishery species ([illegible]).

Management action	Purpose
Marine reserve networks	
ggregations	le spawners
ts	es cies ing age
a er	eef
	of ations
m	
asis	
nto	
ef	m health,
	t of the d bility



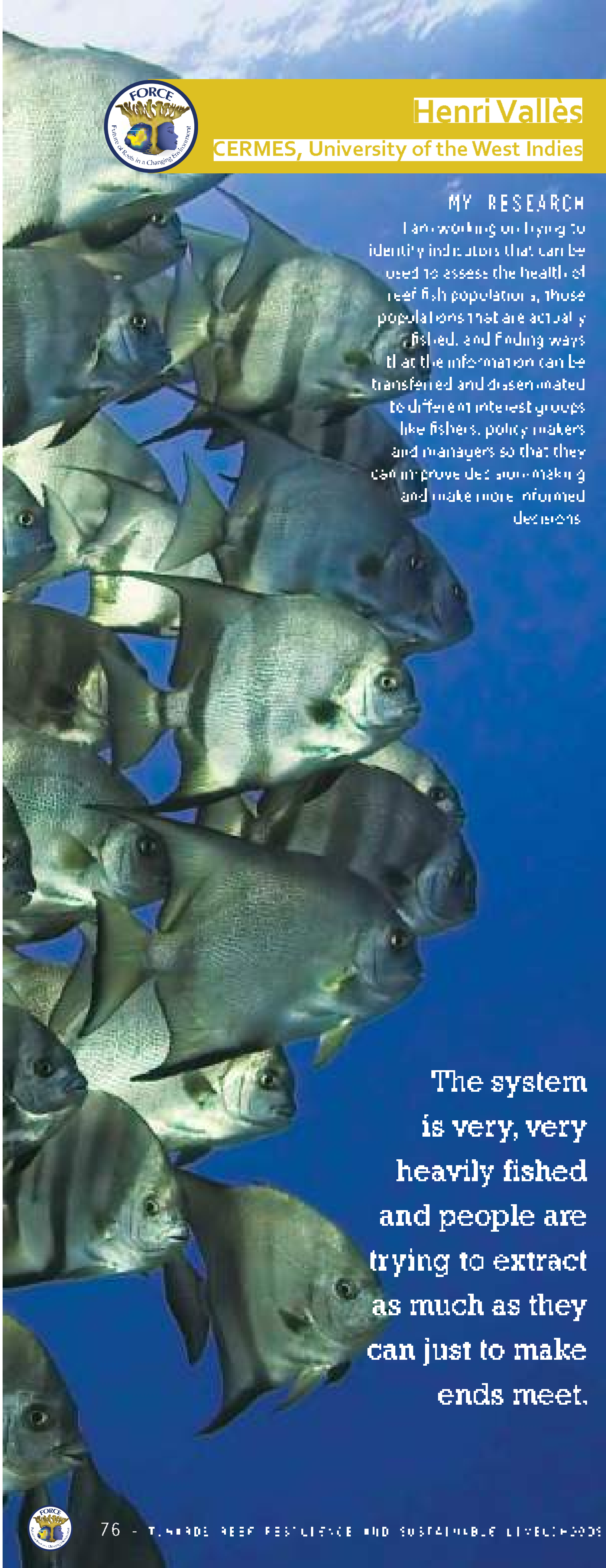
g are common

Nevis.

FURTHER INFORMATION

tools for EBFM:

g to gain a



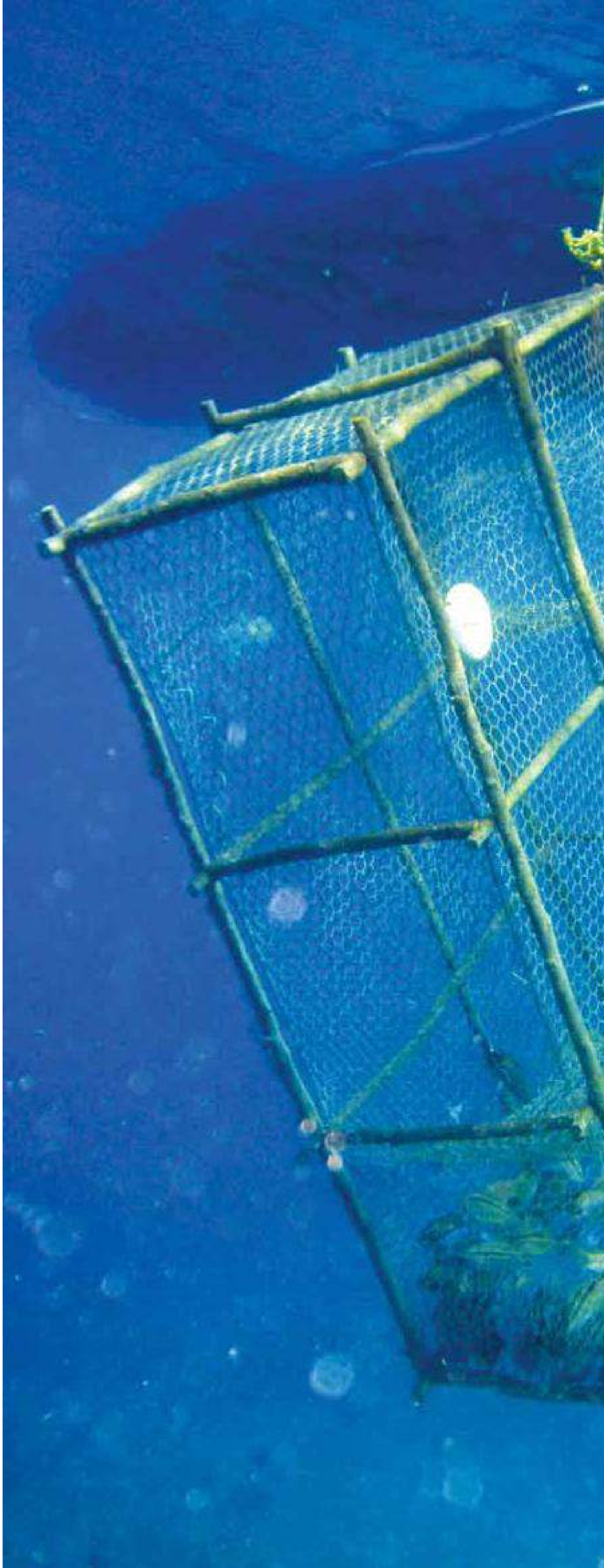
Henri Vallès

CERMES, University of the West Indies

MY RESEARCH

I am working on trying to identify indicators that can be used to assess the health of reef fish populations, those populations that are actually fished, and finding ways that the information can be transferred and disseminated to different interest groups like fishers, policy makers and managers so that they can improve decision-making and make more informed decisions.

The system is very, very heavily fished and people are trying to extract as much as they can just to make ends meet.



FISHERIES

Fishing down the food web: ecosystem effects of fishing

THE ISSUE

Fishing is an important source of employment, food and income for many people within the Caribbean, including some of the poorest. The health of reef fish stocks is important not just for the fishers but also the tourism industry, as divers and snorkelers like to see large and diverse fish populations on reefs. Furthermore, reef fish are a vital part of the ecosystem, with herbivores, such as parrotfish, grazing on algae and thus allowing new corals to settle and grow on the reef.

In many of the world's fisheries, humans have gone through a process of 'fishing down the food web', depleting first the large carnivorous fish then progressively smaller and generally less desirable species. On coral reefs this has meant sharks, groupers and large snappers have been fished to very low levels in many places, so fishers have started to target smaller and less desirable fishes such as parrotfish. This can have negative effects on the coral reef ecosystem as a whole not just the reef fish populations.

Fish caught in net.

THE EVIDENCE

en

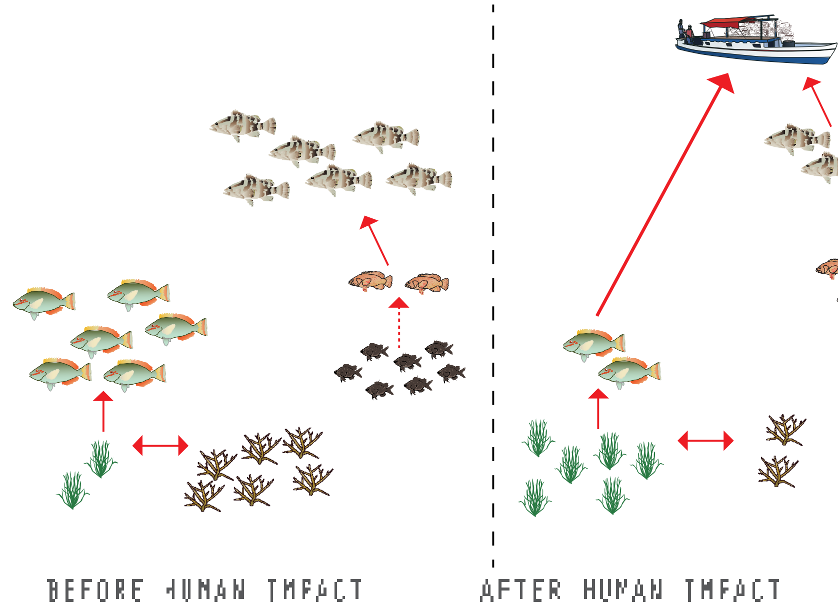
ef

in
e
er
ng

nt

similarly large decreases. Parrotfish were not previously targeted by fishermen, but from 2004 to 2008, they went from being found in just 6% of fishermen's catches to approximately 20%. This change was principally due to the difficulty in catching preferred groupers and snappers.

Smaller reef fishes are susceptible to trap/pot fishing.



ıg

tfish

s)

vel

ed

n.

st

n

on

ne

nge

ae

for space.

MANAGEMENT IMPLICATIONS

Monitoring of reef fishery

This provides information on changes in the composition and abundance of fish caught and can help identify signs of fishing down the food web, such as increasing catches of parrotfish. Where regular monitoring is not feasible due to lack of resources, qualitative information on fish catches can be obtained by talking to fishers and regularly visiting fish markets.

Ban on parrotfish fishing

Belize and Bonaire have both implemented bans on fishing for parrotfish. Given the ecological importance of parrotfish for corals (as a grazer of algae), it is worth considering a ban. Alternatively management could aim to reduce fishing pressure on the large-bodied parrotfish, e.g. stoplight parrotfish, *Sparisoma viride*, and redband parrotfish, *Sparisoma aurofrenatum*, which are the most important grazers of algae.

Indicators of overfishing

Increases in abundances of mesopredators is an indicator of overfishing of larger predators (large groupers and snappers) which normally prey on these species. However it is important to note that fishers might shift to target mesopredators as the process of fishing down the food web continues, hence this effect might not be noticed in a heavily exploited fishery.

Building a sustainable yellowtail snapper fishery on Caribbean coral reefs

THE ISSUE

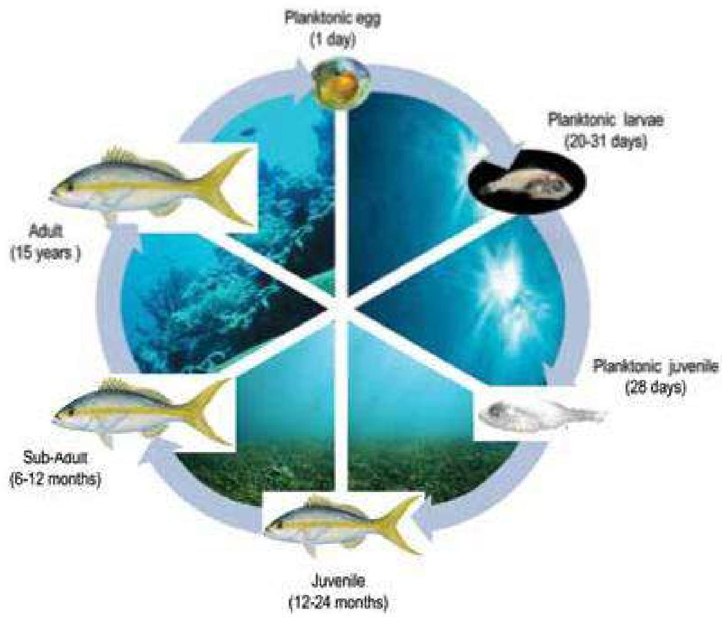
Grouper and snapper are top predators that are important components of Caribbean fisheries and part of the culinary heritage of the region. Unfortunately, the majority of snapper and grouper species are highly vulnerable to overfishing, due to slow growth rates and late maturity, in addition to forming predictable spawning aggregations to reproduce. Targeting these spawning sites has reduced their reproductive capacity and been a principal cause for the collapse of populations of Caribbean species such as the Nassau grouper (Epinephelus striatus) and the Cubera snapper (Lutjanus cyanopterus) throughout the region. As traditional grouper and snapper fisheries decline, fishers increasingly switch to target alternative reef species, often deploying unselective fishing methods such as nets and traps to increase catch volume as a trade off against lower catch quality and poorer market value.

Shifting to mixed species fisheries on coral reefs presents complex challenges as each species may respond differently to management interventions. In addition many smaller coral reef species such as parrotfish play essential ecological functions as parrotfish are essential grazers of algae, preventing reefs being overgrown by algae.

THE EVIDENCE

Unloading reef fish catch in the Bay Islands, Honduras.

but local recruitment is also relatively high. At smaller scales, juveniles from seagrass beds are connected to adult grounds including offshore reefs, across tens of km, meaning local coastal protection is important for local fisheries.



MARKET VALUE

tle
o
cal
and size.

rs
sh
to grow.

MANAGEMENT IMPLICATIONS

Where management has been implemented, yellowtail snapper populations have responded well. For example no-take zones in the Florida Keys found an increase in population biomass of 15% after only 3 years whilst a minimum size and total allowable catch has ensured the fishery has consistently remained sustainable since reviews began in 2000.

Policy Options	Conservative		
	Most	Less	Least
Set minimum size for yellowtail snapper at 25 cm (12"), ¾ lb (350g)	•	•	•
Replace J hooks with circle hooks to reduce hooking mortality in juveniles	•	•	•
Collect yellowtail snapper as a discrete category in fisheries statistics	•	•	•
Prohibit unselective gears like traps and gill nets from coral reef fisheries	•	•	
Closed season during peak reproductive months	•		
Protect identified nursery areas in seagrass	•		

FREQUENTLY ASKED QUESTIONS

ne

ons

es.
ers

d
Nassau groupers.

hat

s.

be
ate
this process.

es
infractions.

ies
n
on

a
lly

n
ay
ng

rs
ss

Identifying fishing grounds across small spatial scales: a low-cost fisheries management tool

THE EVIDENCE

sis

n

ale

HOW IS IT DONE?

ng

nt

l

h

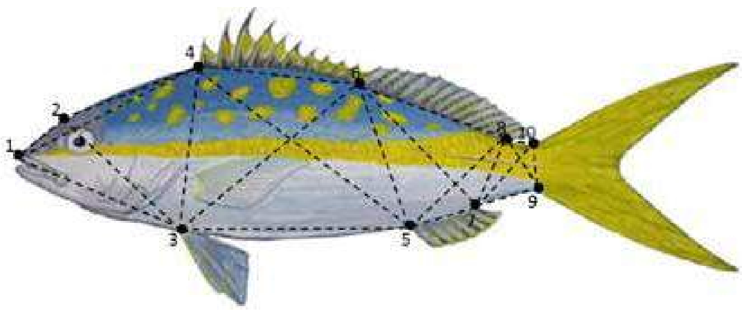
n

THE ISSUE

Fisheries managers frequently have to manage dispersed fishing communities exploiting different fishing grounds spread over extensive geographical ranges. For effective management of fisheries, managers need data on how fishing pressure is distributed. A simple tool to match individual fish to fishing grounds can provide vital data for fisheries management and monitoring.

Several techniques have been developed to differentiate fishing grounds, but many require considerable financial and technical resources, which are often not available in developing countries or small islands. Morphometrics (quantitative measurements of body shape) offers a low-cost, relatively simple tool for fisheries managers. In the Western Caribbean the yellowtail snapper is an important species in both the small-scale and industrial fisheries. For example, in Honduras yellowtail snapper comprise up to 30% of total reef fish landings.

Yellowtail snapper fishing grounds within a small-scale fishery were successfully differentiated using morphometric measurements demonstrating that body measurements can be used by managers to identify the origin of landed catches.



ents

		3-4	3-5
3-6	4-5	5-8	6-7
6-8	7-8	8-10	9-10

FREQUENTLY ASKED QUESTIONS

Is niles?

to assign
y grounds
of 89%.
of different
n comparison
nnot be used
o determine

W le?

ı

c

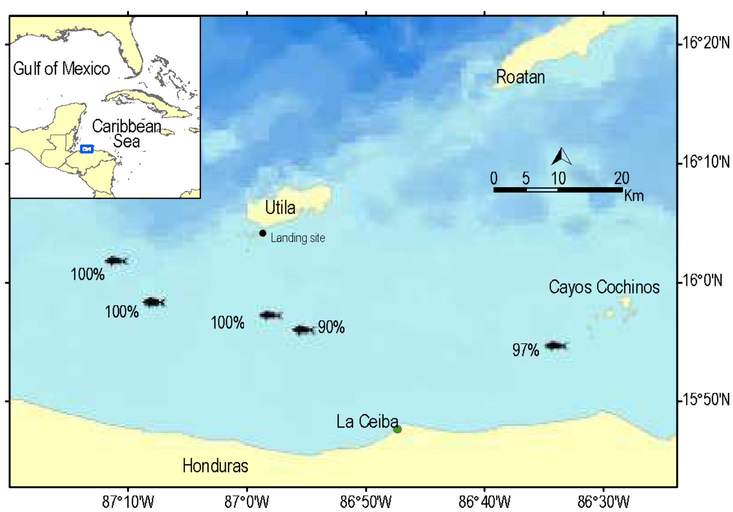
;.

st
n

es
t
in
l

e

e



nometric

MANAGEMENT IMPLICATIONS

This simple tool allows for relatively quick and easy assignment of landed catch to fishing grounds which can be useful in spatial management of fisheries, such as:

- Setting quotas for specific fishing grounds
- Implementing managed access across fishing grounds
- Enforcing no-take zones
- Establishing seasonal closures of fishing grounds.

Average parrotfish weight as a simple but useful indicator of fishing pressure

THE ISSUE

Coral reefs of the Caribbean are being seriously threatened by a combination of local (e.g. land-based run-off, overfishing, storm and hurricane damage) and global stressors (e.g climate change). Evidence is mounting that the capacity of coral reefs to withstand and recover from global stressors hinges upon minimizing the negative effect of local stress

Overfishing is widely recognized as one of the most important local stressors affecting reefs across the Caribbean region. One step towards managing fishing is the identification of indicators of fishing pressure that respond quickly, strongly and predictably to fishing. These indicators need to be easily measurable, simple and intuitive, so that they can be readily implemented and communicated across different stakeholder groups involved in decision making

THE EVIDENCE

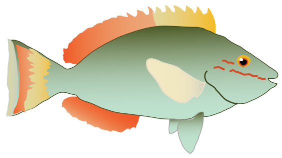
nt

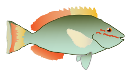
of

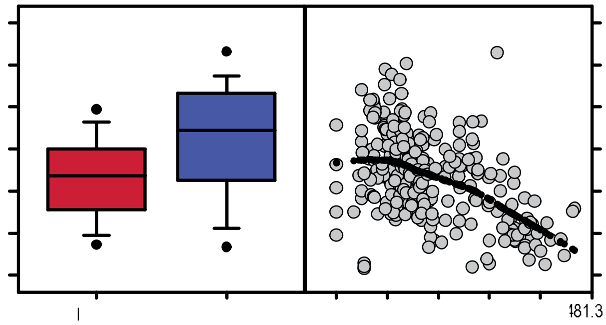
;

and (2) small and large bodied parrotfish species become more and less abundant respectively. One way to measure these size-dependent changes in the parrotfish communities is by simply calculating the average fish weight of the entire parrotfish community. For example, average parrotfish weight in areas that have some protection against fishing is larger than in unprotected areas, and average parrotfish weight decreases as proxies of fishing pressure (such as human population size) increase across the Caribbean region .

The midnight parrotfish (Scarus coelestinus) is the second largest parrotfish in the Caribbean.







'age parrotfish weight.

for
onal
nt,
oupers,
ish
most

al

Parrotfish are often caught by trap fishers.

MANAGEMENT IMPLICATIONS

Average weight of the parrotfish community provides a cost effective, simple and intuitive indicator of fishing effects .From an applied perspective it is easier to measure the attributes (e.g. body size, biomass, density) of the parrotfish communities with high precision than those of the snapper and grouper communities because the latter are now rare across the region.

Coral reefs are highly complex systems affected by multiple stressors. Thus, when possible, the use of average parrotfish weight as an indicator of fishing effects should be accompanied and contrasted with as much independent information available on fishing pressure and other local stressors.

HOW IS IT DONE?

Average parrotfish weight can be calculated using reef survey data that includes the species, abundance and length of parrotfishes. Using

the weight of each fish can be calculated. These weights can then be averaged across all parrotfish species at a site to give an estimate of average parrotfish weight.

FURTHER INFORMATION

eful

Available free at:

Understanding and managing invasive lionfish

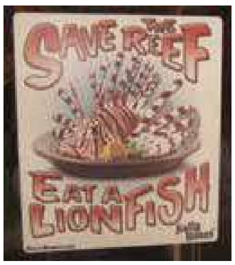
THE ISSUE

Lionfish are extremely efficient and voracious predators, able to eat 10% of their body weight per day. Experiments in the Bahamas showed lionfish were able to reduce their prey abundance by 80% in just 5 weeks.

Lionfish prey on more than 50 species of reef fish. Important reef fishery species, such as groupers and snappers, are consumed by lionfish in their juvenile stage when they are small enough for a lionfish to eat. This is reducing the ability of these often overexploited species to recover. The same principle applies to parrotfish which are important algal grazers. Further reductions in parrotfish numbers on reefs inhibits the ability of corals to recover as reefs become dominated by algae which reduced numbers of parrotfish are unable to control.

THE EVIDENCE

zookeeper.



numbers.

MANAGEMENT IMPLICATIONS

Lionfish are here to stay on Caribbean reefs, but management actions can help alleviate some of the problems. Management options for lionfish will depend on the resources available but might include three components:

Education and awareness

Campaigns to promote understanding lionfish and the impacts they have on reefs can help to reinforce the management of lionfish in a number of ways:

- Reduce risk of people being stung and injured by lionfish.
- Increase support for other management measures.
- Raise awareness of the damaging effects lionfish have on the ecosystem.
- Mobilize support for removal programmes, particularly amongst divers and dive shops.
- Encourage consumption of lionfish.
- Prevent further introductions of invasive species, including additional lionfish.

Removal

Where the density and size of large-bodied grouper is high – after 30 years protection – evidence exists that lionfish densities are relatively low on outer forereefs. However, 99% of Caribbean reefs lack the levels of grouper found on these reefs so grouper are unlikely to serve as a form of biocontrol (Mumby et al 2011). The only ways at present to control lionfish numbers is by active removal. This is normally done by scuba divers using adapted pole spears and sometimes nets or bags. Removal efforts have only a limited effect on lionfish numbers as populations will always be replenished from other reef areas and removal of all lionfish even at a small scale is practically impossible. However sustained local removal efforts can help reduce lionfish numbers on local reefs, thereby reducing their effect on the local reef ecosystem. It is important that removal programs do not harm the very reefs they are trying to conserve hence divers must take no other fish except lionfish and should not damage the reef while hunting for lionfish. Diver safety should also be stressed. To ensure rules are followed, some managers require that divers wishing to hunt lionfish are registered and undergo a training program. Removal of lionfish through the involvement of recreational divers has been effective in places such as Bonaire and the Florida Keys. Derbies are organized where a day or weekend of lionfish hunting and events take place, not only removing large numbers of lionfish from the reefs but also encouraging awareness of the scale of the problem. Consumption of lionfish is also being promoted in many places as they are seen as a sustainable and 'reef-friendly' food source.

Monitoring

Monitoring of lionfish can determine the spread of lionfish on local reefs and the efficacy of any removal programs as well aiding in their improvement, e.g. removal efforts can be targeted on reefs where lionfish are most abundant. Commonly used surveys methods such as AGRRA, REEF and Reef Check already include lionfish in their protocols. Other innovative methods of monitoring include using data from recreational divers; Bonaire has a website devoted to mapping of lionfish around the island using volunteer submitted data: www.lionfishcontrol.org/

Lionfish on measuring board.

FURTHER INFORMATION