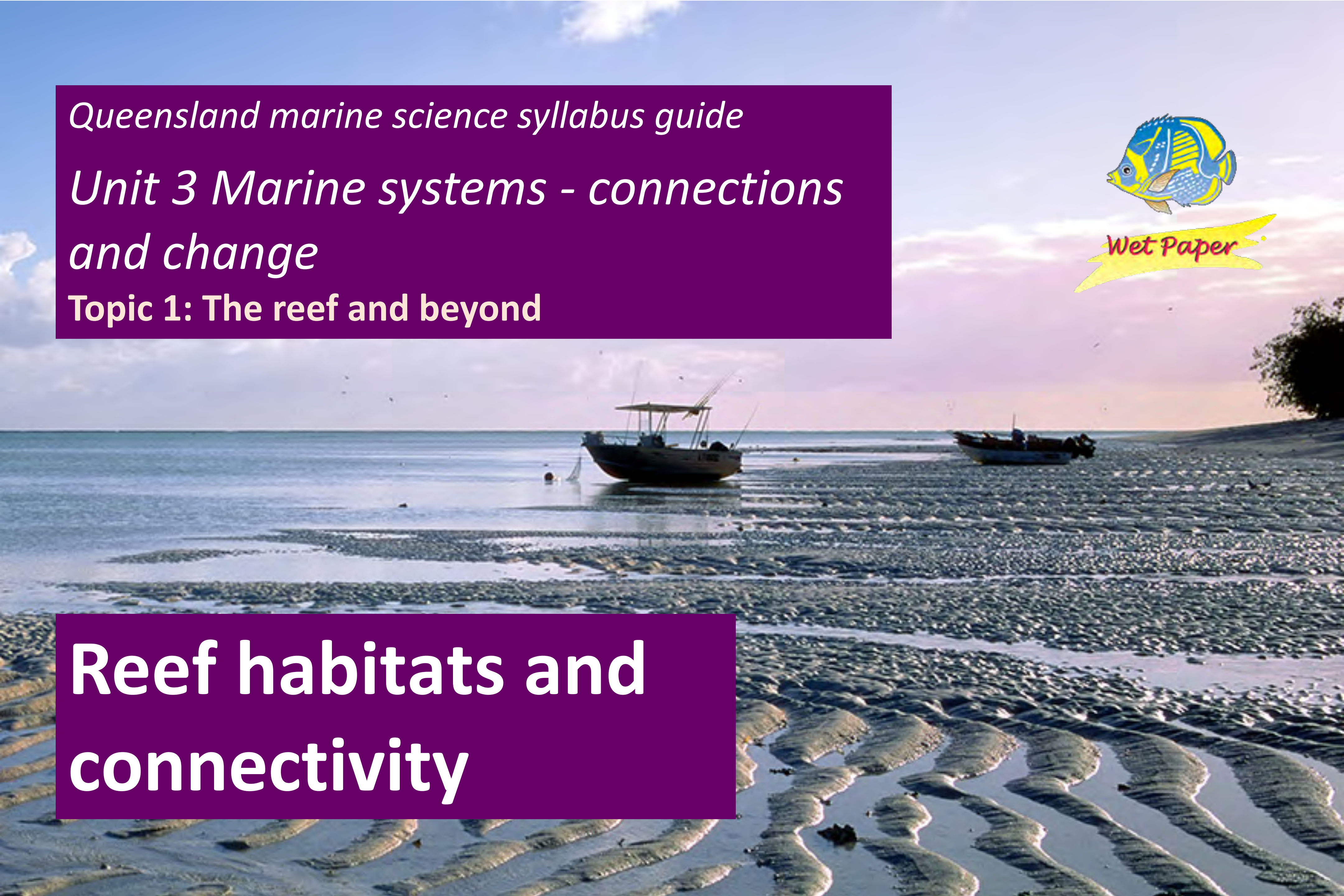

Queensland marine science syllabus guide

Unit 3 Marine systems - connections and change

Topic 1: The reef and beyond

Reef habitats and connectivity

Wet Paper

Topic 1: The reef and beyond

C. Reef habitats and connectivity

T086 Corals as engineers

T087 Reef rugosity

T088 Connectivity in reef ecosystems

T089 Fish life cycles

T090 Fish reef benefits

T091 Ecological tipping points

T092 Reef hysteresis

T093 Assess reef diversity

T094 Analyse reef diversity

T095 Interpret reef changes

T096 Water quality on reefs

T097 Water quality overall effects

T098 Conduct connectivity experiment

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Syllabus reference

Marine Science

Unit 1
Oceanography
- Topic 1: An ocean planet
- Topic 2: The dynamic shore

Unit 2
Marine biology
- Topic 1: Marine ecology and biodiversity
- Topic 2: Marine environmental management

Unit 3
Marine systems — connections and change
- Topic 1: The reef and beyond
- Topic 2: Changes on the reef

Unit 4
Ocean issues and resource management
- Topic 1: Oceans of the future
- Topic 2: Managing fisheries

Classification of verbs – degree of difficulty

★	★★	★★★
calculate (e.g. numerical answer; mathematical processes)	analyse	appraise
clarify	apply	appreciate
comprehend (meaning)	categorise	argue
construct (e.g. a diagram)	classify	assess
define	compare	comment (make a judgment)
demonstrate	consider	conduct (e.g. investigations)
describe	contrast	construct (e.g. an argument)
document	critique	create (e.g. a unique product/ artefact; language texts; meaning)
execute	deduce	decide/determine
explain	derive	discuss/explore
identify	determine	evaluate
implement (e.g. a plan, proposal)	discriminate	experiment/test (e.g. ideas, methods)
recall	distinguish	generate/test (e.g. hypotheses)
recognise (e.g. features)	identify	investigate/examine
select	infer/extrapolate	justify/prove (e.g. an argument, statement or conclusion)
understand	interpret (e.g. meaning)	modify
use		predict (e.g. a result)

Approximate exam paper match

Unit 3: Marine systems – connections and change

Topic 1 The reef and beyond

C. Reef habitats and connectivity		Exam example	
Power point titles	**Matching syllabus statements**	**School**	**Public**
T086 Corals as engineers	T 86 Recognise that corals are habitat formers or ecosystem engineers	P2. S/a Q1	
T087 Reef rugosity	T 87 Explain that habitat complexity (rugosity), established by corals, influences diversity of other species		P1. M/c Q21
T088 Explain connectivity	T 88 Explain connectivity between ecosystems and the role this plays in species replenishment	P1. M/c Q13	P2. S/a Q12
T089 Fish life cycles	T 89 Understand that fish life cycles are integrated within a variety habitats including reef and estuarine systems	P1. S/a Q28	
T090 Fish reef benefits	T 90 Describe how fish, particularly herbivore populations, benefit coral reefs	P1. M/c Q23	P2. S/a Q10
T091 Ecological tipping points	T 91 Identify ecological tipping points and how this applies to coral reefs		P1. S/a Q31
T092 Reef hysteresis	T 92 Describe hysteresis and how this applies to the concept of reef resilience	P1. M/c Q14 P1. M/c Q14	
T093 Assess reef diversity	T 93 Assess the diversity of a reef system using a measure that could include line intercept transects, quadrats & fish counts using underwater video survey techniques, benthic surveys, invertebrate counts and rugosity measurements	P2. S/a Q12	P1. M/c Q21
T094 Analyse reef diversity	T 94 Analyse reef diversity data, using an index, to determine rank abundance		P1. S/a Q28
T095 Interpret reef changes	T 95 Interpret, with reference to regional trends, how coral cover has changed on a reef over time		P1. M/c Q4
T096 Water quality on reefs	T 96 Recognise that some of the factors that reduce coral cover (e.g. crown-of-thorns) are directly linked to water quality	P2. S/a Q8	
T097 Water quality overall effects	T 97 Understand that the processes in this sub-topic interact to have an overall net effect, i.e. they do not occur in isolation.	P2. S/a Q8 (?)	P1. M/c Q4
T098 Conduct connectivity experiment	T 98 Examine the concept of connectivity in a habitat by investigating the impact of water quality on reef health. Mandatory practical:		P2. S/a Q6

T086 Corals as engineers

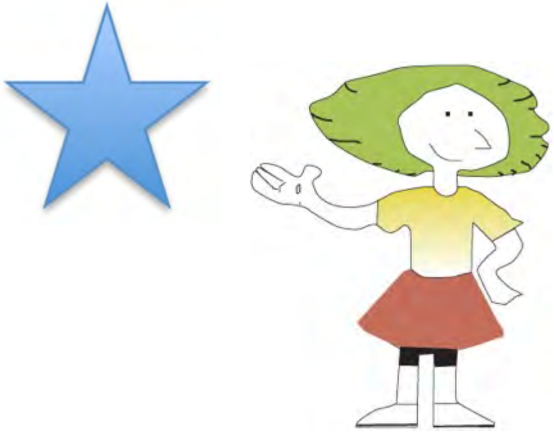
Adam Richmond

Syllabus statement

At the end of this topic you should be able to ...

Recognise

that corals are habitat formers or ecosystem engineers

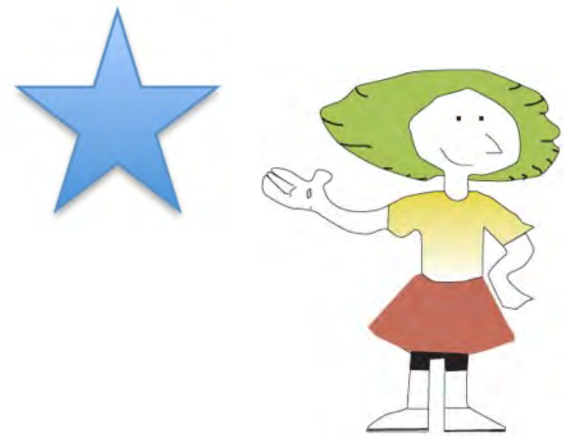


Recognise

- identify or recall particular features of information from knowledge;
- identify that an item, characteristic or quality exists; perceive as existing or true;
- be aware of or acknowledge

Identify

- distinguish;
- locate, recognise and name;
- establish or indicate who or what someone or something is;
- provide an answer from a number of possibilities;
- recognise and state a distinguishing factor or feature



Objectives

Recall definitions for habitat former and ecosystem engineer.

Describe features of corals that make them habitat formers and ecosystem engineers.

Note:

The syllabus implies that you will need an understanding of **habitat formers** and **habitat cascades.**

Editors note:

This topic introduces many new terms and once taught for the first time may need reviewing as to how many terms are necessary.

Definitions

From the Marine Science syllabus:

Ecosystem engineer

An organism that directly or indirectly controls the availability of resources to other species by causing physical state changes in biotic or abiotic material.
They modify, maintain and create habitats.

(Jones, Lawton & Shachak, 1994)

Habitat former

Any organism that forms a habitat. They

- can be primary, secondary or focal;
- at least three habitat formers are required to create a habitat cascade.

"The habitat cascade is defined as indirect positive effects on focal organisms mediated by successive facilitation in the form of biogenic formation or modification of habitat."

Habitat
Place where an organism normally occurs.

Cascade
Succession/sequence of stages, processes, or units.

Focal organisms
Eg: On a reef = Christmas tree worms, small fish, small crustceans that live in and around coral.

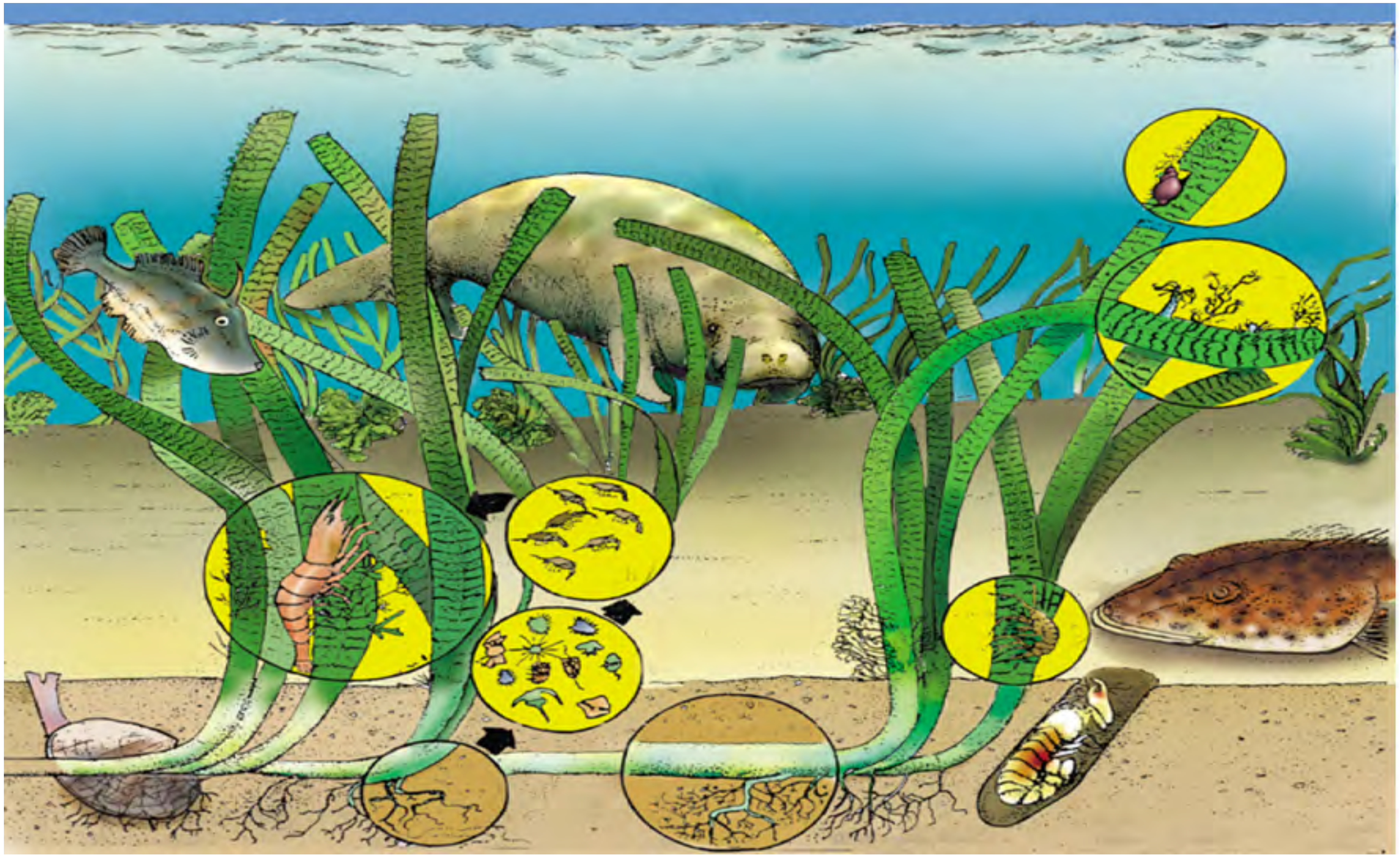
Ecological **facilitation** describes species interactions that benefit at least one of the participants and cause harm to neither.

Biogenic
Produced or brought about by living organisms.

References
http://www.thomsenlab.com/research/habitat-cascades/

Stachowicz, J. J. 2001. Mutualism, facilitation, and the structure of ecological communities. BioScience 51: 235-246

Habitat cascades are a general phenomenon that enhances species abundance and diversity in forests, salt marshes, coral reefs, seagrass meadows, and seaweed beds.

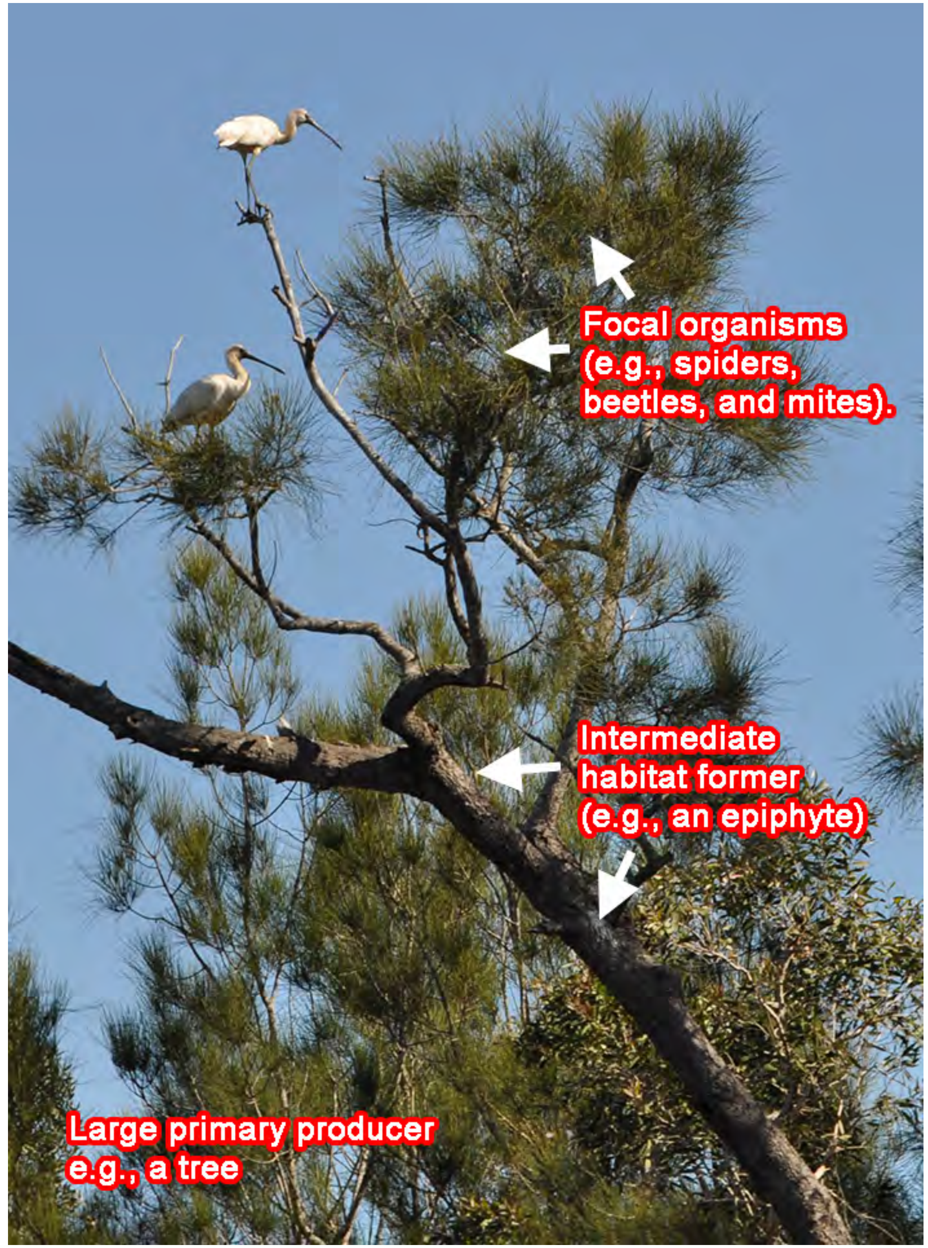


Habitat cascades are characterized by a ***hierarchy*** of ***facilitative interactions*** in which a basal habitat former.

Typically a large primary producer e.g., a tree

creates living space for an intermediate habitat former (e.g., an epiphyte)

that in turn
creates living space for the focal organisms (e.g., spiders, beetles, and mites).



Habitat cascade

Ecosystem engineers

"Ecosystem engineers are organisms that directly or indirectly modulate the availability of resources to other species, by causing physical state changes in biotic or abiotic materials. In so doing they modify, maintain and create habitats."[1]

Jones, C., Lawton, J., & Shachak, M. (1994), p.373

Organisms that interact with the physical environment, and in doing so create, modify or maintain a habitat are **ecosystem engineers**.

The process of modifying the environment as **ecosystem engineering**.

1. Jones, C., Lawton, J., & Shachak, M. (1994). Organisms as Ecosystem Engineers. *Oikos*, *69*(3), 373. doi: 10.2307/3545850.

Humans are ecosystem engineers that create, modify and maintain habitat.

Beavers are a well-known example of ecosystem engineers.

They cut down trees and use them to build dams across streams.

These dams affect water flow by

- creating wetlands;
- modifying nutrient and sediment flows;
- changing the structure of the riparian zone;

and

- influencing the composition and diversity of plant and animal communities downstream.

A beaver dam

Two types of ecosystem engineers are **autogenic** and **allogenic**.

Complex coral habitat provides home for many reef dwellers.
Image: C. Jones, Copyright Commonwealth of Australia (GBRMPA) 141459

Autogenic engineers "change the environment via their own physical structures, i.e. their living and dead tissues."[1]

1. Jones, C., Lawton, J., & Shachak, M. (1994). Organisms as Ecosystem Engineers. *Oikos*, *69*(3), 373. doi: 10.2307/3545850.

Corals are autogenic engineers, because in producing complex, hard and stable skeletal structures,

- they change the physical, chemical, and biological environment and
- create habitats for other reef organisms. [1]

Illustration copyright Sophie Hall. Reproduced with permission.

1. Wild, C., Hoegh-Guldberg, O., Naumann, M., Colombo-Pallotta, M., Ateweberhan, M., & Fitt, W. et al. (2011). Climate change impedes scleractinian corals as primary reef ecosystem engineers. *Marine And Freshwater Research*, *62*(2), 205. doi: 10.1071/mf10254

Allogenic engineers change the environment by transforming living or nonliving materials from one physical state to another, via mechanical or other means.[1]

Corals act as allogenic ecosystem engineers because they intensively generate and transform inorganic and organic materials. Coral skeletons are transformed into calcareous reef sands by bioerosion and physical erosion processes.[2]

You shouldn't have to remember the two types of ecosystem engineers- but coral is both kinds of ecosystem engineer!

Parrotfish "making" sand.

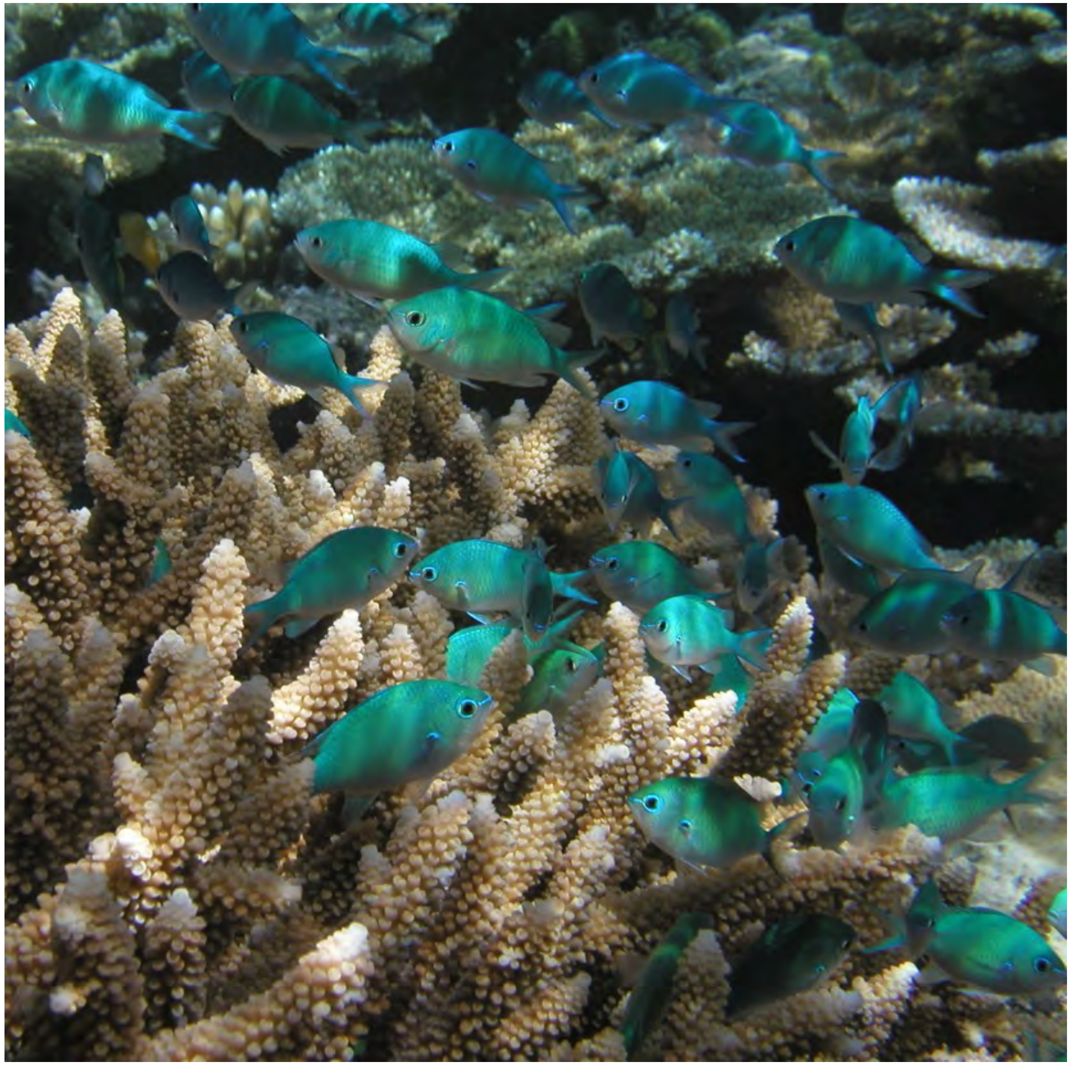
Image: Ji Wang, reproduced with permission

1. Jones, C., Lawton, J., & Shachak, M. (1994). Organisms as Ecosystem Engineers. *Oikos*, *69*(3), 373. doi: 10.2307/3545850.
2. Wild, C., Hoegh-Guldberg, O., Naumann, M., Colombo-Pallotta, M., Ateweberhan, M., & Fitt, W. et al. (2011). Climate change impedes scleractinian corals as primary reef ecosystem engineers. *Marine And Freshwater Research*, *62*(2), 205. doi: 10.1071/mf10254

Habitat formers

Species able to support another species by

- providing suitable environmental conditions,
- enhancing the availability of or access to limiting resources, or
- reducing the effects of negative species interactions, such as competition, predation, and diseases.[1]



Branching coral provide protection from predation

Image: Justin Marshall, Copyright CoralWatch. Reproduced with permission.

1. Text verbatim from: Bulleri, F., Eriksson, B., Queirós, A., Airoldi, L., Arenas, F., & Arvanitidis, C. et al. (2018). Harnessing positive species interactions as a tool against climate-driven loss of coastal biodiversity. *PLOS Biology*, *16*(9), e2006852. doi: 10.1371/journal.pbio.2006852. Open Access

Habitat formers are ecosystem engineers, since they create habitat.

Although not all ecosystem engineers are habitat formers some ecosystem engineers causes habitat destruction.

By (WT-en) Jpatokal at English Wikivoyage, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=22934836

Primary, secondary and focal habitat formers

Primary habitat formers are ecosystem engineers; and are also known as ultimate habitat formers, basal habitat formers, and foundation species.

They are habitat forming organisms like trees, seagrass, kelp or corals that **create** a habitat.

Hard corals create a habitat for many organisms

Secondary habitat formers live in the habitat created by the primary habitat former.

- Examples include climbing vines, epiphytes and bivalves.

Focal organisms live in the secondary habitat.

- They are also known as clients, end-users, habitat-users or inhabitants.

Thomsen et al clarify these terms in this article:

Thomsen, M., Wernberg, T., Altieri, A., Tuya, F., Gulbransen, D., & McGlathery, K. et al. (2010). Habitat Cascades: The Conceptual Context and Global Relevance of Facilitation Cascades via Habitat Formation and Modification. *Integrative And Comparative Biology*, *50*(2), 158-175. doi: 10.1093/icb/icq042

Available: https://academic.oup.com/icb/article/50/2/158/612831

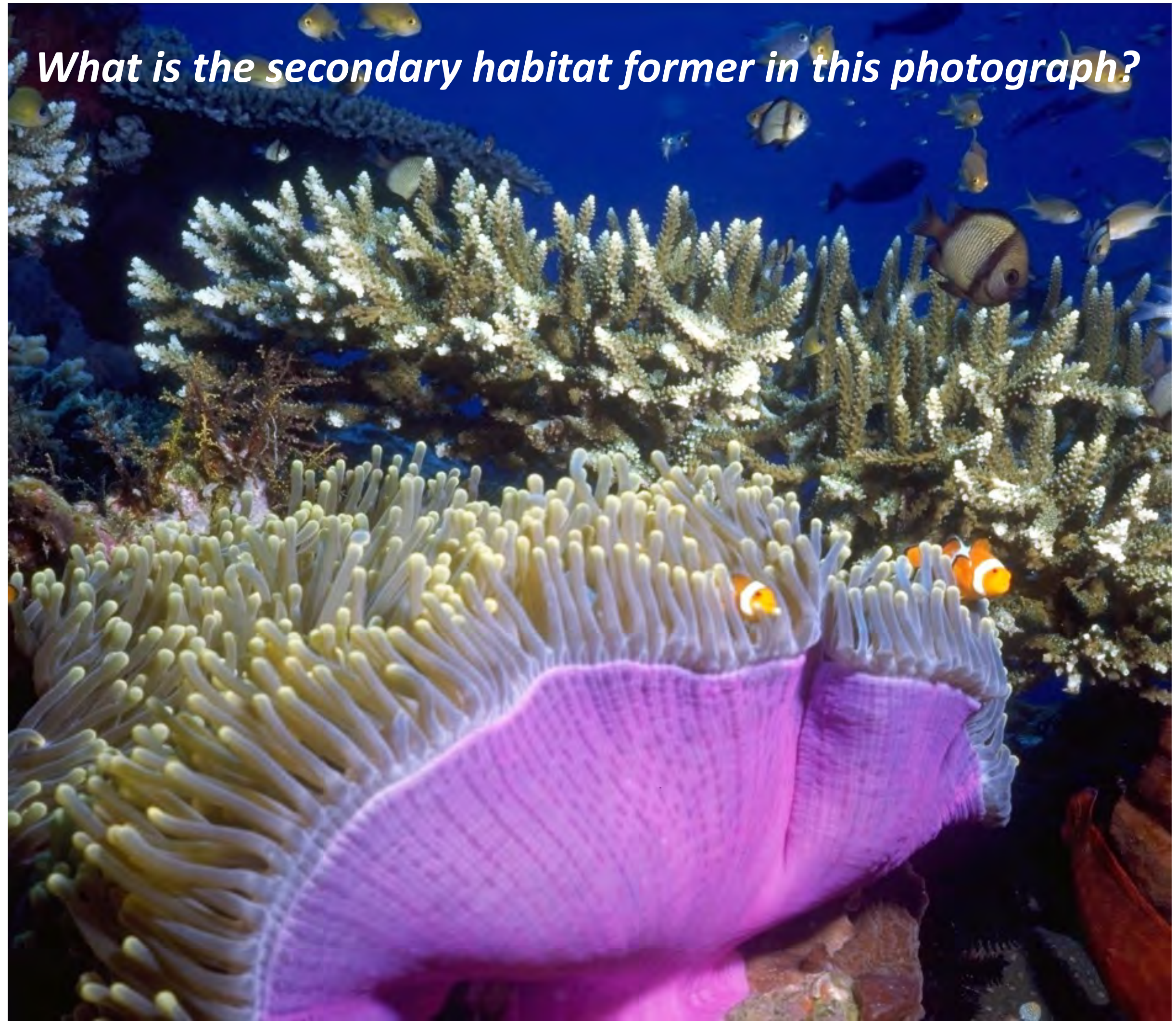


Image:E. Matson, Copyright Commonwealth of Australia (GBRMPA) 124781

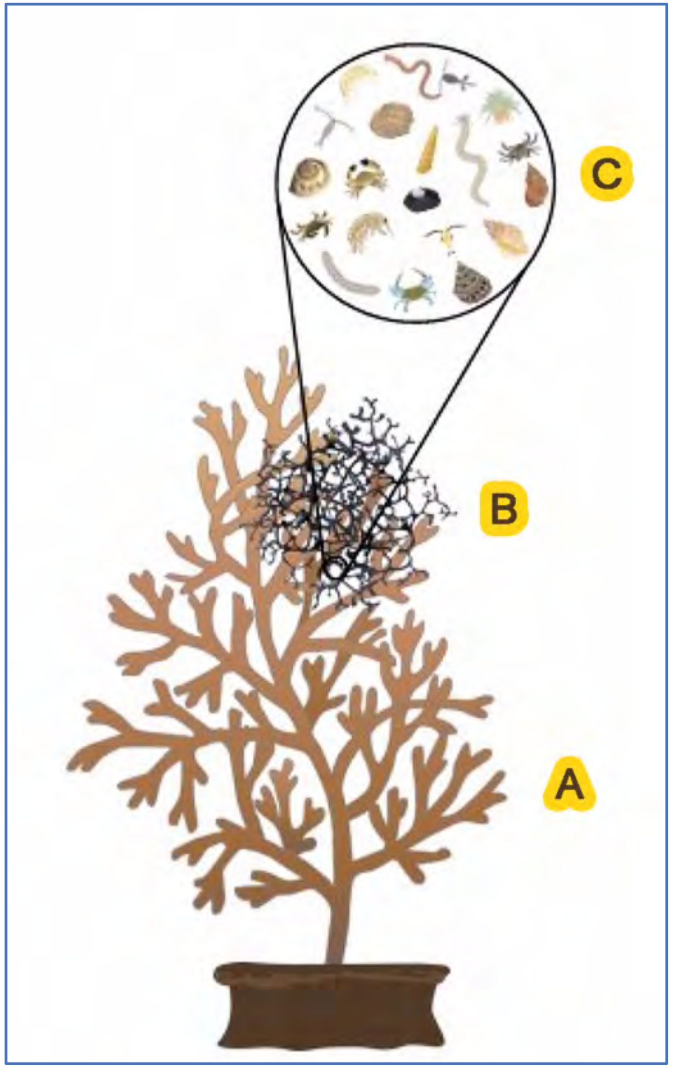
Habitat cascades

A habitat cascade is a term for a positive interaction "where a species A provides habitat for a species B, which in turn provide habitat for a species C… and so on."

In the example on the right, the seaweed (A) is the primary habitat former.

- It provides habitat for the epiphyte (B), which in turn
- provides habitat for the small invertebrates (C).

These small invertebrates are the **focal organisms**.



An example of a habitat cascade

Image and Quote from: Alfonso Siciliano , Reproduced with permission.
Available: http://www.alfonsosiciliano.com/research/phd/

Hard corals deposit a solid structure that provides habitat for the yellow and red soft corals.

The yellow sea fan provides a habitat for several feather stars.

Feather stars can also provide habitat for commensal shrimp.

Image: CC Prilfish, from Flickr, available https://flic.kr/p/cNmqbU. CC 4.0 BY

Questions

1. Recall definitions for habitat former and ecosystem engineer

1b. (Extension: Compare habitat formers and ecosystem engineers)

2. Describe the key features of corals that make them habitat formers and ecosystem engineers

**The syllabus implies that you will need an understanding of habitat formers and habitat cascades*

3. Recall an example of a habitat cascade on a coral reef. Identify the primary and secondary habitat formers, and focus organism in your example.

Answers

1. Recall definitions for habitat former and ecosystem engineer

A habitat former is any organism that forms a habitat. They

- can be primary, secondary or focal;
- at least three habitat formers are required to create a habitat cascade.

An ecosystem engineer is an organism that directly or indirectly controls the availability of resources to other species by causing physical state changes in biotic or abiotic material. They modify, maintain and create habitats.

1b. (Extension: Compare habitat formers and ecosystem engineers)

Habitat formers create a habitat for other species. Ecosystem engineers create, modify, maintain or destroy habitats. Habitat formers are ecosystem engineers, but not all ecosystem engineers are habitat formers.

2. Describe the key features of corals that make them habitat formers and ecosystem engineers

Corals create a hard substrate for other organisms to live on, in or near (habitat former), their size and stability affects currents and water movement, cycles nutrients and creates sediment (engineer)

3. Recall an example of a habitat cascade on a coral reef. Identify the primary and secondary habitat formers, and focus organism in your example.

    Hard coral- primary habitat former
    anemone- secondary habitat former
    clownfish- focus organism

Further activity

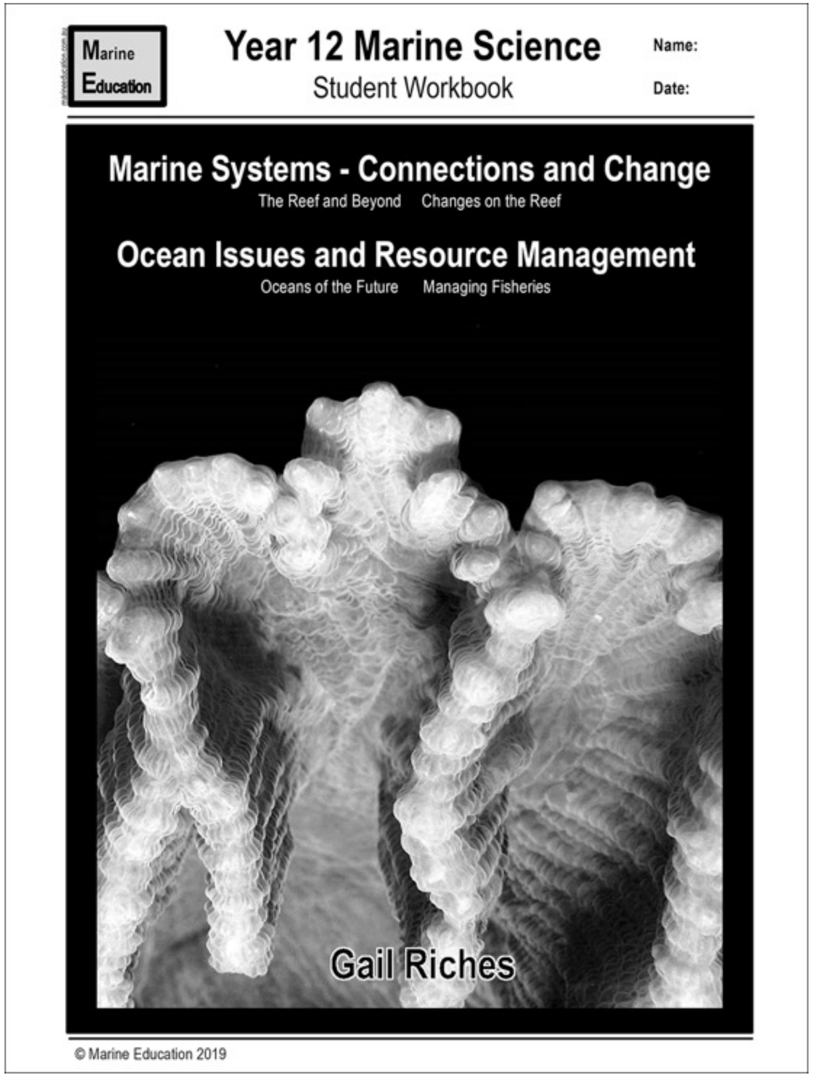
Worksheet –

Home sweet home

by

Gail Riches

www.marineeducation.com.au



T087 Reef rugosity

Adam Richmond

Syllabus statement

At the end of this topic you should be able to ...

Explain

that habitat complexity (rugosity), established by corals, influences diversity of other species.

Explain

make an idea or situation plain or clear by describing it in more detail or
revealing relevant facts; give an account;
provide additional information


Objective

Give a four point summary of how the rugosity of a coral reef affects the diversity of other species.

Definition

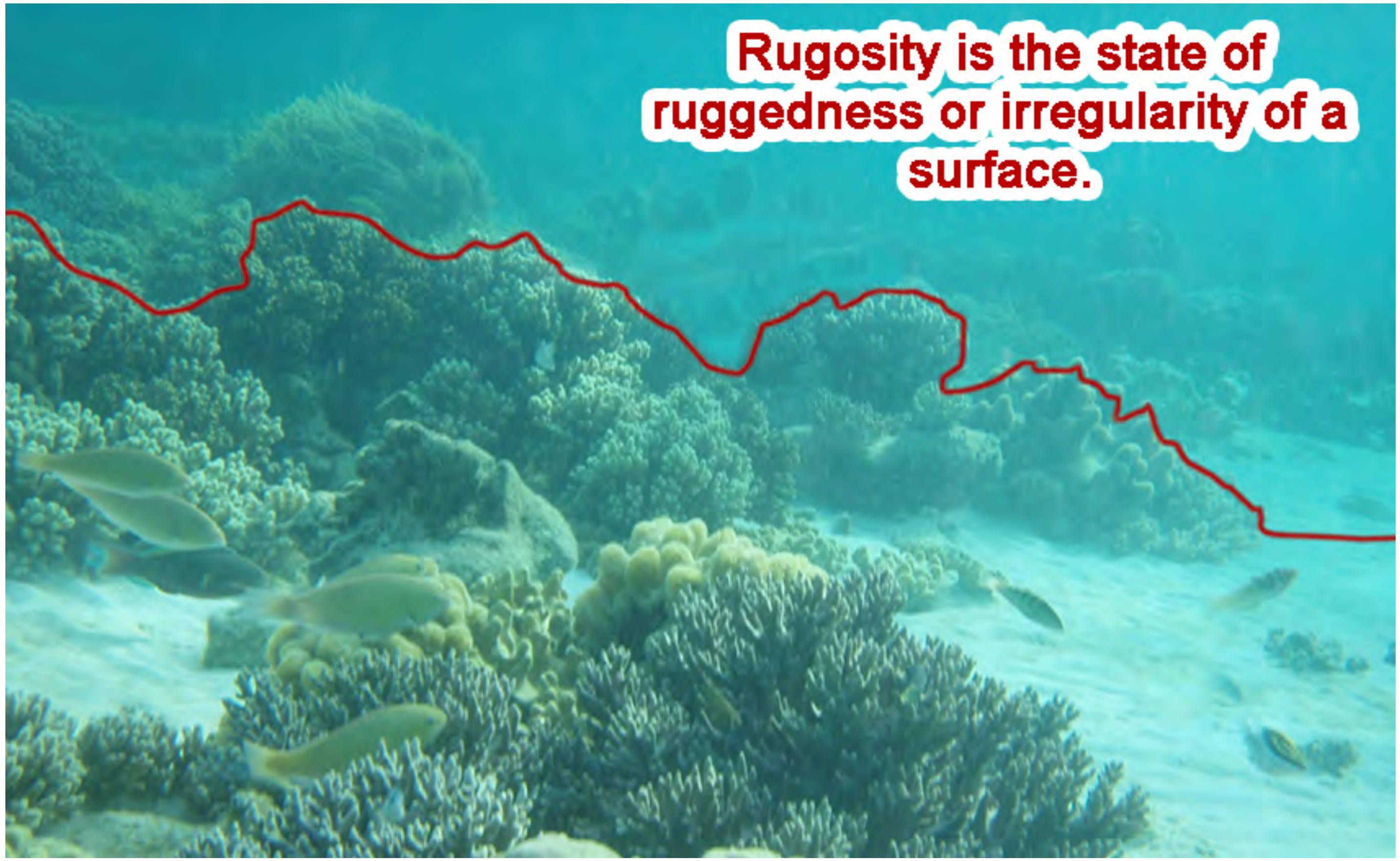
Habitat complexity is the real size, number and diversity of habitat types and distinct ecological zones within a specified area[1].

The Great Barrier Reef has many different ecological zones and habitat types

[1]Definition from NOAA

The habitat complexity of a benthic marine environment is known as rugosity.
The terms “topographic complexity” and “substrate complexity” all mean the same thing.

Rugosity is the state of ruggedness or irregularity of a surface.



In a reef context, it refers to the amount of “wrinkling” or roughness of the reef profile.

This coral outcrop provides habitat complexity

The complex skeletons of calcium carbonate created by scleractinian corals increase rugosity.

A rugosity index is a measure that provides an indication of the structural habitat complexity.

Rugosity can be measured on different scales- just as habitat complexity occurs on different scales

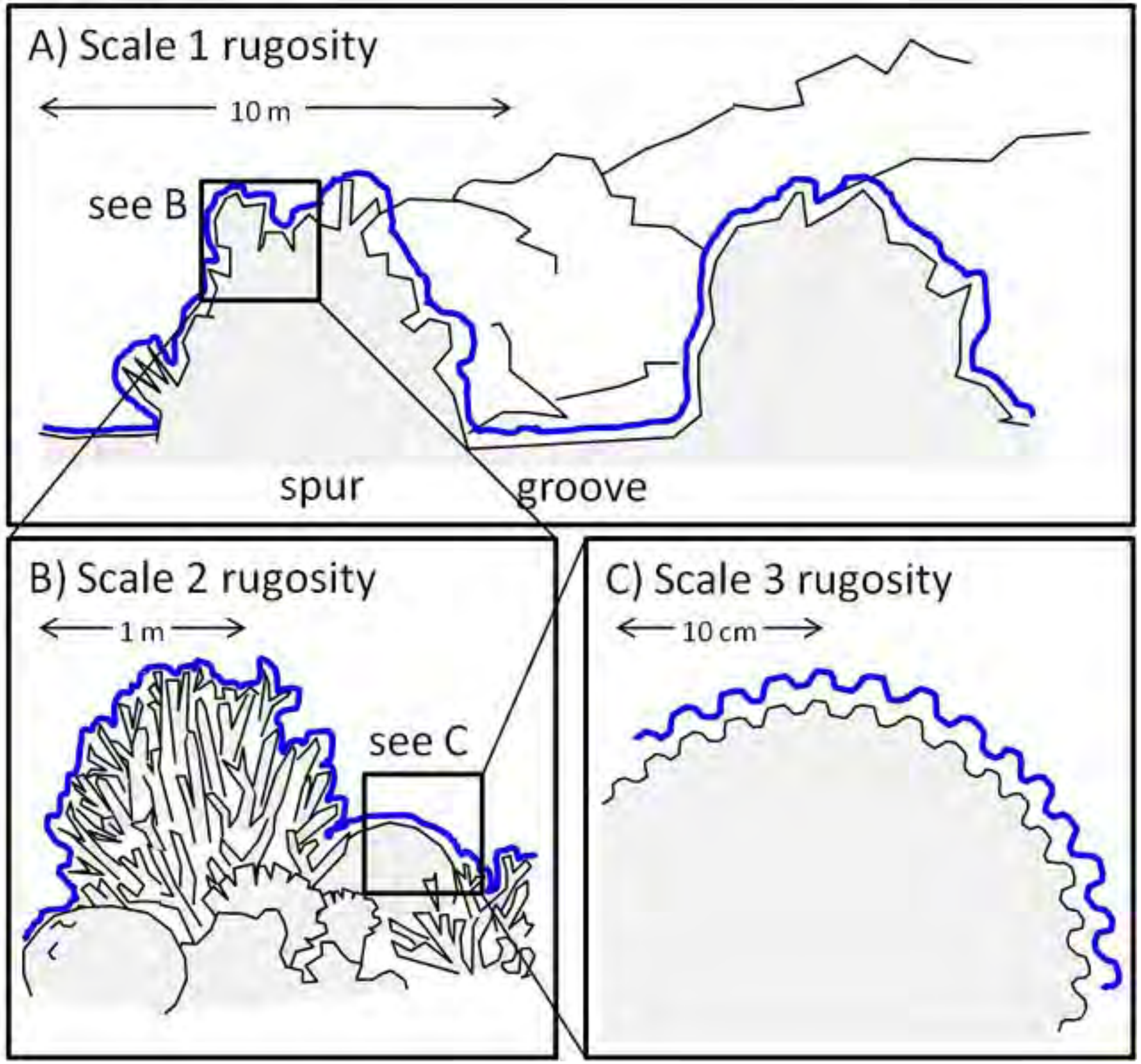


Image Peter Mumby. Reproduced with permission from: Kennedy, E., Perry, C., Halloran, P., Iglesias-Prieto, R., Schönberg, C., & Wisshak, M. et al. (2013). Avoiding Coral Reef Functional Collapse Requires Local and Global Action. *Current Biology*, *23*(10), 912-918. doi: 10.1016/j.cub.2013.04.020, Rugosity can be measured using the chain-tape method.

Image: Copyright Nyssa Silbiger. Reproduced with permission.

Note:
Laying out a chain must be done carefully to avoid damaging the coral.

Rugosity is measured as the **ratio** between the length of the chain and the tape.

The chain follows the contoured surface profile, and the tape measures the linear distance between the two end points.

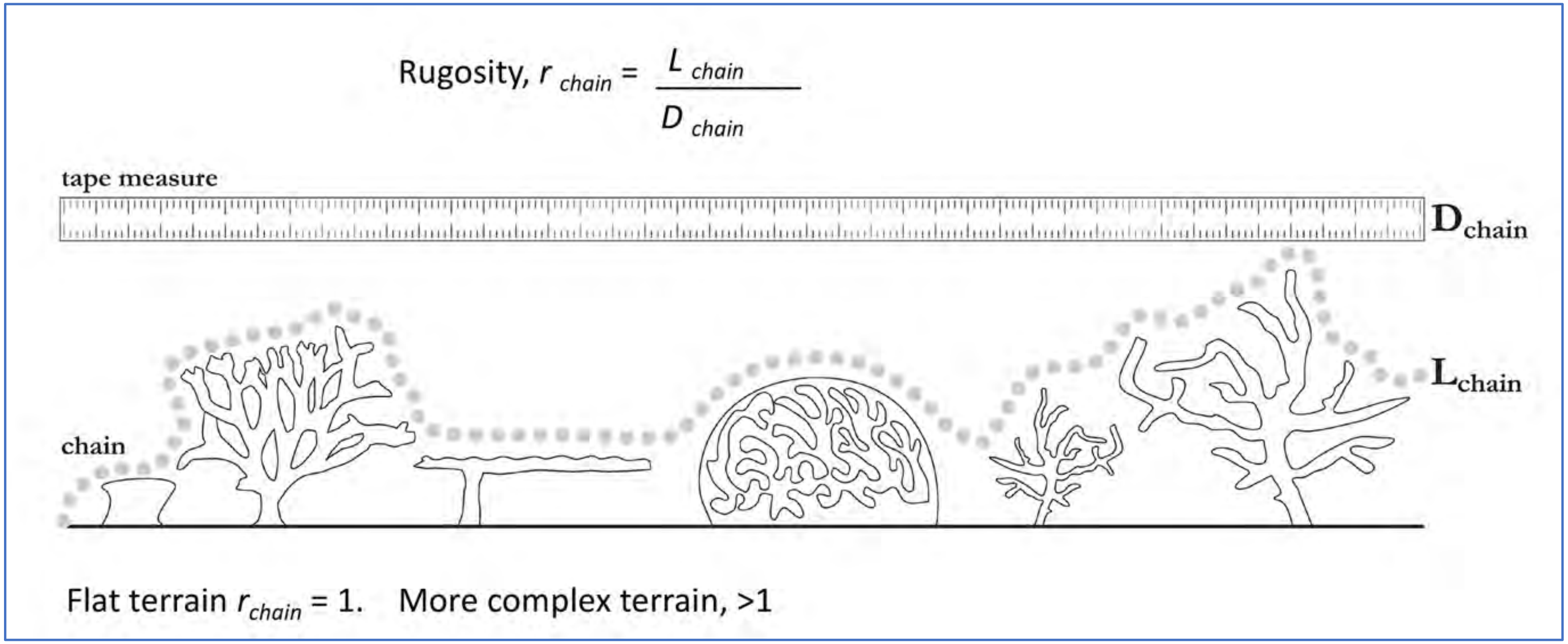


Image: Friedman, A., Pizarro, O., Williams, S., & Johnson-Roberson, M. (2012). Multi-Scale Measures of Rugosity, Slope and Aspect from Benthic Stereo Image Reconstructions. *Plos ONE*, *7*(12), e50440. doi: 10.1371/journal.pone.0050440 adapted from Hill J, Wilkinson C (2004) Methods for ecological monitoring of coral reefs. Technical report. [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)]
Available:
https://doi.org/10.1371/journal.pone.0050440.g002

Underwater cameras and imaging also enable 3D imaging of the seafloor. The advantages include:

- Virtual calculations using data collected by underwater drones are faster,
- have no environmental impact and
- can be easily repeated on different scales.

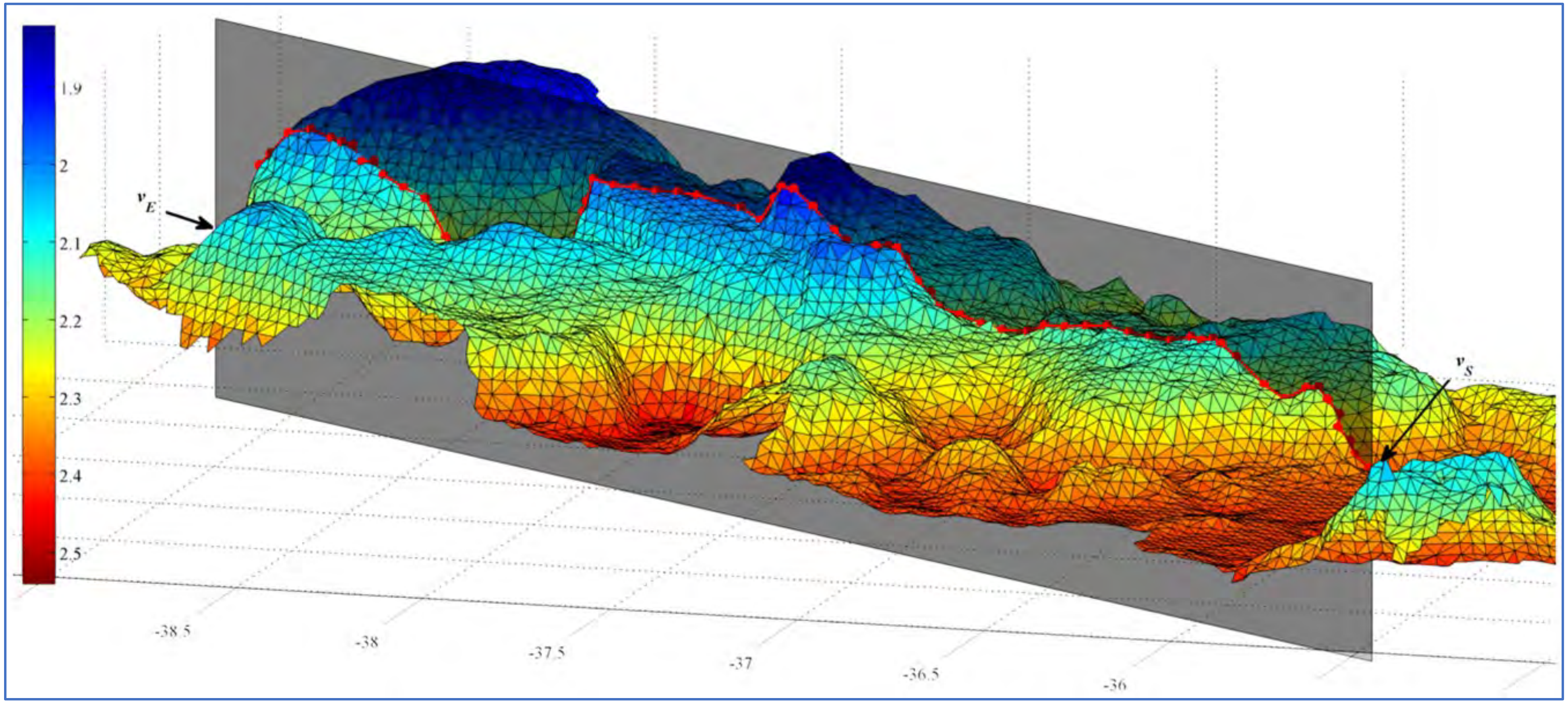


Image and Reference: Friedman, A., Pizarro, O., Williams, S., & Johnson-Roberson, M. (2012). Multi-Scale Measures of Rugosity, Slope and Aspect from Benthic Stereo Image Reconstructions. *Plos ONE*, *7*(12), e50440. doi: 10.1371/journal.pone.0050440. [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)]

Some scientists use a digital plumb bob as it is faster and has less impact.

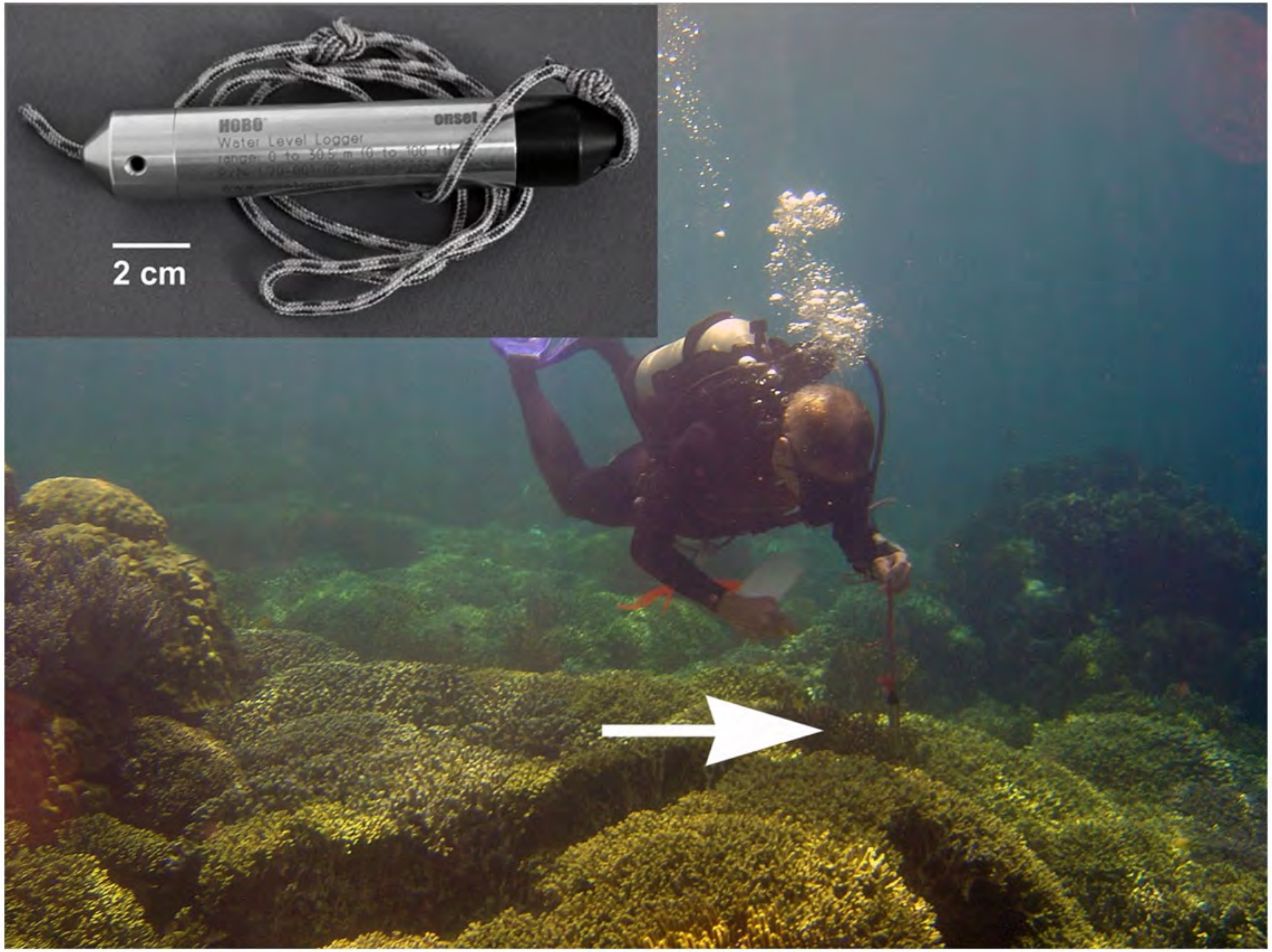
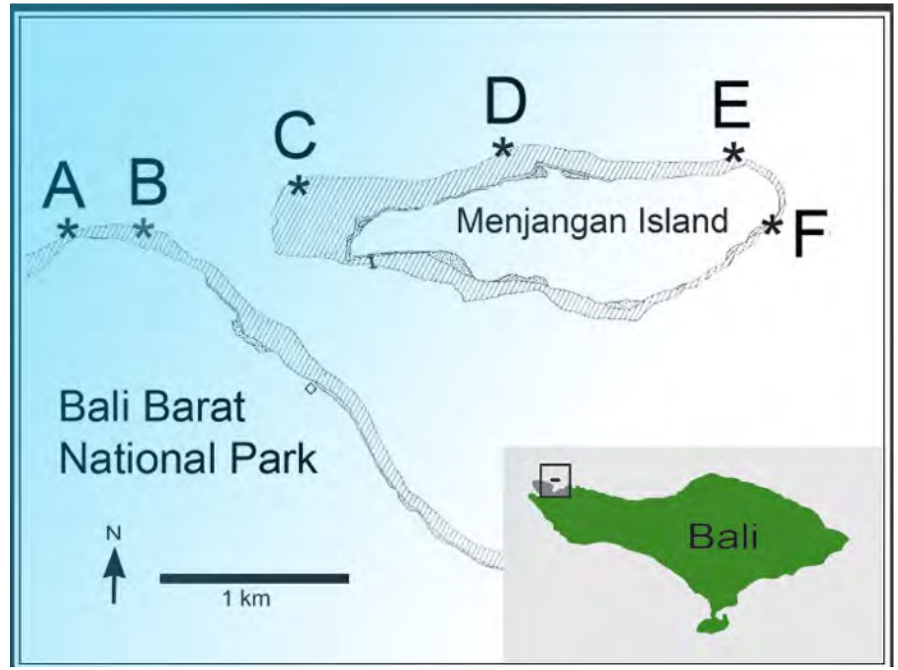


Image: Dustan, P., Doherty, O., & Pardede, S. (2013). Digital Reef Rugosity Estimates Coral Reef Habitat Complexity. *Plos ONE*, *8*(2), e57386. doi: 10.1371/journal.pone.0057386. [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)]

In 2013, three scientists used this digital reef rugosity to estimate coral reef habitat complexity on reefs to the north of Bali.

You need to skim read this article before you go further.

https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0057386



They found that areas with high rugosity provide more cover for reef fish and more places for attachment for algae, corals and other sessile invertebrates.[1]

The contribution of live coral cover to reef rugosity can be clearly seen in the diagram opposite.

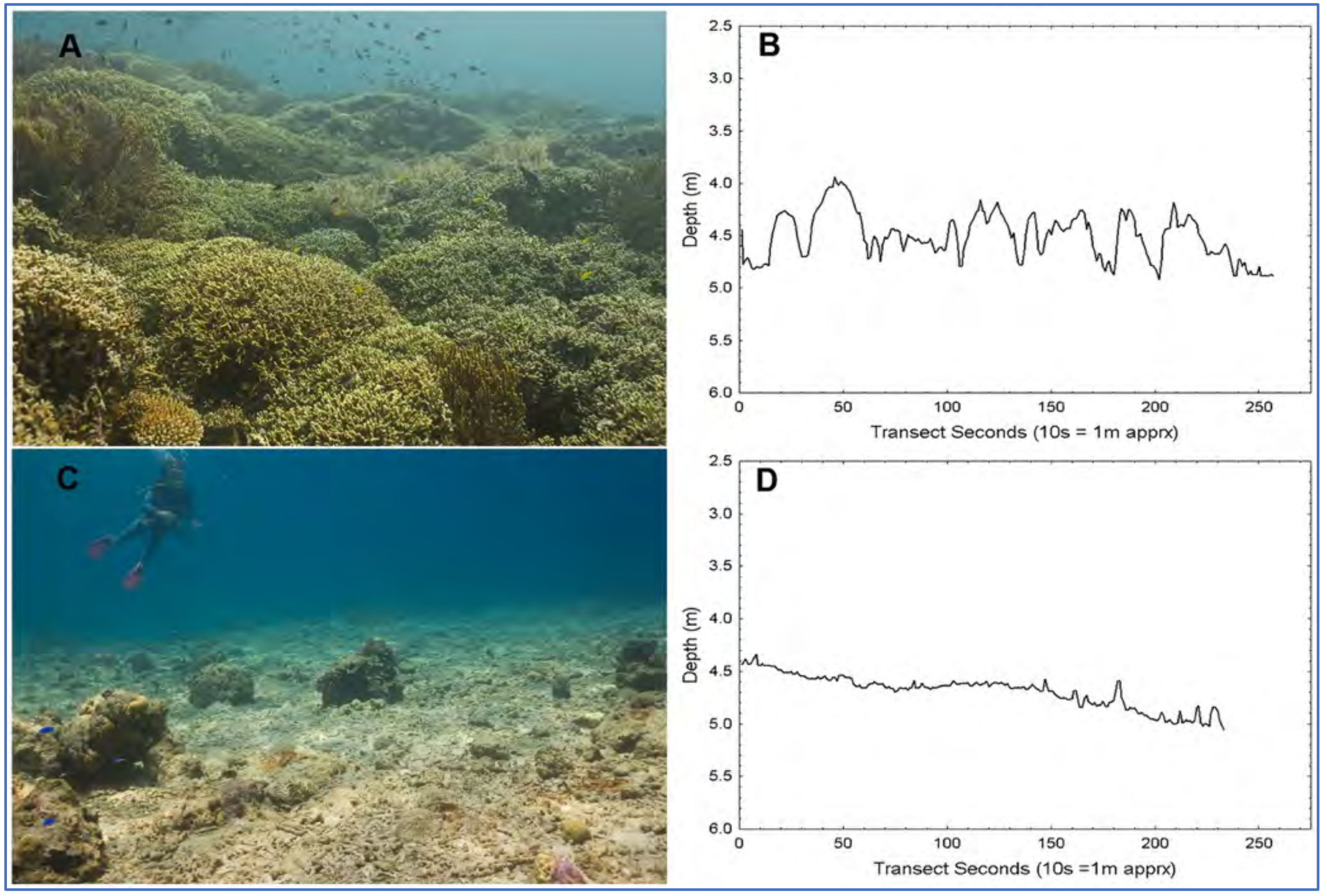


Image: Dustan, P., Doherty, O., & Pardede, S. (2013). Digital Reef Rugosity Estimates Coral Reef Habitat Complexity. *Plos ONE*, *8*(2), e57386. doi: 10.1371/journal.pone.0057386. [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)]

1. Fuad, M. (2010). *Coral reef rugosity and coral biodiversity*. Enschede: University of Twente Faculty of Geo-Information and Earth Observation (ITC).

By using Shannons index – H they found that the biodiversity of 5 families of fish based on abundance and biomass is significantly correlated with rugosity as shown in the graphs below.

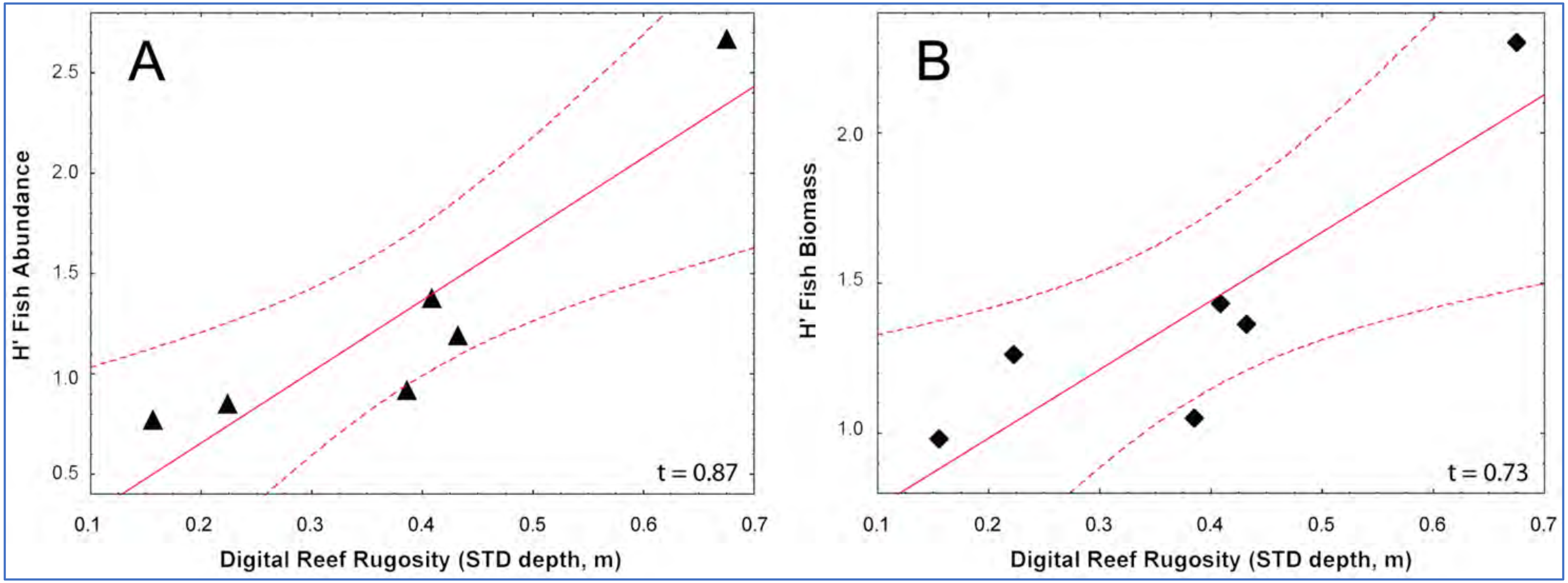


Image and reference: Dustan, P., Doherty, O., & Pardede, S. (2013). Digital Reef Rugosity Estimates Coral Reef Habitat Complexity. *Plos ONE*, *8*(2), e57386. doi: 10.1371/journal.pone.0057386. [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)]

Remember from T037 last year

Genetic diversity:
the variety of genetic material present in a gene pool or population of a species

Species diversity:
the variety of species per unit area (e.g. habitat or a region) that includes both the number of species present and their relative abundance

Ecosystem diversity:
the variety per unit area of ecosystems, comprising the variety of habitats, number of ecological niches, trophic levels, ecological processes and the associated communities (per unit area); the largest scale of biodiversity

https://en.wikipedia.org/wiki/Species_diversity
https://en.wikipedia.org/wiki/Genetic_diversity
https://en.wikipedia.org/wiki/Ecosystem_diversity

Image Bob Moffatt

High rugosity **increases** fish diversity because it reduces interspecific competition by providing a greater range of niches and resources.

Image: Justin Marshall, Copyright CoralWatch. Reproduced with permission.

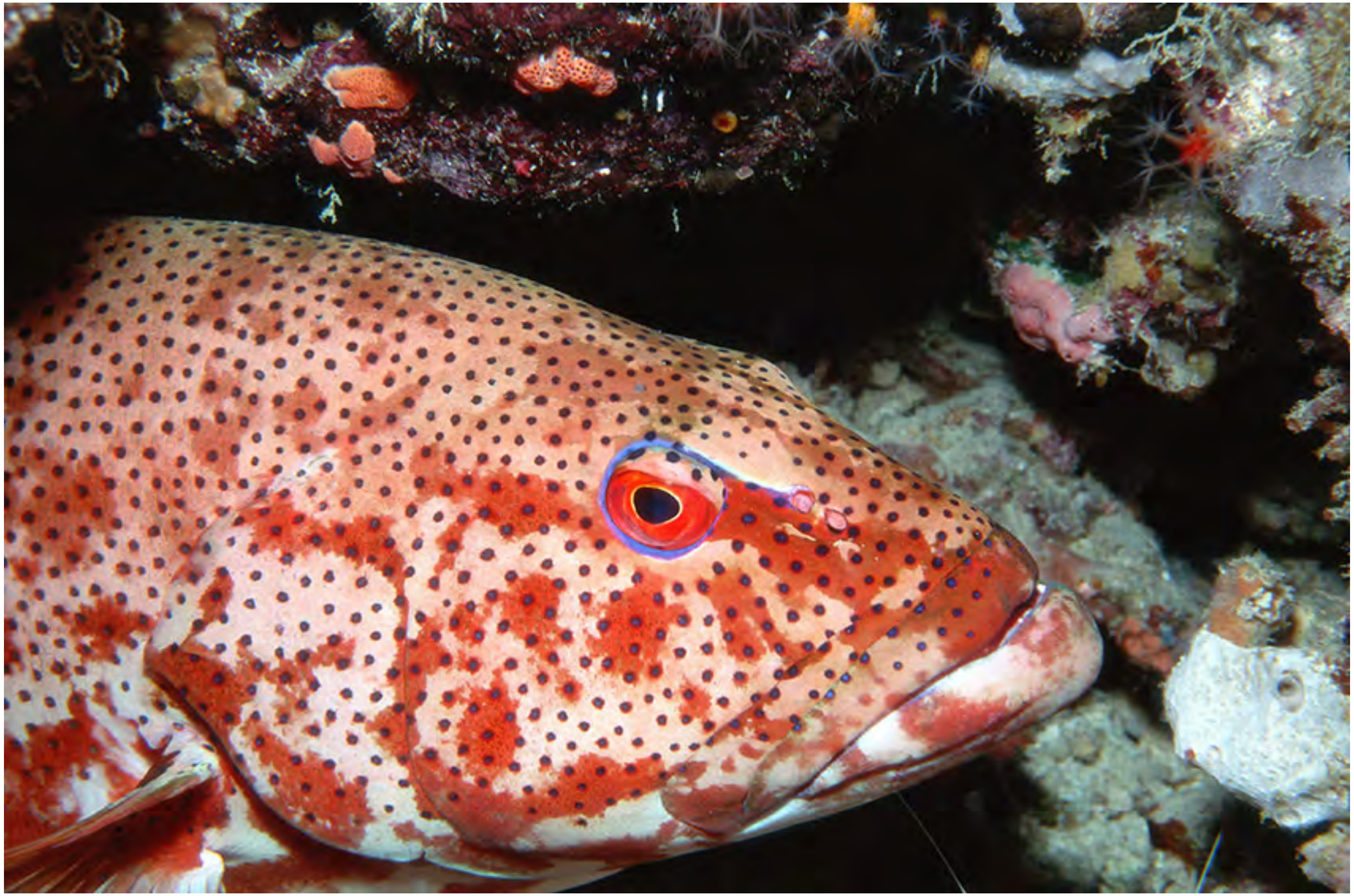
It also increases fish survivorship by reducing prey-predator encounter rates by offering more places to hide.

Large areas of branching corals provide habitat for a huge number of fish from relatively few species.
These areas house a higher density of fish, but a less diverse and even fish community.

Researchers[1] have determined that 85% of the individual fish in a branching coral community belonged <u>to just 5 species</u>.

Ref: [1] Palacios, M., & Zapata, F. (2014). Fish community structure on coral habitats with contrasting architecture in the Tropical Eastern Pacific. *Revista De Biología Tropical*, *62*, 343. doi: 10.15517/rbt.v62i0.16360

An area with massive coral species with a diversity of shapes and sizes provides a more complex and high-relief reef scape, that sustains a more diverse and even fish community.



Larger predatory fish seek the shade and concealment offered by coral outcrops.

Explanation 4 point summary

1. High rugosity increases fish diversity because it reduces interspecific competition by providing a greater range of niches and resources.

2. Large areas of branching corals provide habitat for a huge number of fish from relatively few species.

3. These areas house a higher density of fish, but a less diverse and even fish community. Researchers have determined that 85% of the individual fish in a branching coral community belonged to just 5 species.

4. An area with massive coral species with a diversity of shapes and sizes provides a more complex and high-relief reef scape, that sustains a more diverse and even fish community.

This YouTube video provides a quick summary:

https://youtu.be/fOTgMSKQhsA

How does reef rugosity affect fish diversity?
YouTube video by Megan Francis, available: https://youtu.be/fOTgMSKQhsA

Questions

1. What is habitat complexity?

2. How do corals create it?

3. Recall a definition for rugosity.

4. How can rugosity be measured?

5. Explain how the rugosity of a coral reef affects the diversity of other species.

Answers

1. What is habitat complexity? The size, number and diversity of habitat types and ecological zones within a specified area

2. How do corals create it? Complex shapes of reefs are created by coral skeletons

3. Recall a definition for rugosity. The state of ruggedness or irregularity of a surface

4. How can rugosity be measured? Chain and tape, or other methods; and then compared using a rugosity index.

5. Explain how the rugosity of a coral reef affects the diversity of other species. See previous slides

Further activity

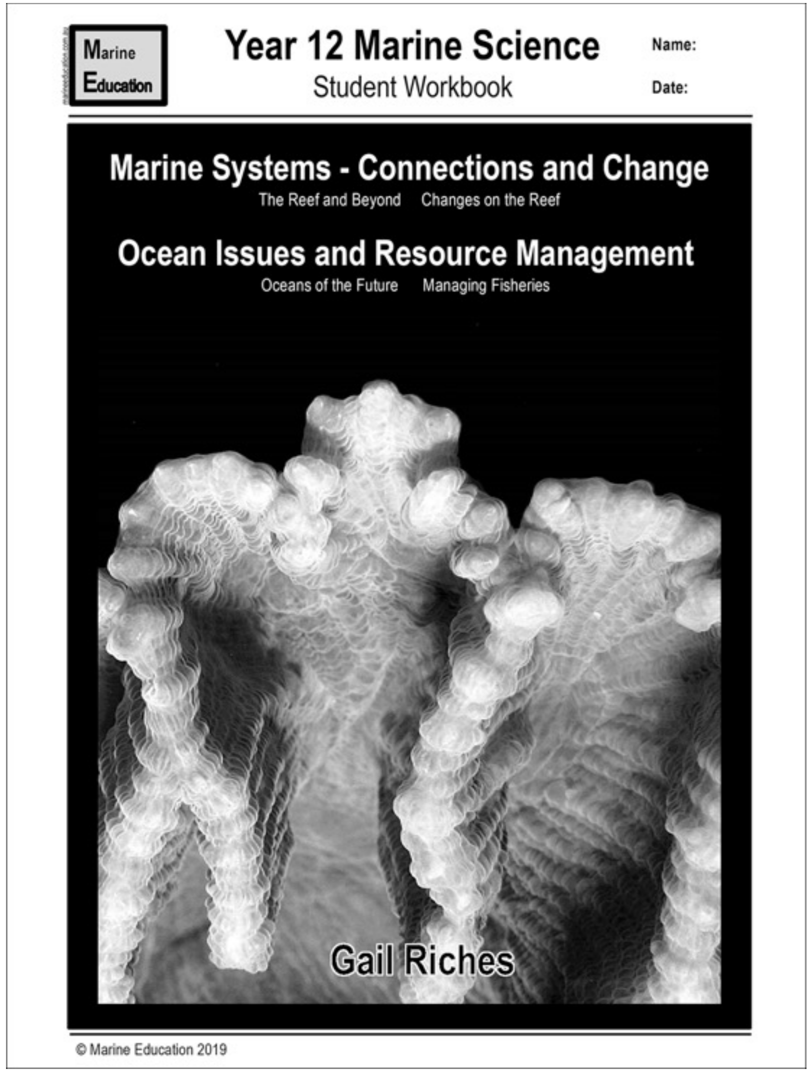
Worksheet –

Bumpy or flat

by

Gail Riches

www.marineeducation.com.au



T088 Connectivity in reef ecosystems

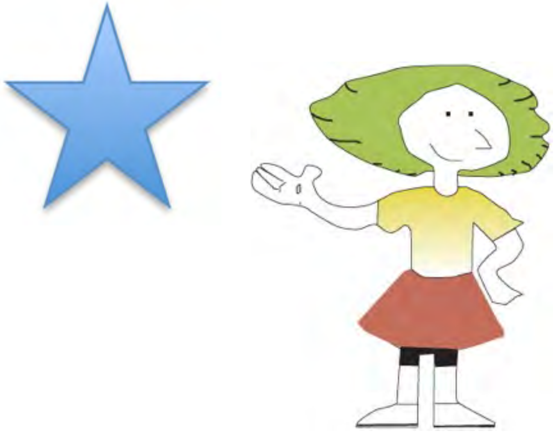
Adam Richmond

Syllabus statement

At the end of this topic you should be able to ...

Explain

connectivity between ecosystems and the role this plays in species replenishment



Explain

- make an idea or situation plain or clear by describing it in more detail or revealing relevant facts; give an account;
- provide additional information

Objectives

1. Define connectivity

2. What is meant by “species replenishment”

3. Describe in detail how connectivity between ecosystems is necessary for species replenishment.

Definitions

Connectivity is defined as the extent to which populations are linked by the exchange of eggs, larval recruits, juveniles or adults as well as ecological linkages associated with adjacent and distant habitats over time.

Species replenishment refers to the reproduction and recruitment of organisms to replace those that have died as the result of disturbances (eg, bleaching, cyclones, fishing) or natural processes.

This term is mostly used in fisheries and ecosystem management.

"Coral reefs are inherently patchy and fragmented habitats, and many reef organisms exist as spatially distinct local populations connected by an unknown degree and distance."
(Sale *et al*, 2010, p 35)

Reference:

P.F. Sale, H. Van Lavieren, M.C. Ablan Lagman, J. Atema, M. Butler, C. Fauvelot, J.D. Hogan, G.P. Jones, K.C. Lindeman, C.B. Paris, R. Steneck and H.L. Stewart. 2010. Preserving Reef Connectivity: A Handbook for Marine Protected Area Managers. Connectivity Working Group, Coral Reef Targeted Research & Capacity Building for Management Program, UNU-INWEH.

Patches of coral reef are scattered across the deep blue ocean waters of Slashers Reef

The movement of organisms between habitats is ‘populational’ connectivity.

This can occur within the same habitat type, eg reef- reef, or between different habitat types, eg. Mangrove- coral reef.

View of mangrove forests and fringing reef in Bolger Bay, on Magnetic Island in Townsville.

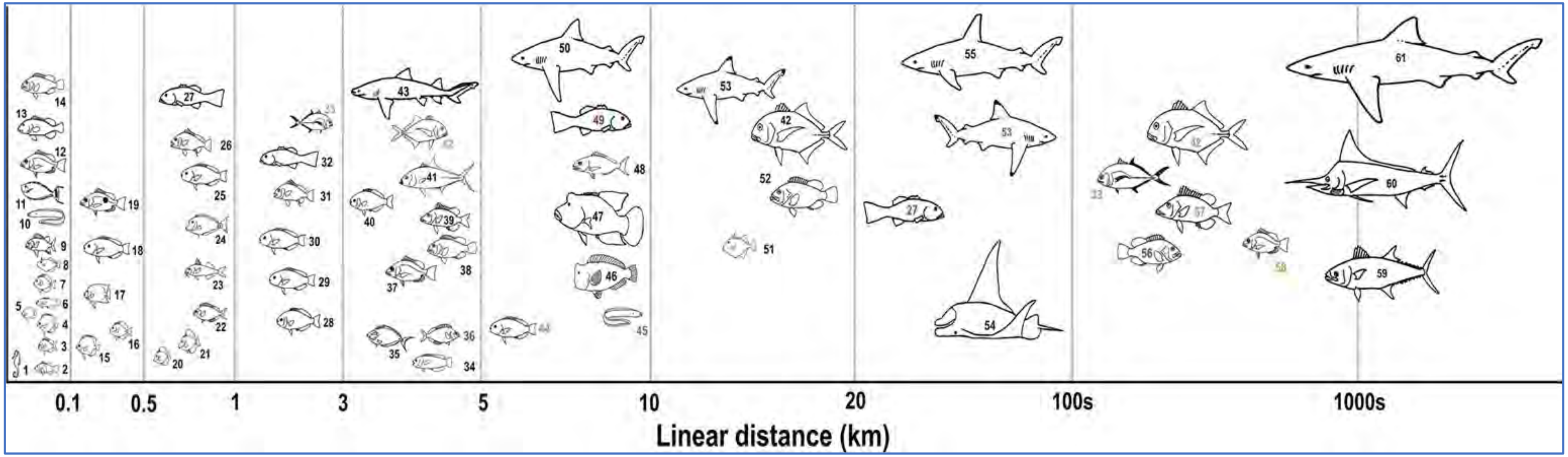
‘Genetic’ connectivity is the amount of geneflow between populations over several generations.

Habitat fragmentation can lead to genetic isolation, genetic drift, mutation and the evolution of new species.

Dascyllus trimaculatus, the three-spot damselfish is part of a 7 part species complex thought to have been created by geographical isolation

Reference: P.F. Sale, H. Van Lavieren, M.C. Ablan Lagman, J. Atema, M. Butler, C. Fauvelot, J.D. Hogan, G.P. Jones, K.C. Lindeman, C.B. Paris, R. Steneck and H.L. Stewart. 2010. Preserving Reef Connectivity: A Handbook for Marine Protected Area Managers. Connectivity Working Group, Coral Reef Targeted Research & Capacity Building for Management Program, UNU-INWEH. Available: https://www.coralcoe.org.au/wp-content/uploads/2017/08/crtr_connectivityhandbook_web_english.pdf

‘Ecological’ connectivity is the movement of individuals between populations, that can influence the population demographics and dynamics. [1]



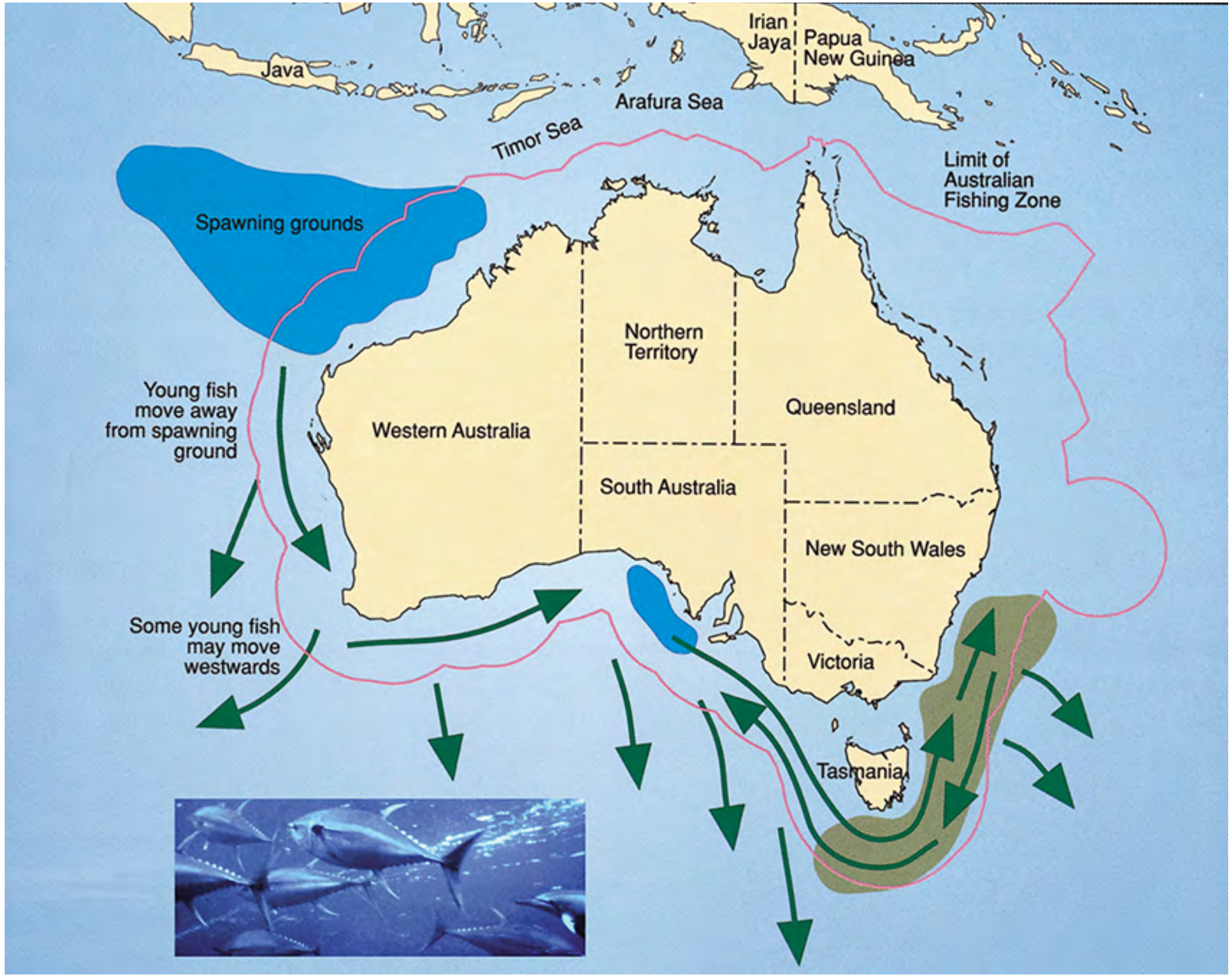
Green, A., Maypa, A., Almany, G., Rhodes, K., Weeks, R., & Abesamis, R. et al. (2014). Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. In doi: 10.1111/brv.12155 CC 4.0 BY NC ND

Reference: 1 P.F. Sale, H. Van Lavieren, M.C. Ablan Lagman, J. Atema, M. Butler, C. Fauvelot, J.D. Hogan, G.P. Jones, K.C. Lindeman, C.B. Paris, R. Steneck and H.L. Stewart. 2010. Preserving Reef Connectivity: A Handbook for Marine Protected Area Managers. Connectivity Working Group, Coral Reef Targeted Research & Capacity Building for Management Program, UNU-INWEH,
Available:
https://www.coralcoe.org.au/wp-content/uploads/2017/08/crtr_connectivityhandbook_web_english.pdf

The scale of migration of adult fish varies.

Distances can range from metres between habitat "patches" to hundreds of km across ecosystems. [2]

Reference 2 and Image: Green, A., Maypa, A., Almany, G., Rhodes, K., Weeks, R., & Abesamis, R. et al. (2014). Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. *Biological Reviews*, *90*(4), 1215-1247. doi: 10.1111/brv.12155, open access article, available: https://onlinelibrary.wiley.com/doi/full/10.1111/brv.12155



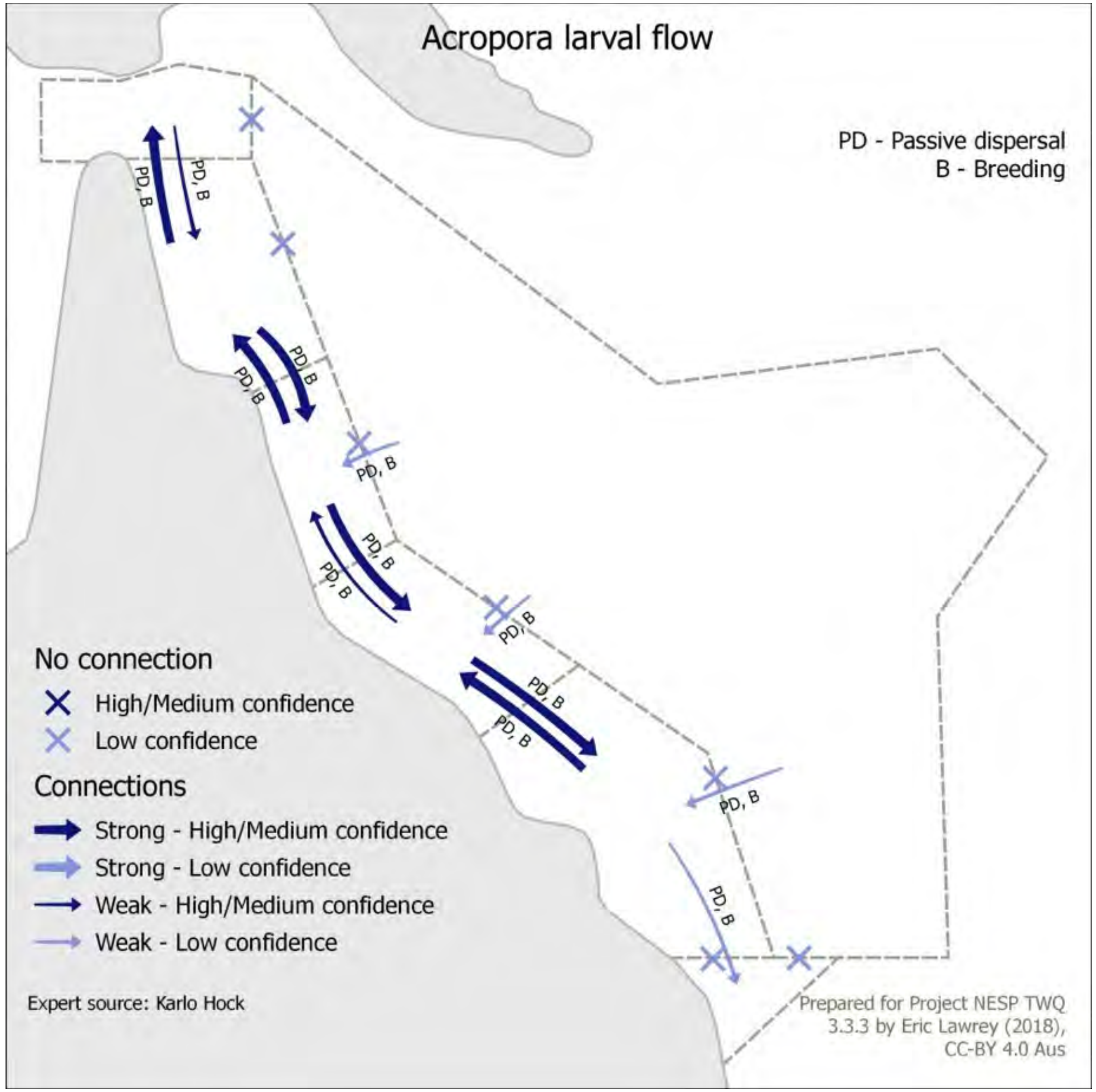
Tuna migrations

Corals and other sedentary or sessile invertebrates rely on planktonic or pelagic larvae to disperse.

This map shows the connectivity of larval flow in the Great Barrier Reef.

The arrows indicate the strength of the connection.

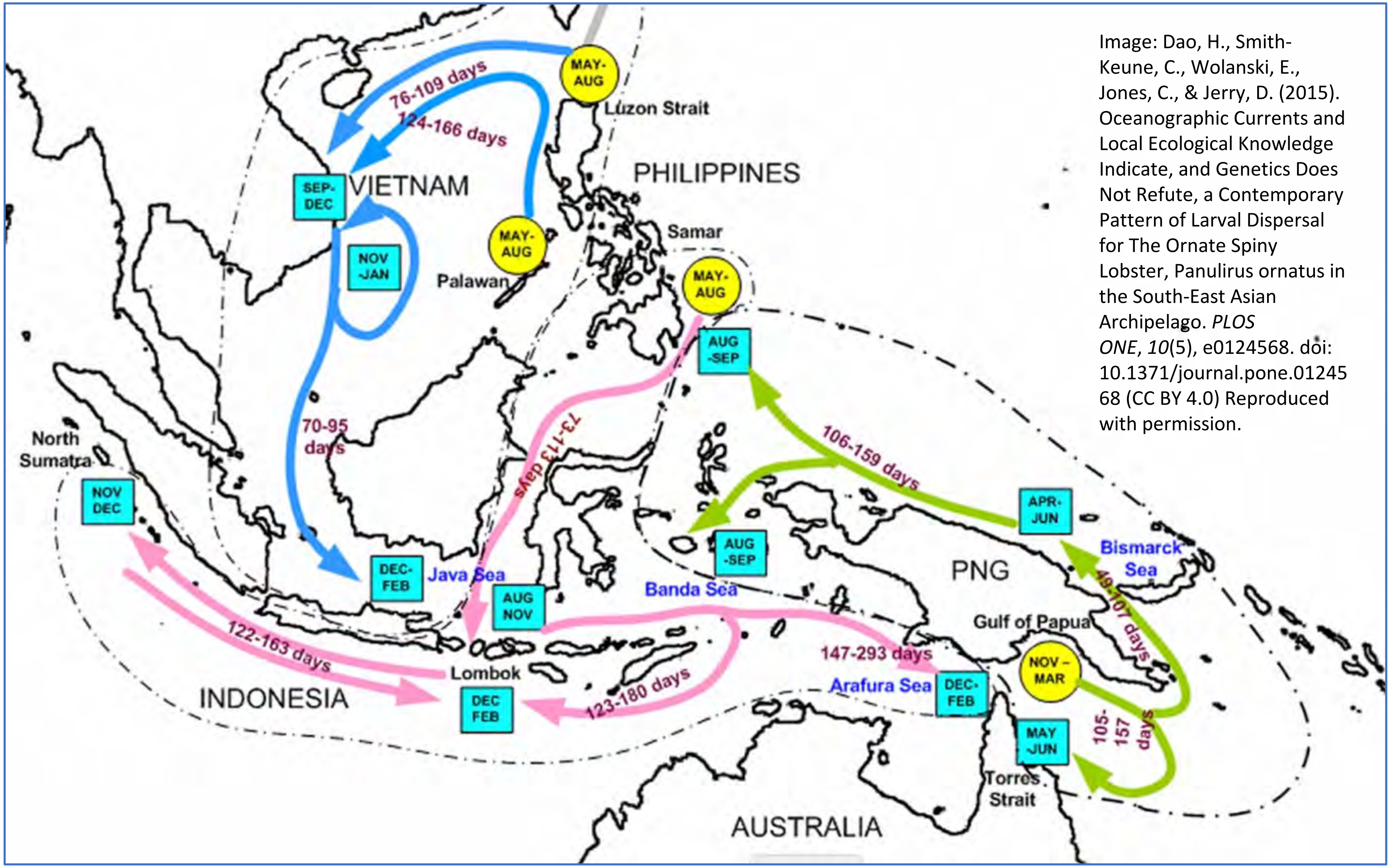
Image:
Eric Lawrey (AIMS) CC BY 3.0, available https://eatlas.org.au/ne-aus-seascape-connectivity/acropora-larval-flow



Populations of organisms living on coral reefs have long been thought to be dependent on the recruitment of larvae from distance sources "upstream". [1]

Reference: 1 Abesamis, Rene A. (2011) Replenishment and connectivity of reef fish populations in the central Philippines. PhD thesis, James Cook University.
Available:
http://eprints.jcu.edu.au/27947/

This map shows the spawning grounds (yellow circles) and larval dispersal pathways of spiny crayfish, *Panulirus ornatus,* larvae in the South-East Asian archipelago.



The behavior of pre-settlement larvae, as well as ocean currents, influences the connectivity of reef organisms. Larvae respond to magnetic, light, sound, olfactory and chemical cues to orientate towards reefs.

Image: Andrew J. Green / Reef life Survey. [CC BY 3.0 (https://creativecommons.org/licenses/by/3.0)]

Late stage larvae of coral reef fish are remarkable swimmers, capable of speeds up to 65cm/second and distance equivalent to 140km [1.]

1. Bellwood, D., & Fisher, R. (2001). Relative swimming speeds in reef fish larvae. *Marine Ecology Progress Series*, *211*, 299-303. doi: 10.3354/meps211299

Amphiprion melanopus larvae can swim at 49 body lengths/second.

This TED talk discusses the dispersal and habitat selection of the yellow tang surgeonfish.

https://youtu.be/iCM6CawGBRk

The secret lives of baby fish - Amy McDermott

YouTube video by TED Ed, available https://youtu.be/iCM6CawGBRk

Mangrove and seagrass habitats serve as a nursery ground for a range of species that live on coral reefs. The "nursery hypothesis" suggests that inshore juvenile ecosystems replenish adult populations in adjacent ecosystems.

This is an example of ontogenetic migration.

The blue highway poster (right, and next slide) illustrates connectivity between a range of habitats within the Great Barrier Reef and its catchment.

Download a copy here:
http://www.russellkelley.info/print/the-blue-highway/

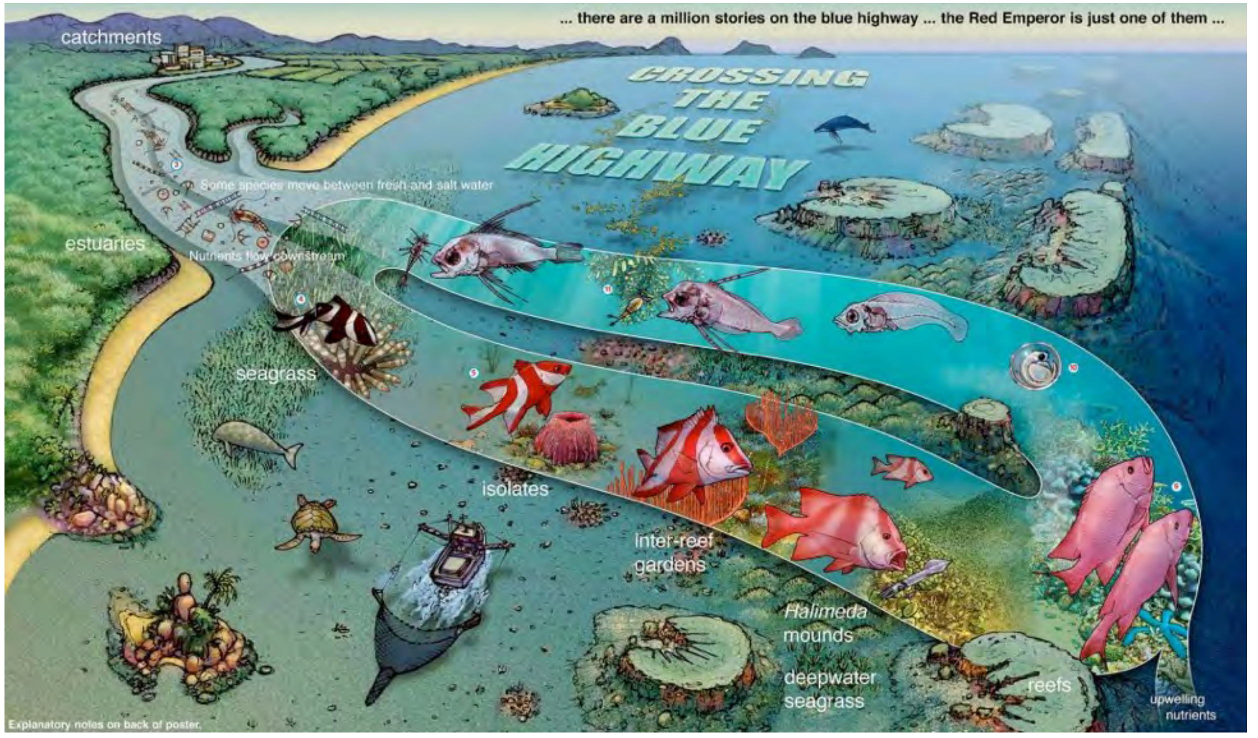


Image copyright Russell Kelley, Reproduced with permission.

Reference: Nagelkerken, I., Huebert, K., Serafy, J., Grol, M., Dorenbosch, M., & Bradshaw, C. (2017). Highly localized replenishment of coral reef fish populations near nursery habitats. *Marine Ecology Progress Series*, *568*, 137-150. doi: 10.3354/meps12062. Attribution 4.0 International (CC BY 4.0)

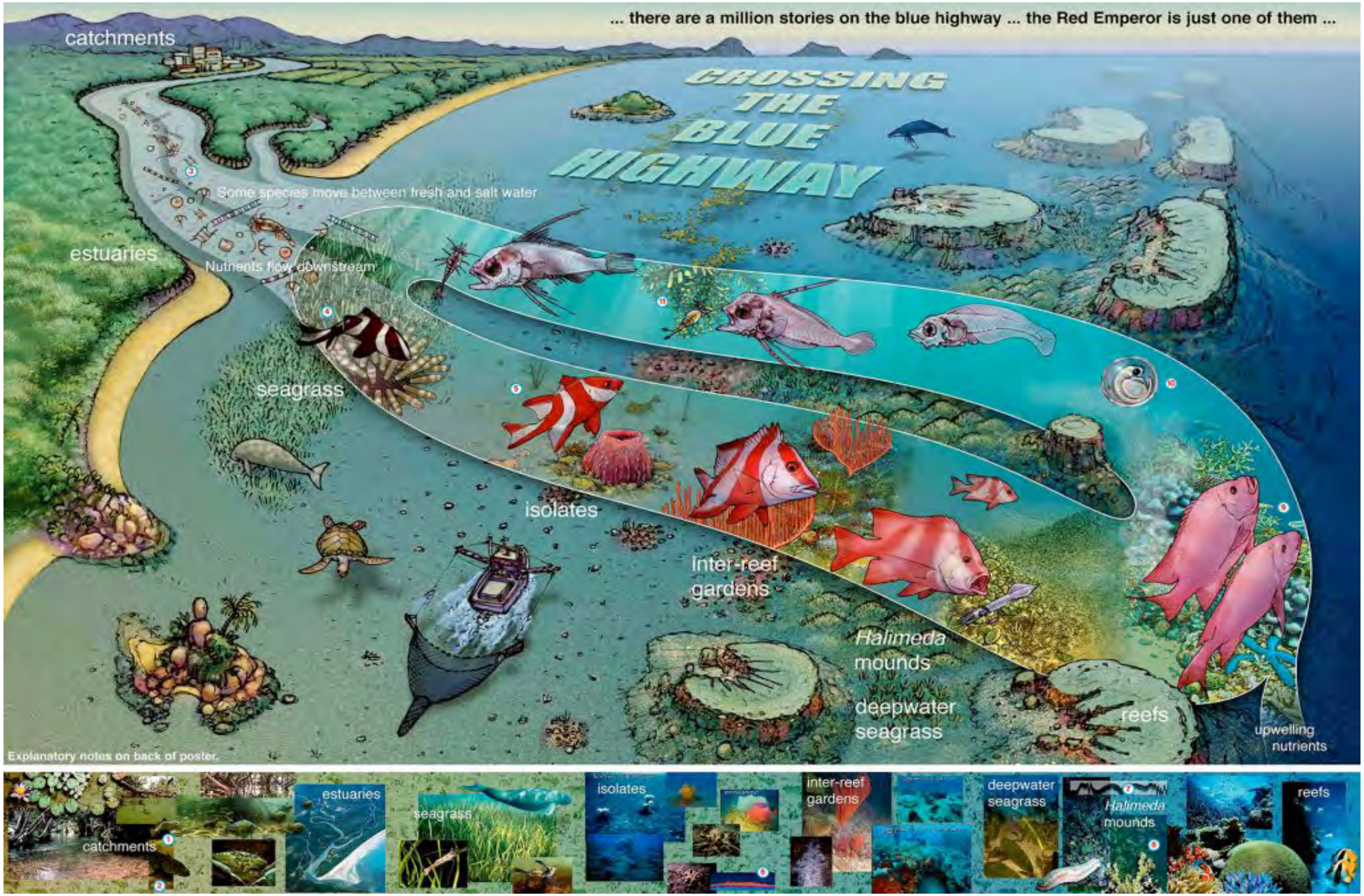


Image: with permission, Russell Kelley

Download a copy.

Download link

http://www.russellkelley.info/print/the-blue-highway/

Download a copy.

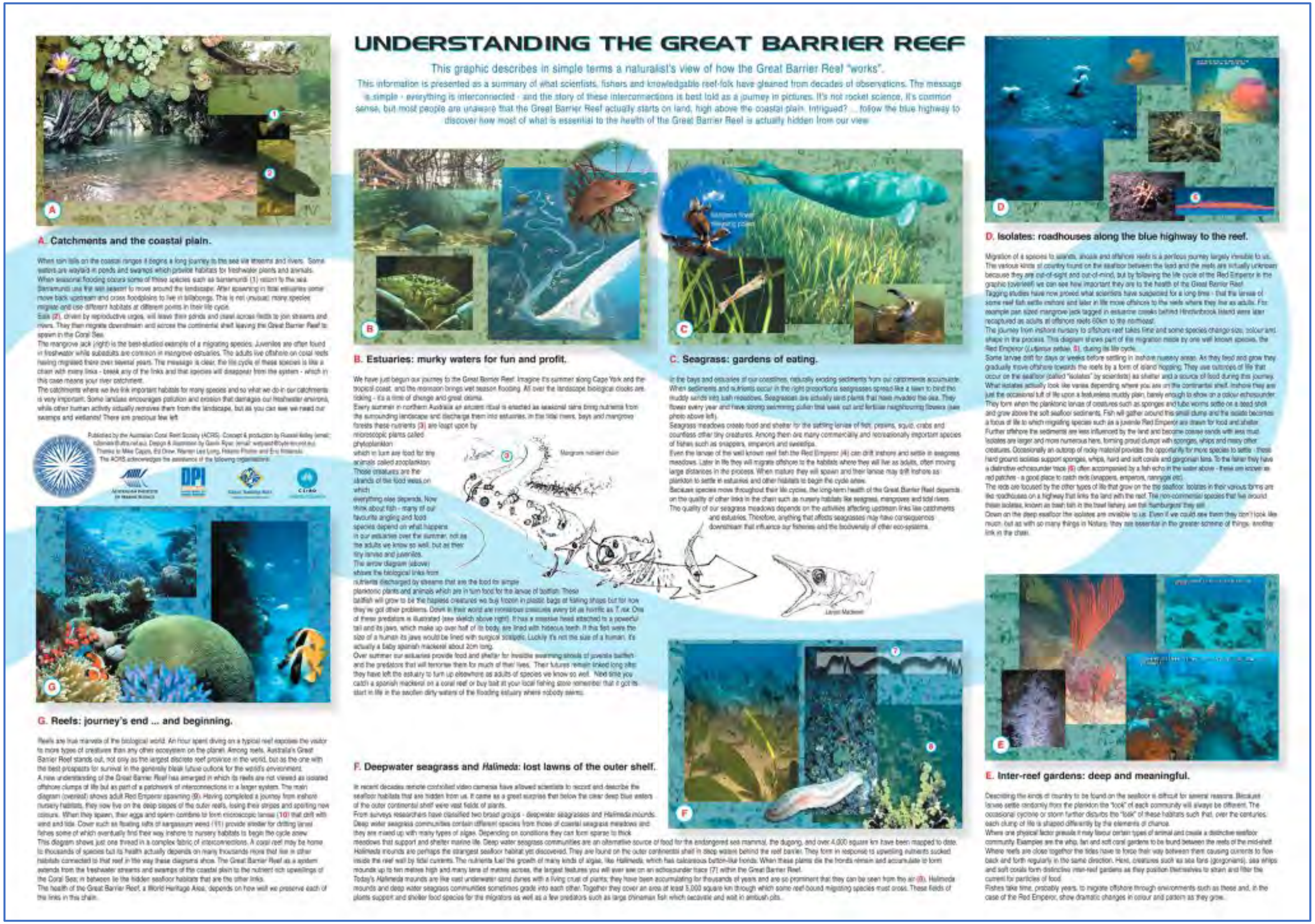
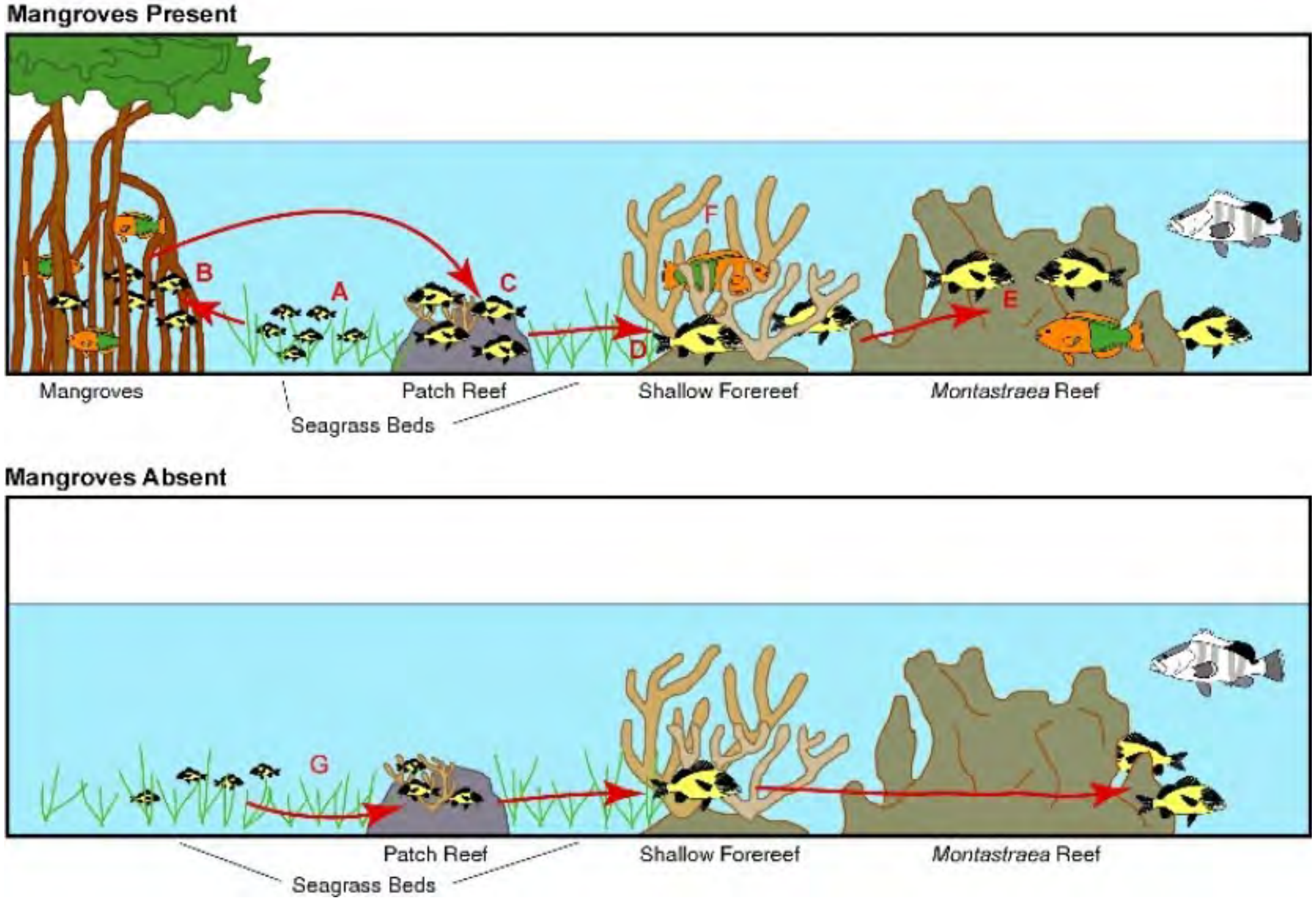


Image: with permission, Russell Kelley

Download link
http://www.russellkelley.info/print/the-blue-highway/

Having a connected mangrove habitat influences the community structure of fish on nearby coral reefs.

For example, the abundance of commercially important species on a protected reef close to mangroves is significantly greater, (some say double), than that on a protected reef isolated from mangroves.



Mangroves act as nursery grounds for coral reefs.

Nagelkerken *et al* investigated the dependency of commercially significant fish species, and found that some species have high dependence on the connectivity between their nursery and adult habitat, others have low or no dependence.

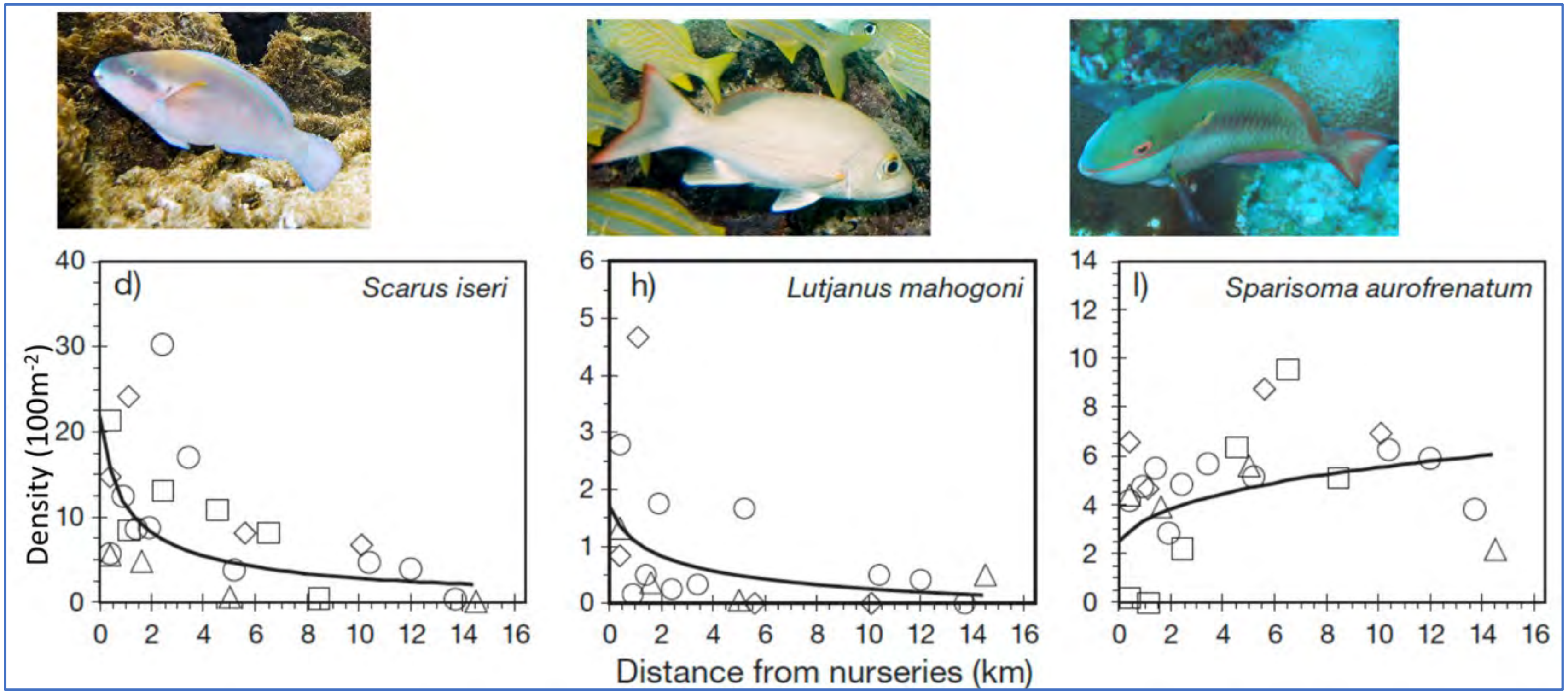


Figure- cropped section of Figure 2, in Nagelkerken, I., Huebert, K., Serafy, J., Grol, M., Dorenbosch, M., & Bradshaw, C. (2017). Highly localized replenishment of coral reef fish populations near nursery habitats. *Marine Ecology Progress Series*, *568*, 137-150. doi: 10.3354/meps12062

Fish Images: Scarus and Lutjanus: Paul Asman and Jill Lenoble; Sparisoma:
NOAA CCMA Biogeography Team [CC BY 2.0 (https://creativecommons.org/licenses/by/2.0)],

Some coral reefs are so isolated that their connectivity to other reefs is low.   These reefs are self-replenishing; their recruits come from the same reef complex.

For example, a study[1] found the three- striped Butterfly fish *Chaetodon tricinctus* at Norfolk island were found to be 95% self-replenished.

95%

Image: Ian V. Shaw / Reef Life Survey. License: CC By Attribution

Reference:

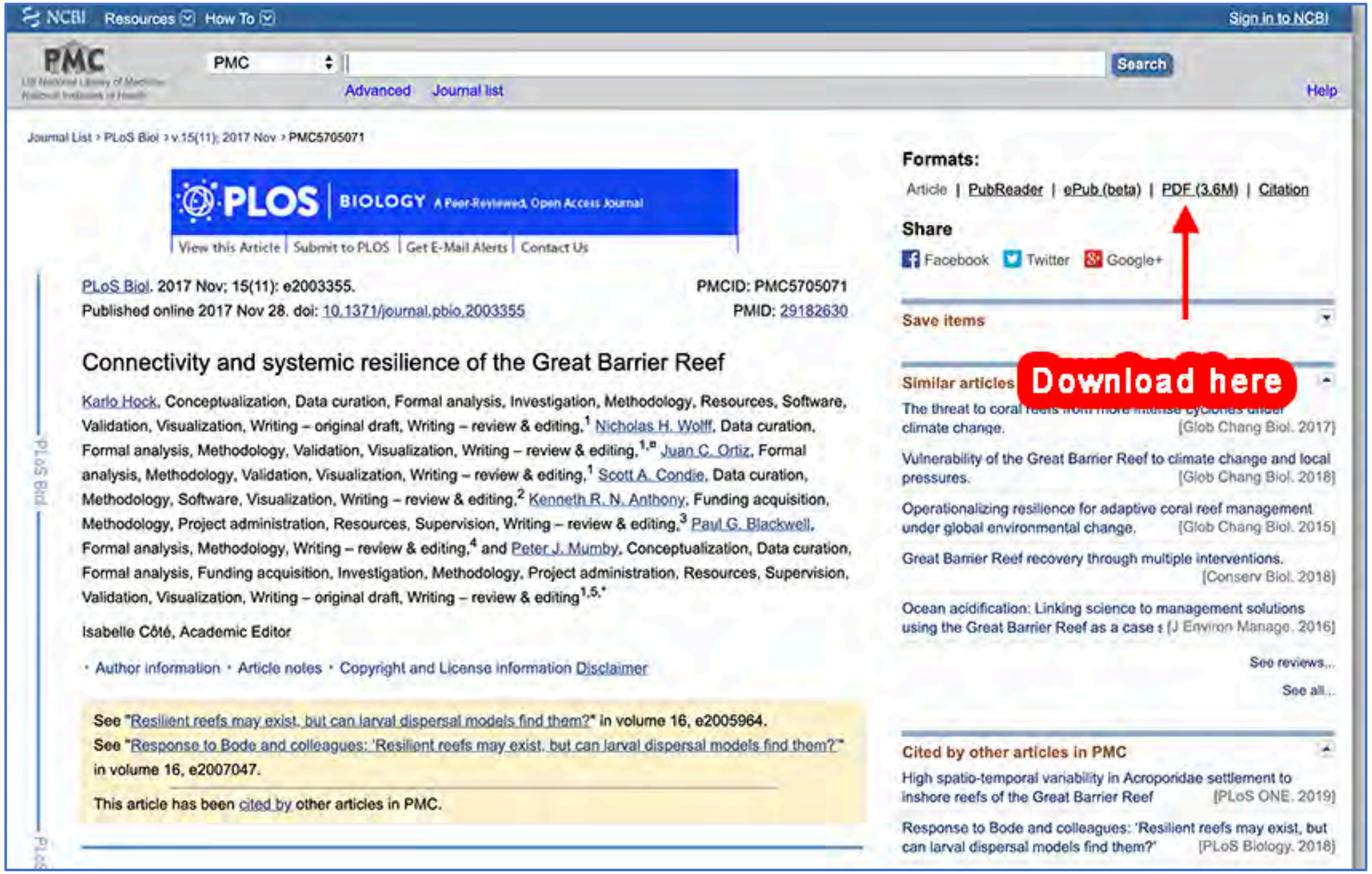
1. van der Meer, M., Horne, J., Gardner, M., Hobbs, J., Pratchett, M., & van Herwerden, L. (2013). Limited contemporary gene flow and high self-replenishment drives peripheral isolation in an endemic coral reef fish. *Ecology And Evolution*, *3*(6), 1653-1666. doi: 10.1002/ece3.584

Source and sink reefs

Hock *et al* identified 100 “robust source reefs” on the Great Barrier Reef that have ideal characteristics, including high levels of connectivity, that have the potential to replenish 47% of the reef in one dispersal event.

Download the Open Access article here:

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5705071/



PLOS – the Public Library of Science, is referenced significantly in this power point series

In this study

Ocean currents were found to disperse larvae and create connectivity links among reefs, leading to an emergence of source reefs with high potential to support coral replenishment.

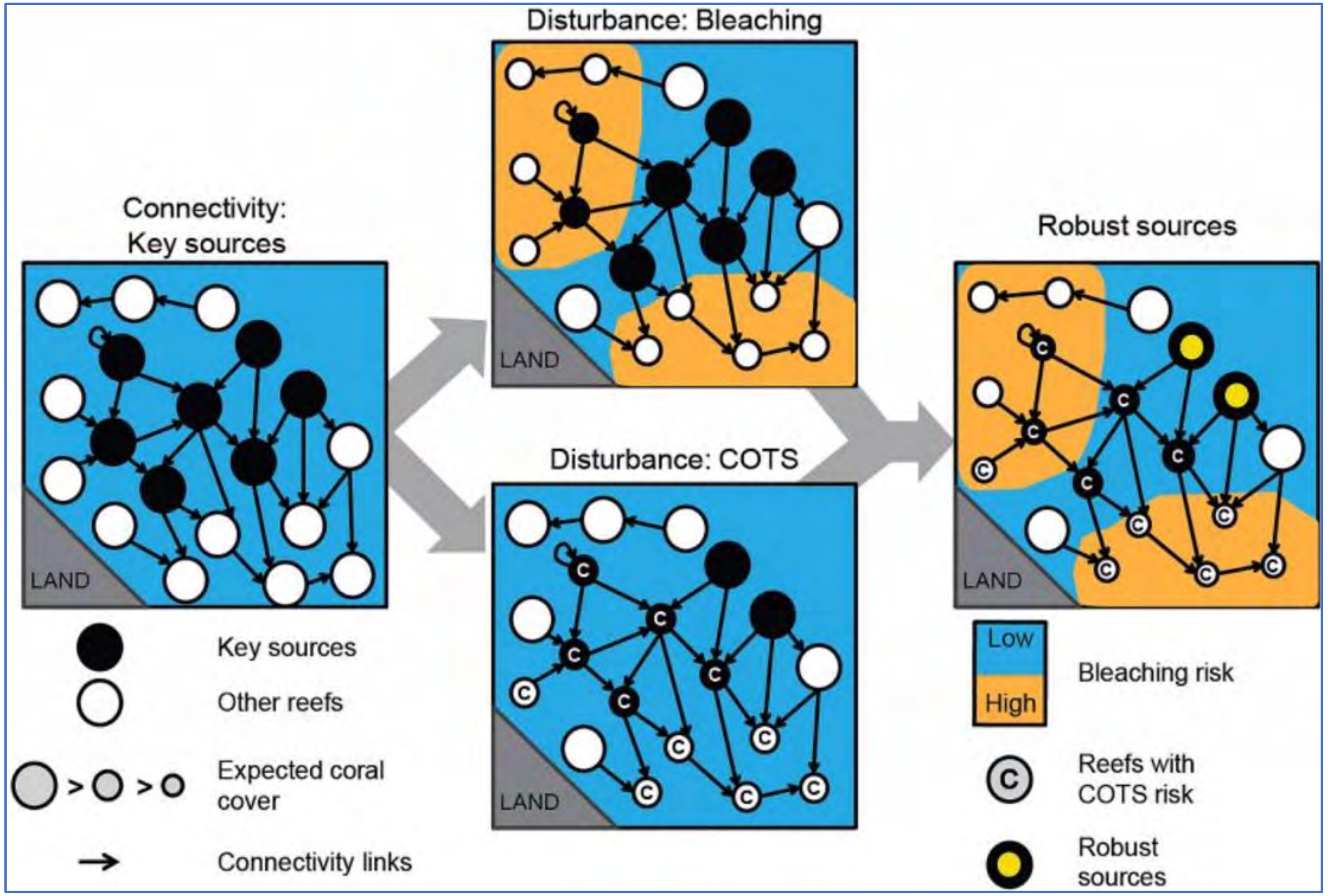
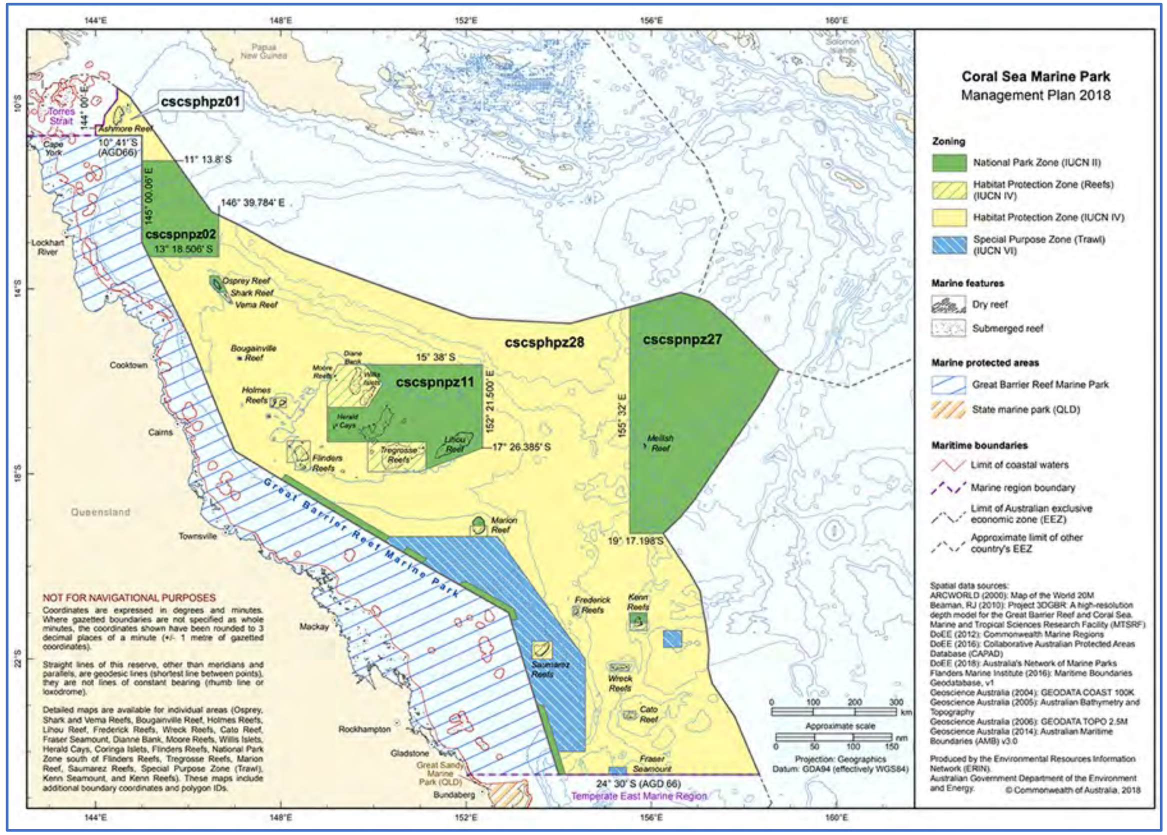


Image and Reference: Hock, K., Wolff, N., Ortiz, J., Condie, S., Anthony, K., Blackwell, P., & Mumby, P. (2017). Connectivity and systemic resilience of the Great Barrier Reef. *PLOS Biology*, *15*(11), e2003355. doi: 10.1371/journal.pbio.2003355 Creative Commons 4.0 (CC BY)

An understanding of connectivity of marine habitats was deemed necessary for effective special management of fisheries and the establishment of marine reserves.

For example, a Marine Protected Area that protects only the habitat of the adult part of an organism's lifecycle will be ineffective if their nursery habitat is degraded.

Note:
Material supplied by the Great Barrier Reef Marine Park Authority in the next two slides, accredited as © Commonwealth of Australia (GBRMPA) 2019 has been supplied for this project only, for the purposes of research and study only.

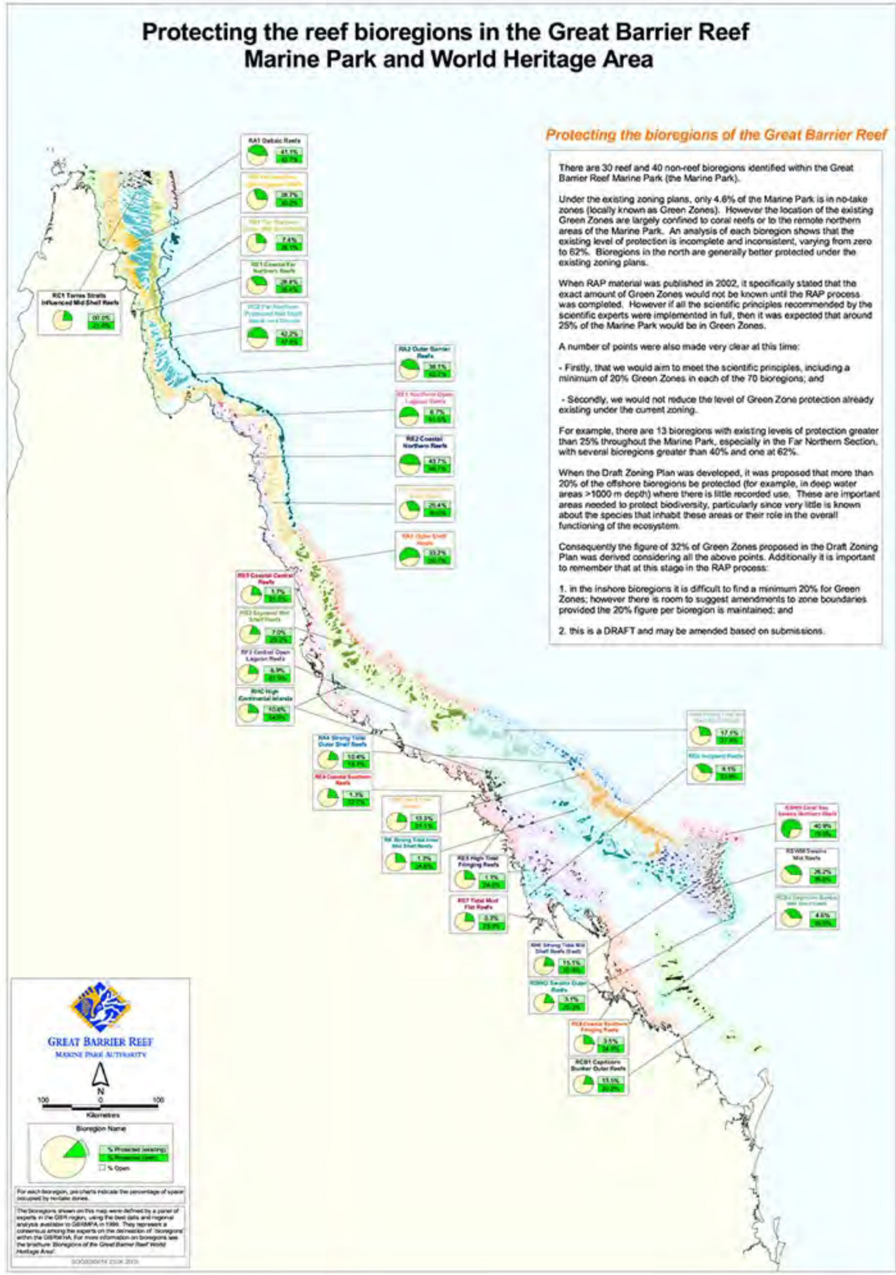


Copyright Commonwealth of Australia.
https://parksaustralia.gov.au/marine/pub/maps/fnl-mp-2018-cs-map-zones.pdf

GBRMPA undertook a bioregion analysis of the reef and produced non reef and reef bioregional maps.

For a better view, you can download these at:

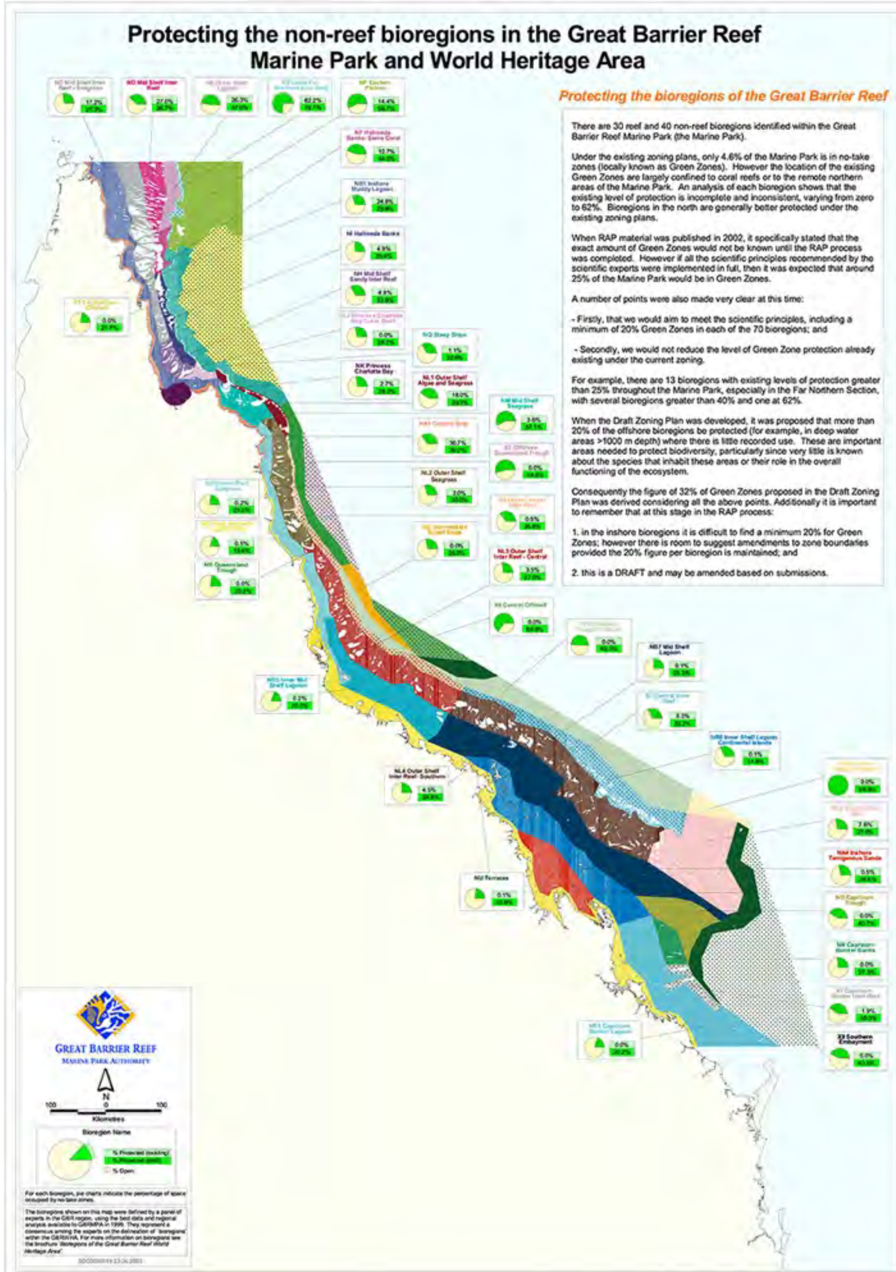
http://www.gbrmpa.gov.au/our-work/our-programs-and-projects/rap



In the review of reef biodiversity, 1999 and 2004, the **R**epresentative **A**reas **P**rogram of the Great Barrier Reef Marine Park (RAP), recognised 70 bioregions based on existing biological and geomorphological knowledge.

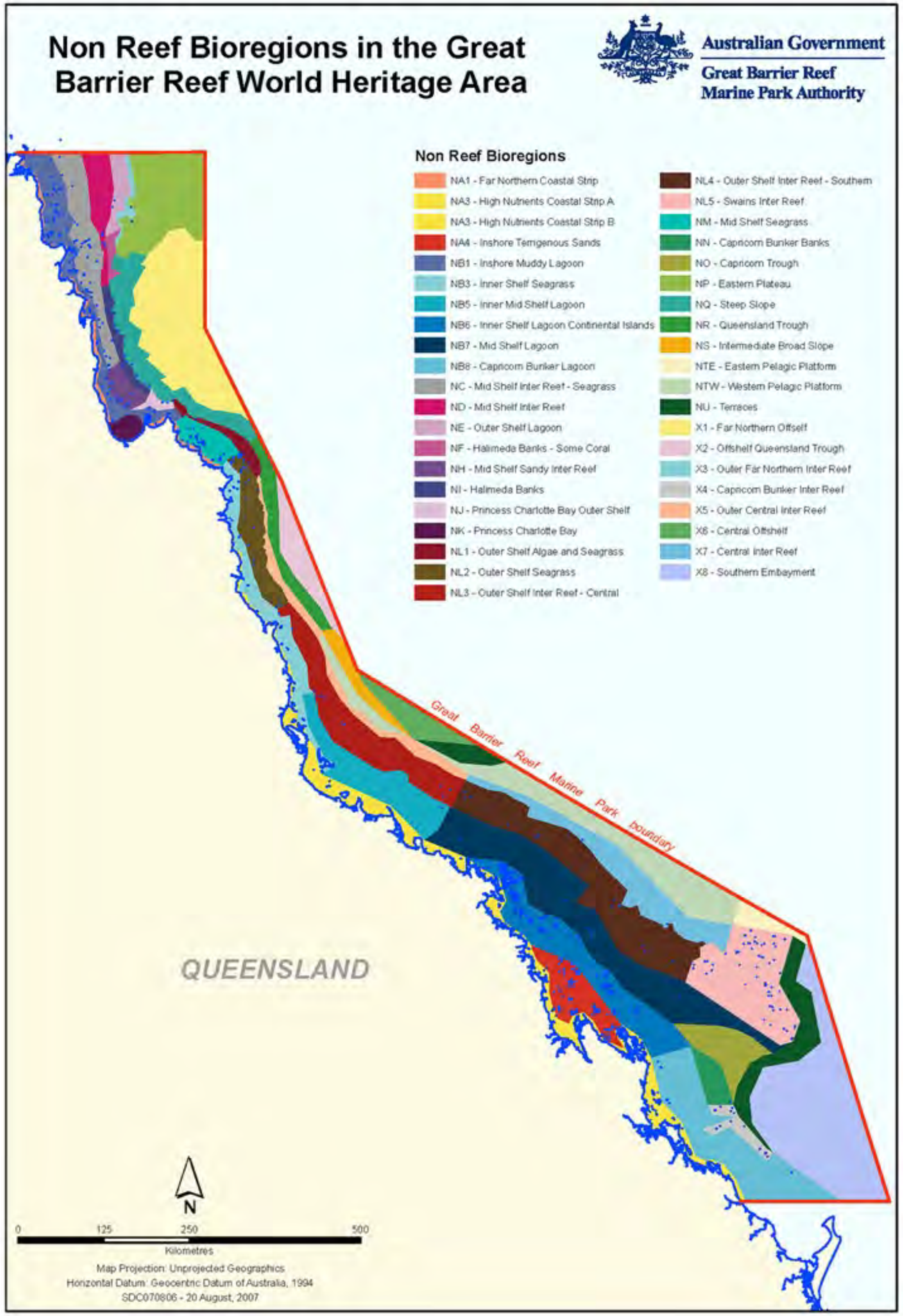
Download the program and answer the following question:

What was the aim of each bioregion?



For a better view, you can download these at:

http://www.gbrmpa.gov.au/our-work/our-programs-and-projects/rap



Activity

Cut and paste into your notes and enlarge to suit.

Question

Define connectivity

What is meant by "species replenishment"

Describe in detail how connectivity between ecosystems is necessary for species replenishment

Answers

Connectivity is defined as the extent to which populations are linked by the exchange of eggs, larval recruits, juveniles or adults as well as ecological linkages associated with adjacent and distant habitats over time.

Species replenishment: This term is mostly used in fisheries and ecosystem management. It refers to the reproduction and recruitment of organisms to replace those that have died as the result of disturbances (eg, bleaching, cyclones, fishing) or natural processes.

Describe in detail how connectivity between ecosystems is necessary for species replenishment: see slides 6-17

Further activities

See

https://coralwatch.org/index.php/education-2/curriculum-materials/marine-science/

by

CORALWATCH

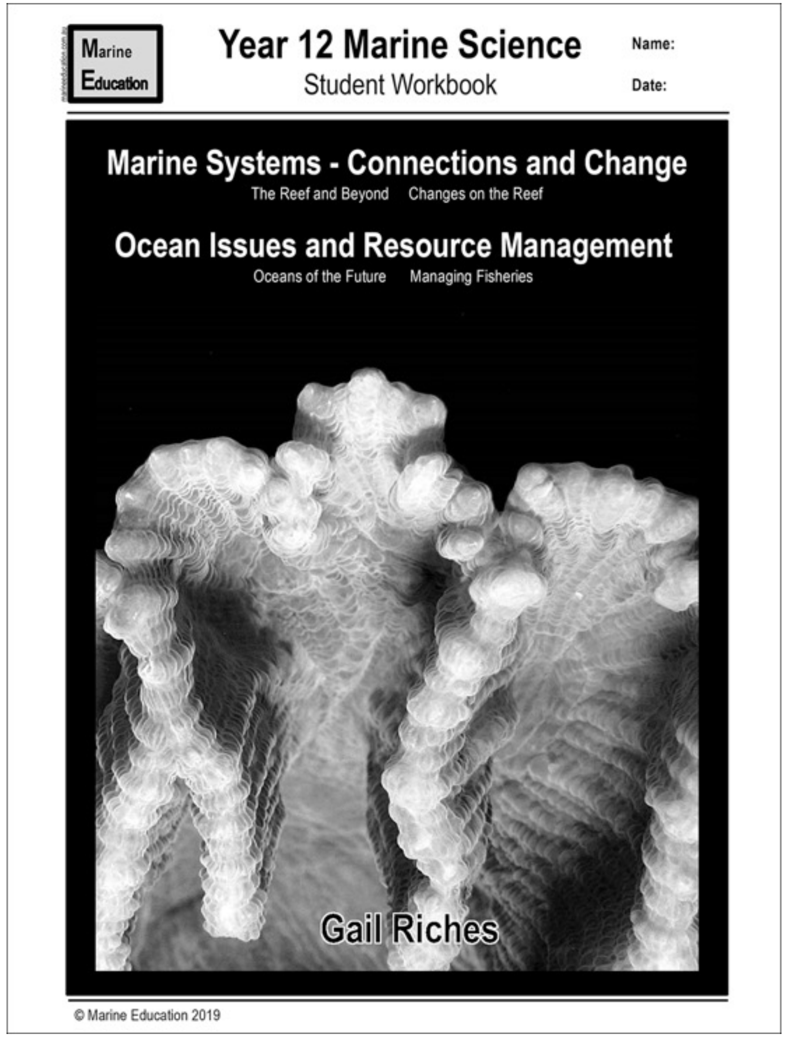
Further activity

Worksheet –

S.O.S.

by
Gail Riches

www.marineeducation.com.au



T089 Fish life cycles

Adam Richmond

Syllabus statement

At the end of this topic you should be able to ...

Understand

that fish life cycles are integrated within a variety of habitats including reef and estuarine systems.

Understand

- perceive what is meant by something; grasp;
- be familiar with (e.g. an idea);
- construct meaning from messages, including oral, written and graphic communication

Objective

Draw a diagram to show how fish lifecycles incorporate different habitats.

Watch this YouTube video for a refresher of larval dispersal and a great introduction to this topic

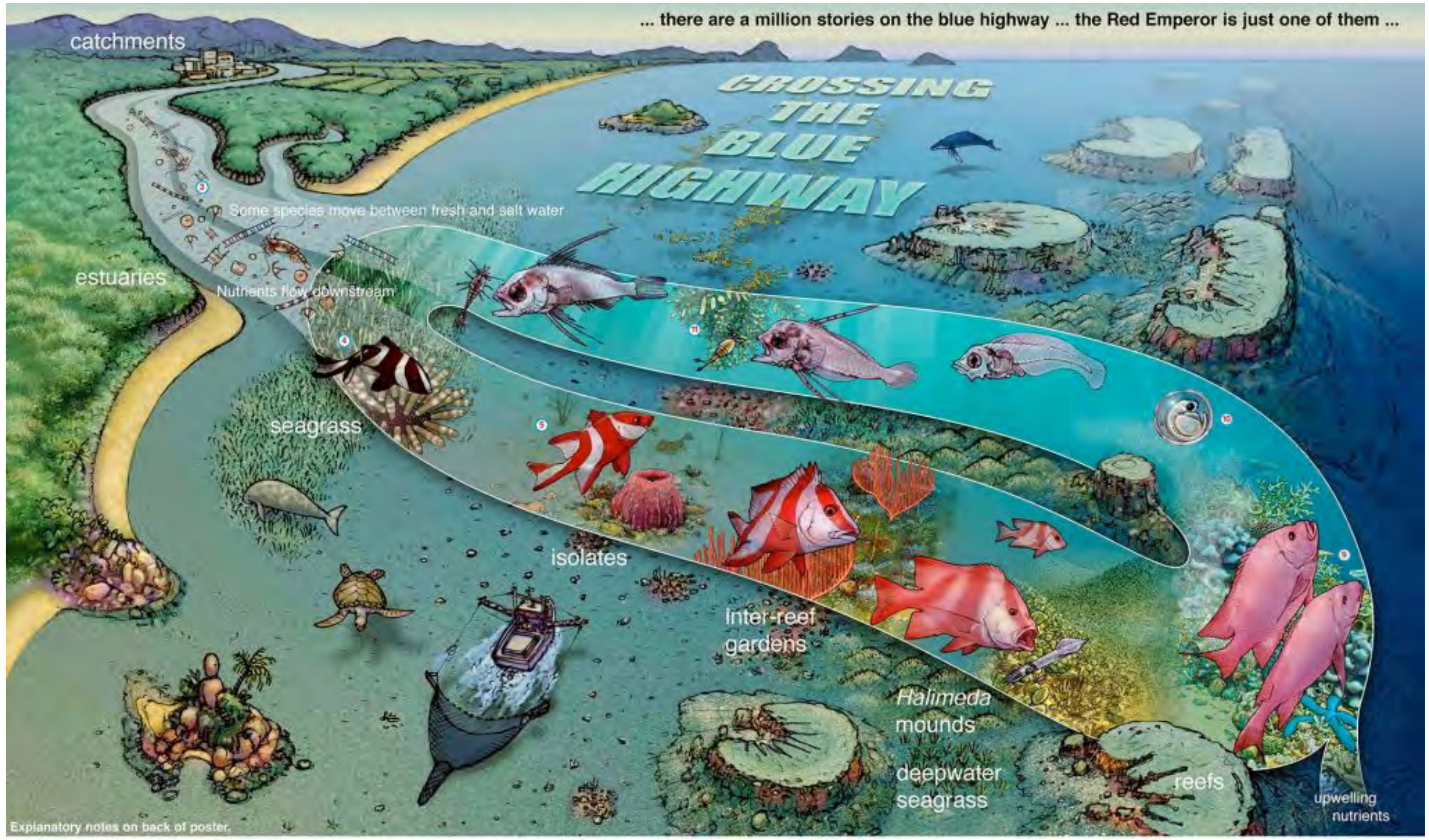
https://youtu.be/FyTO-UHi-0c

Animation of a Parrotfish lifecycle

YouTube video by XL CATLIN SEAVIEW SURVEY, University of Queensland CC-BY-SA, available: https://youtu.be/FyTO-UHi-0c

Connectivity review

"In the GBR, the connection between mangrove habitats, seagrass beds, and coral reefs is critical for the completion of some fishes' life cycles, such as the red emperor" [1]



The lifecycle of the red emperor, *Lutjanus sebae*

1. Goudkamp, K. and Chin, A. June 2006, 'Mangroves and Saltmarshes' in Chin. A, (ed) The State of the Great Barrier Reef On-line, Great Barrier Reef Marine Park Authority, Townsville. Viewed on 26/4/2019, http://www.gbrmpa.gov.au/publications/sort/mangroves_saltmarshes

Ontogenetic migration is the migration to different habitats at different life cycle stages.

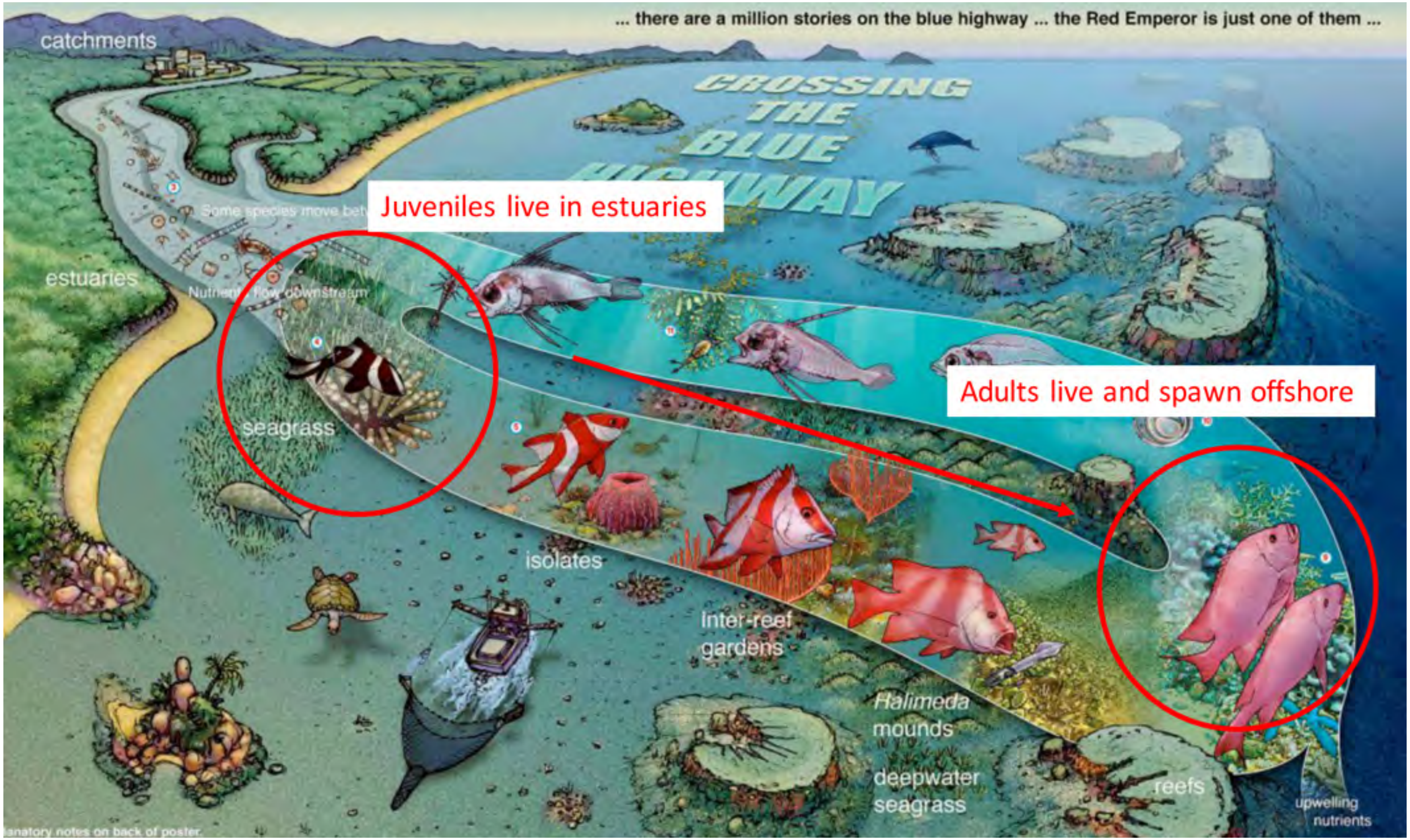
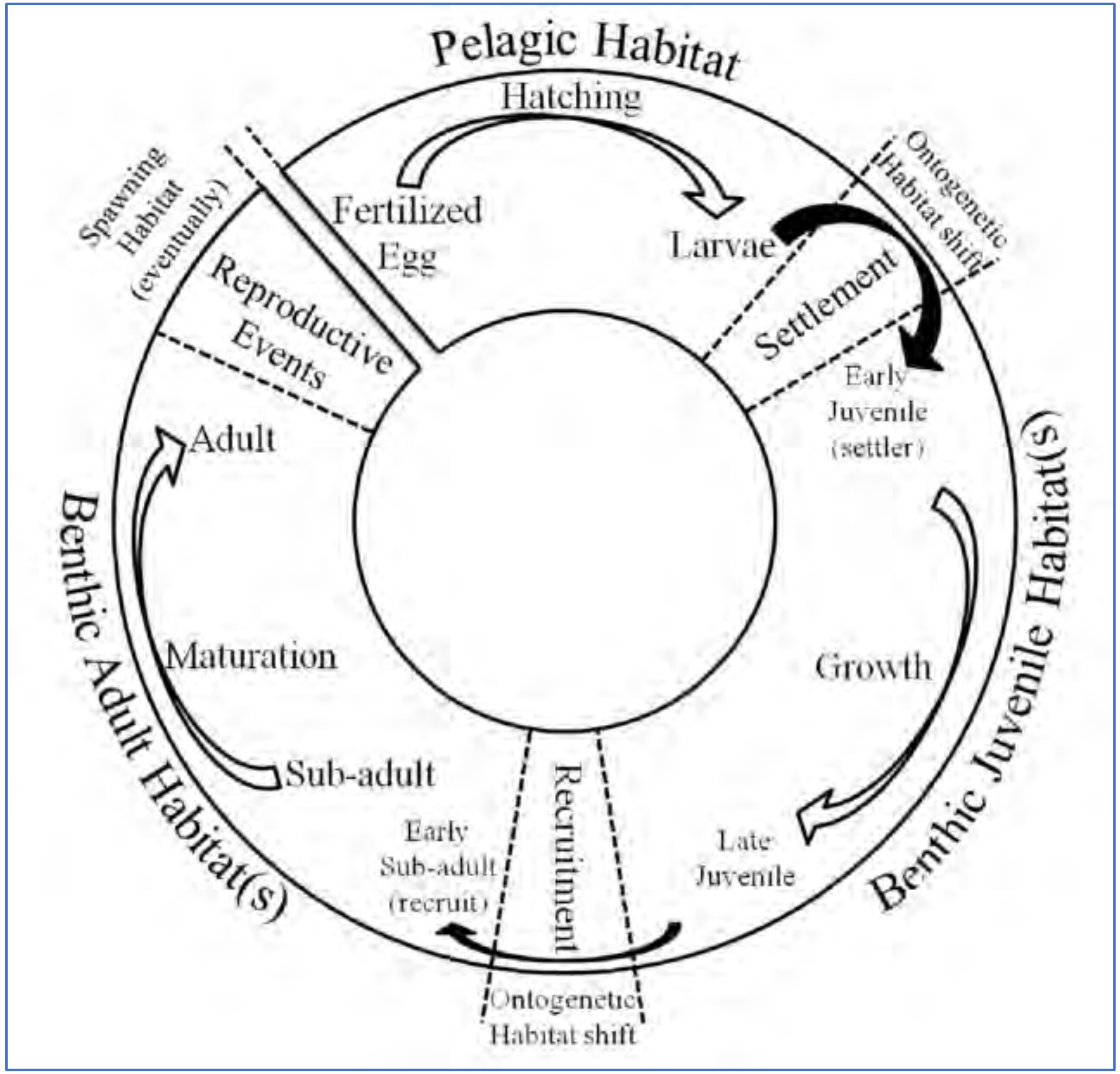


Image copyright Russell Kelley, Reproduced with permission

A typical coral reef fish has a two-part life cycle:

- a pelagic (or planktonic) egg and larval stage,
- followed by demersal (bottom-dwelling) juveniles and adult stages.

Most fish are broadcast spawners - like the parrotfish and red emperor in the previous slides.



Some larger species such as snappers and grouper (Lutjanidae and Serranidae) migrate to spawning sites.

Twinspot snapper (*Lutjanus bohar*) releasing a cloud of sperm and eggs

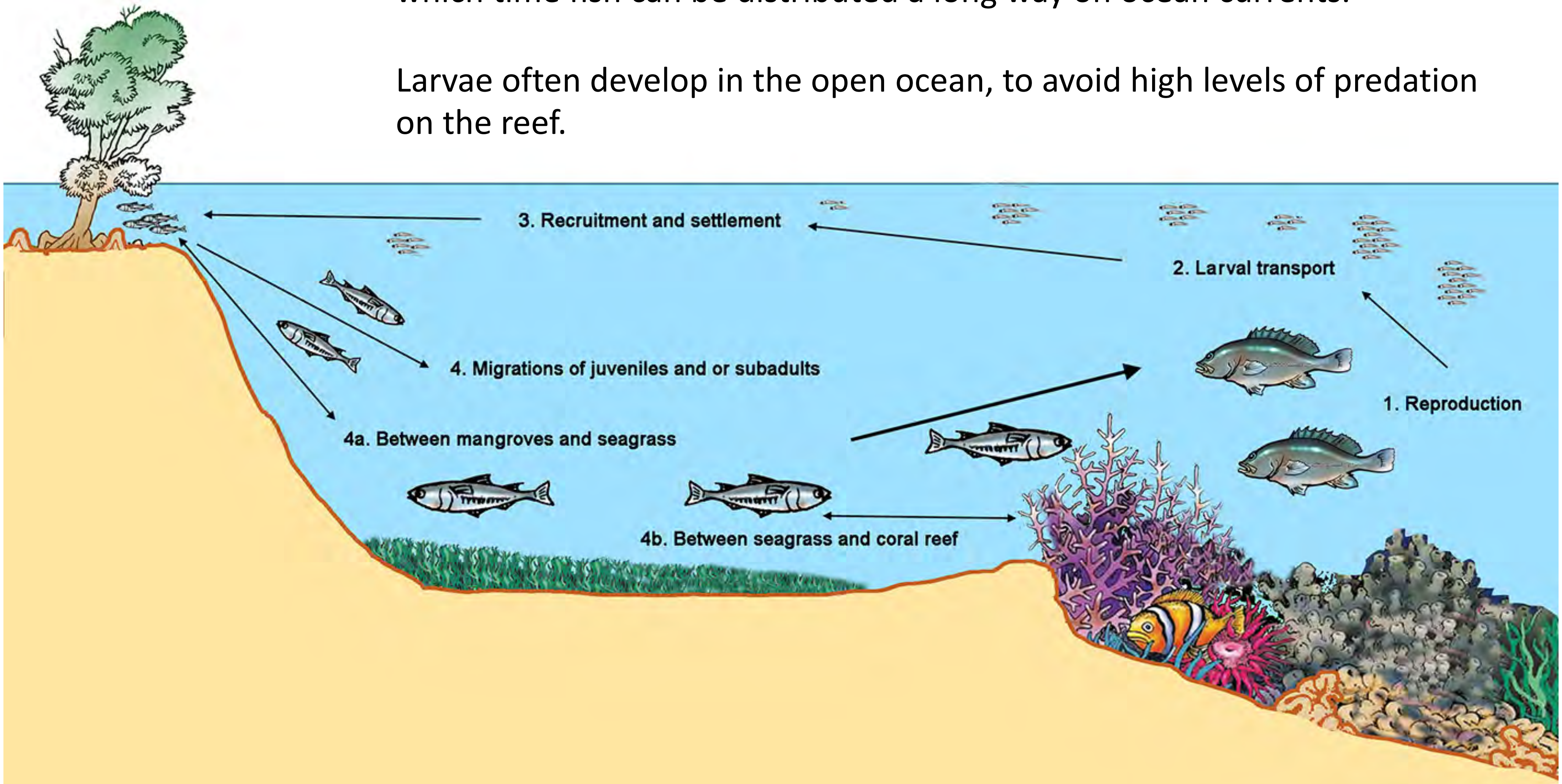
Some smaller fish, like damsel fish and clownfish, brood their eggs until they hatch. Clownfish eggs are defended by the male until they hatch. The juveniles then spend 2 -3 weeks in the water column.

Watch the video
https://youtu.be/xFyOv72g9oo?t=27

Clownfish laying eggs
YouTube video by Scuba Diving Resource, Available: https://youtu.be/xFyOv72g9oo?t=27

The larval stage of fish ranges from a few days to several months, during which time fish can be distributed a long way on ocean currents.

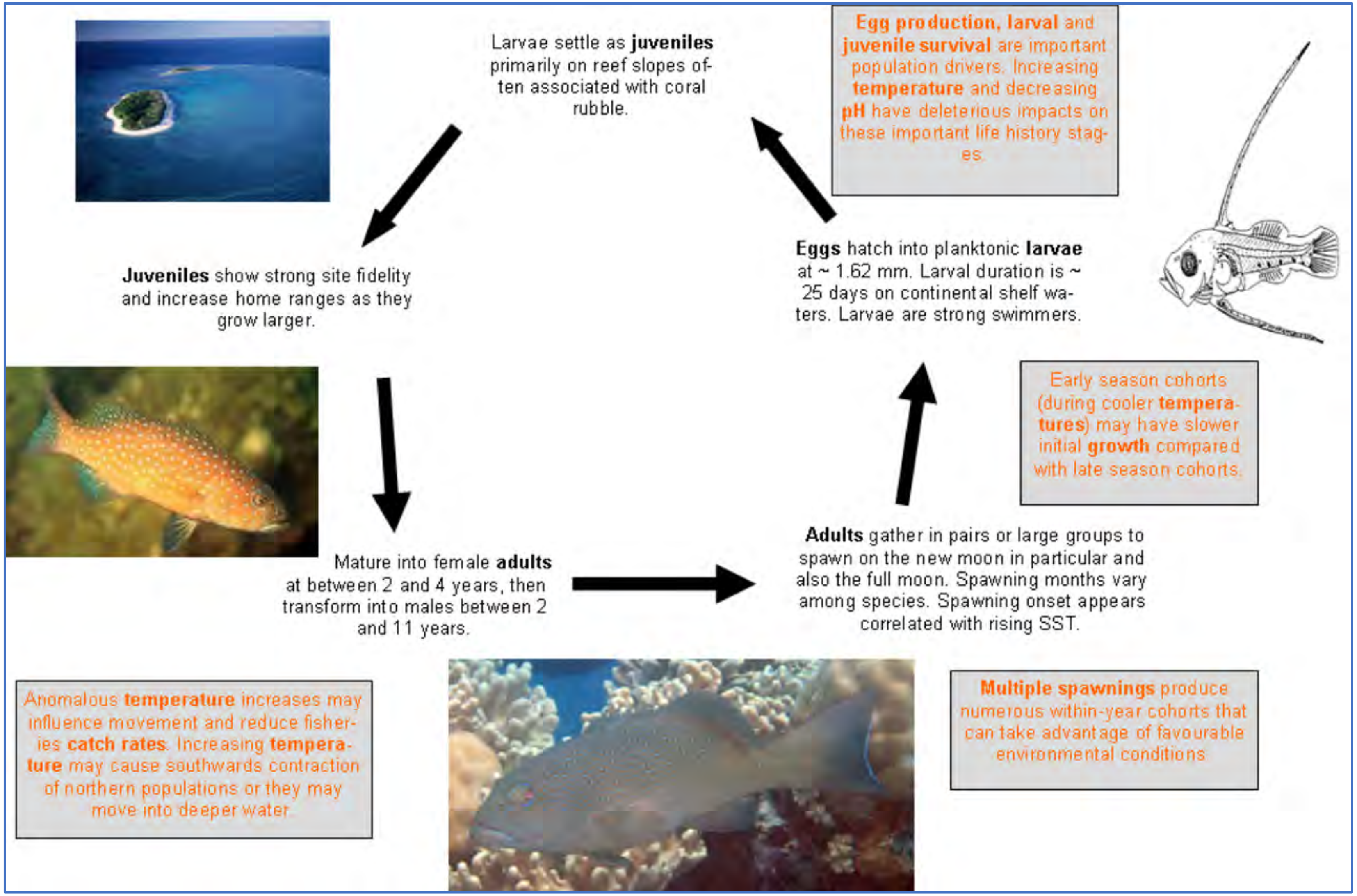
Larvae often develop in the open ocean, to avoid high levels of predation on the reef.



A stylised reef fish life cycle

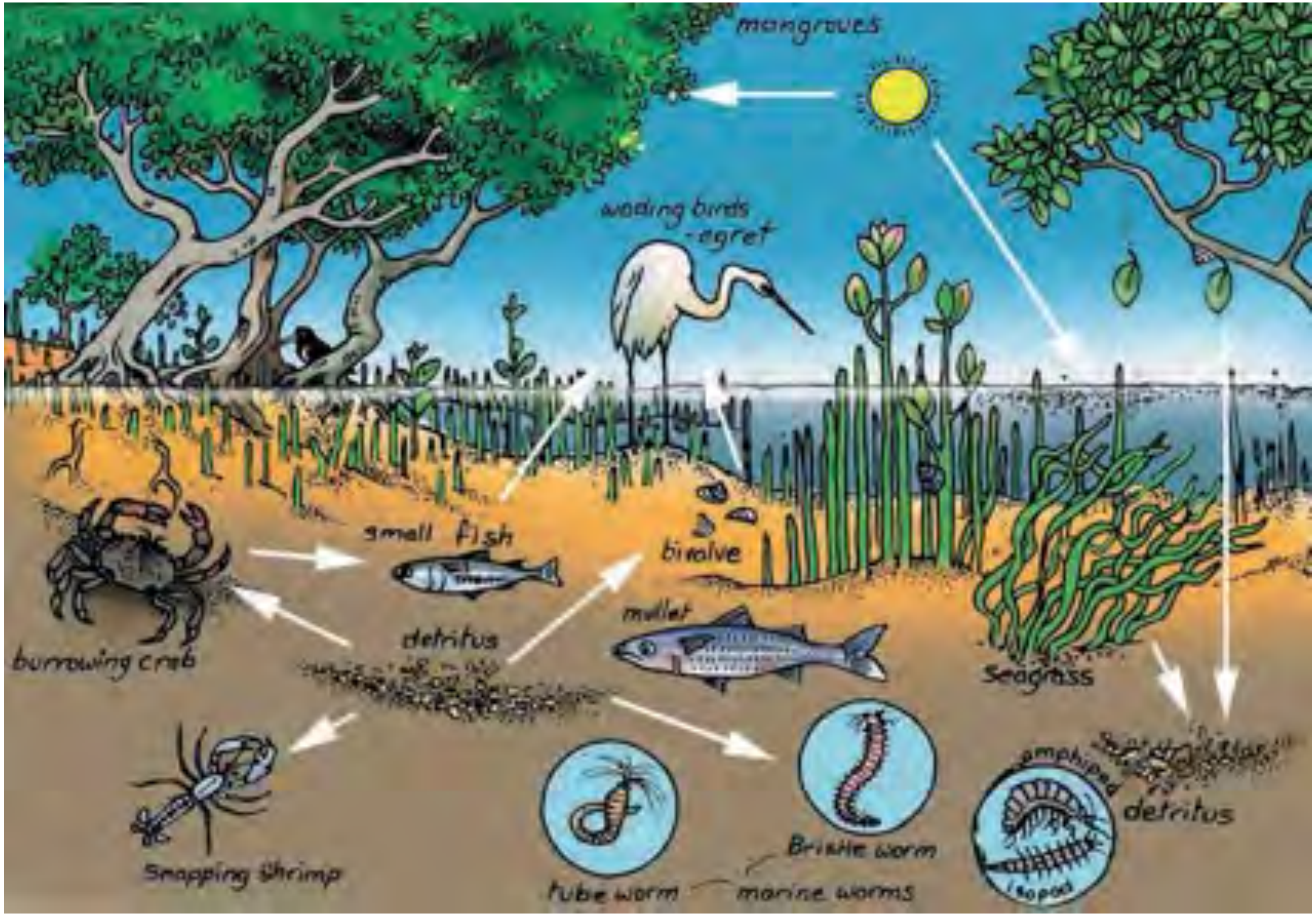
Some coral reef fish, like coral trout, settle straight into a coral reef environment.

However many coral reef fish spend the juvenile stage of their life cycle in an estuarine environment.



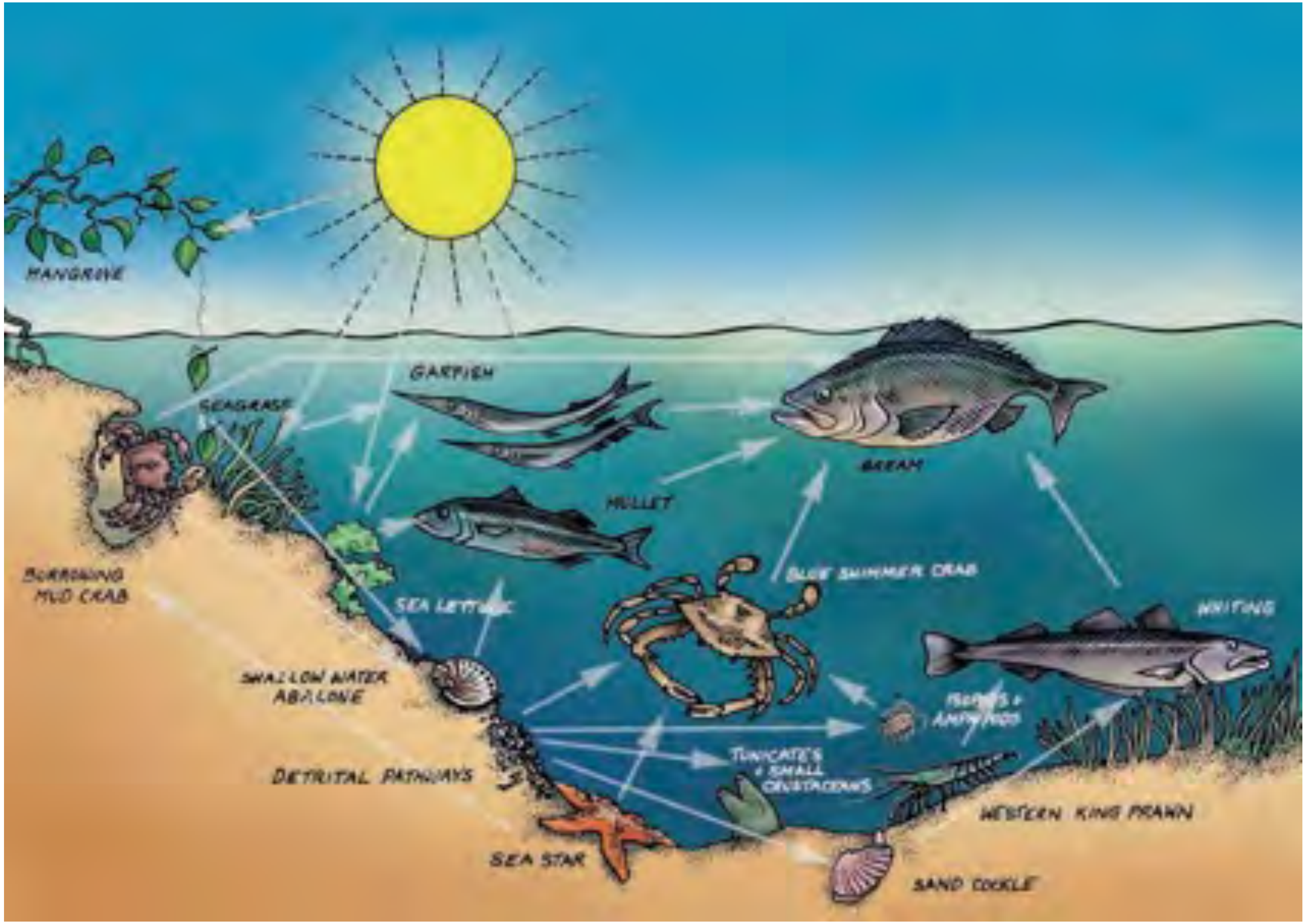
The life cycle of the Coral trout, *Plectropomus leopardus*

Seagrass beds and mangroves often serve as nursery habitats.



Concept by Nancy Tsernjavski, Illustration by Sharyn Madder and Kerry Kitzelman , copyright MESA, reproduced with permission.

Mangrove and sheltered waters ecosystems provide larval fish a sheltered environment, an abundant and diverse food supply and protection from predation.



Concept by Nancy Tsernjavski, Illustration by Sharyn Madder and Kerry Kitzelman , copyright MESA, reproduced with permission.

Mangrove prop roots create a habitat essential for many fish and invertebrates.

Juvenile lutjanids shelter among mangrove roots.
Image : with permission, Matthew Costa, Aburto Laboratory, Scripps Institution of Oceanography

Learn more about mangrove and seagrass nursery grounds here:

Saenger, P, Gartside, D & Funge-Smith, S 2013, A review of mangrove and seagrass ecosystems and their linkage to fisheries and fisheries management, report to Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific Bangkok, Thailand. ISBN: 9789251077733 Accessible: https://epubs.scu.edu.au/cgi/viewcontent.cgi?article=3251&context=esm_pubs

Large estuary cod and mangrove jack found in North Queensland estuaries were all found to be juveniles.[1.]

These "estuary" fish are really coral reef fish- the adults live offshore.

Estuary cod *Epinephelus coioides* and Mangrove jack, *Lutjanus argentimaculatus*

1. Sheaves, M. (1995). Large lutjanid and serranid fishes in tropical estuaries: Are they adults or juveniles?. *Marine Ecology Progress Series*, *129*, 31-41. doi: 10.3354/meps129031

This diagram shows the lifecycle of the mangrove jack in the Great Barrier Reef catchment.

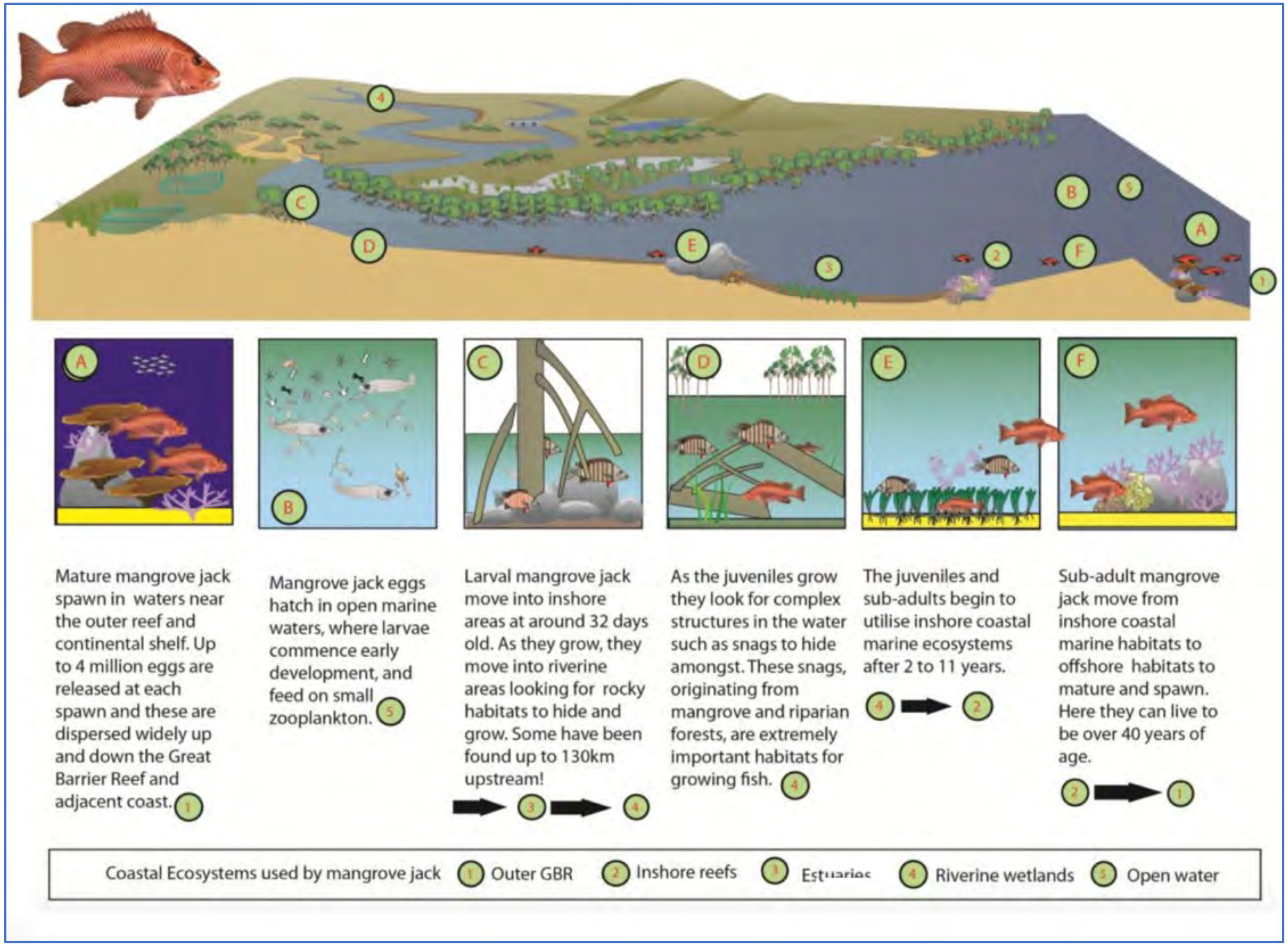
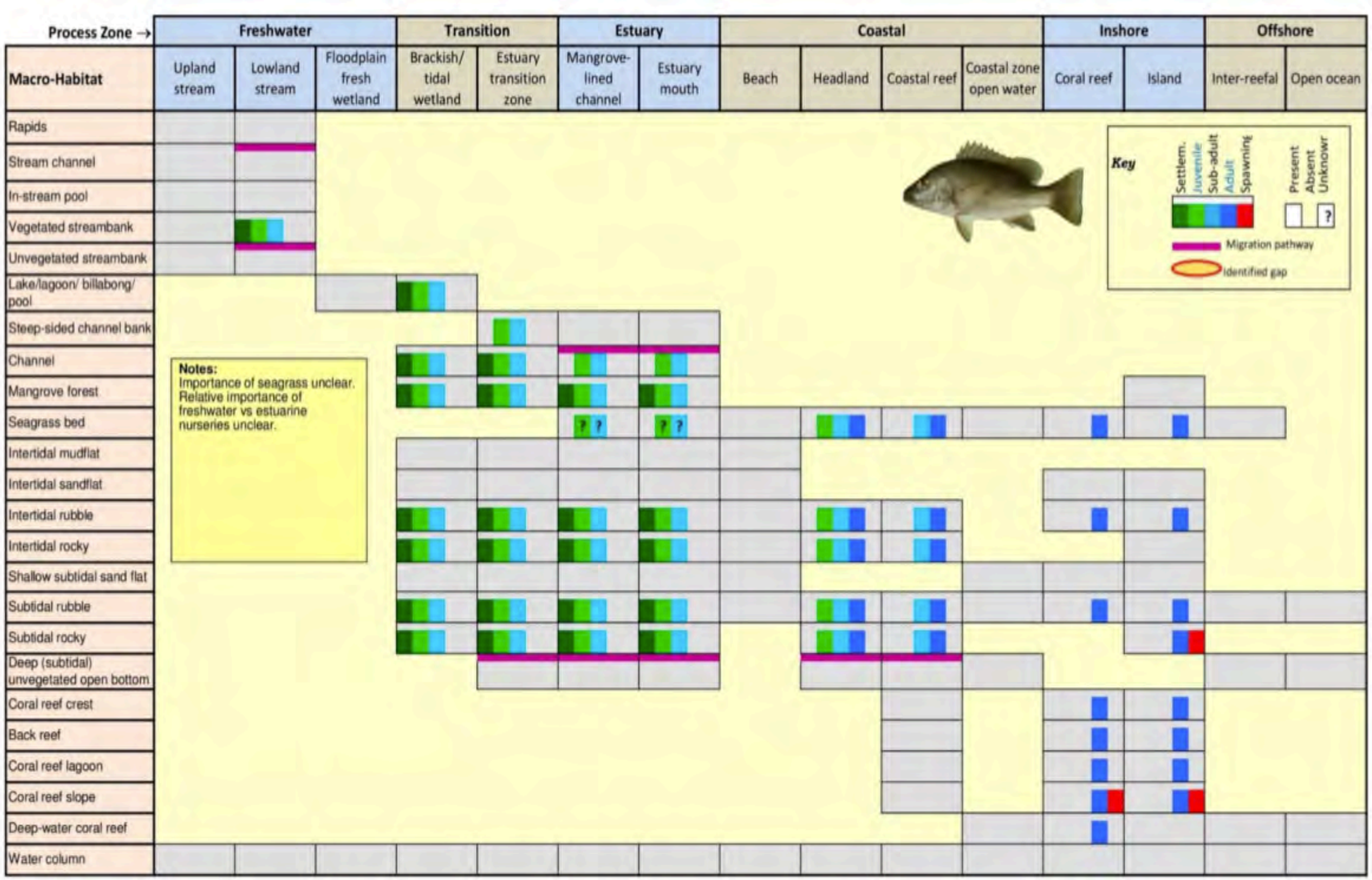


Image: Copyright Commonwealth of Australia (GBRMPA) for the diagram which was created by Paul Groves Courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/)

Download the pdf version here:

http://elibrary.gbrmpa.gov.au/jspui/bitstream/11017/822/3/Mangrove_Jack_Life_Cycle.pdf

The mangrove jack uses a range of macro-habitats, that changes during their life cycle.



See page 39 of:

http://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2013-046_DLD.pdf

for the next 3 slides

Image: Sheaves M., Barnett A., Bradley M, Abrantes K.G., Bryans M., James Cook University, 2016, *Life history specific habitat utilisation of tropical fisheries species*, Townsville, Australia, July. CC BY 3.0, available: http://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2013-046_DLD.pdf

Mangrove jack use a range of macro-habitats, that changes during their life cycle.

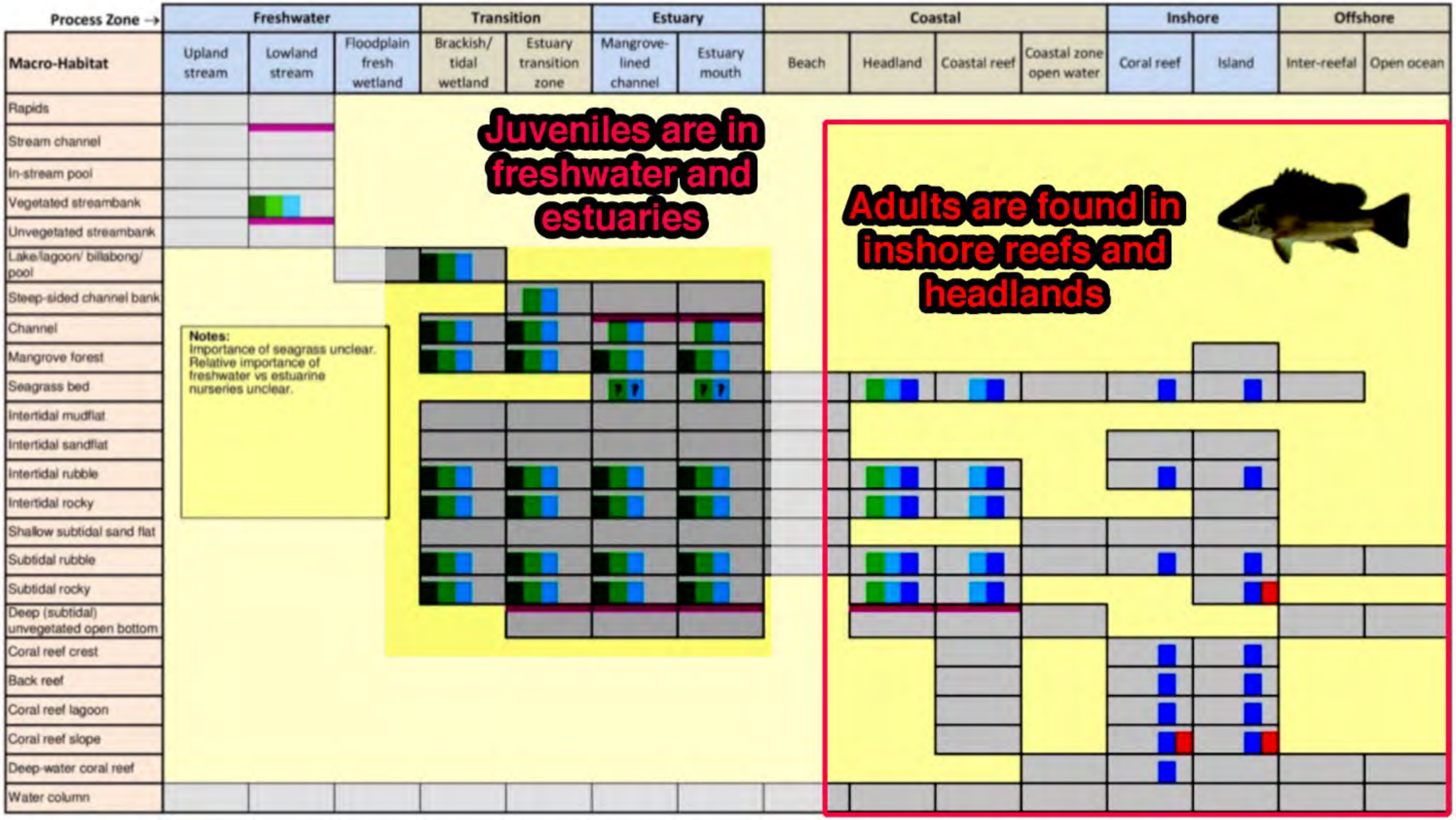


Image: Sheaves M., Barnett A., Bradley M, Abrantes K.G., Bryans M., James Cook University, 2016, *Life history specific habitat utilisation of tropical fisheries species*, Townsville, Australia, July. CC BY 3.0, available: http://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2013-046_DLD.pdf

Mangrove Jack also use meso-habitats with structure within a macro-habitat

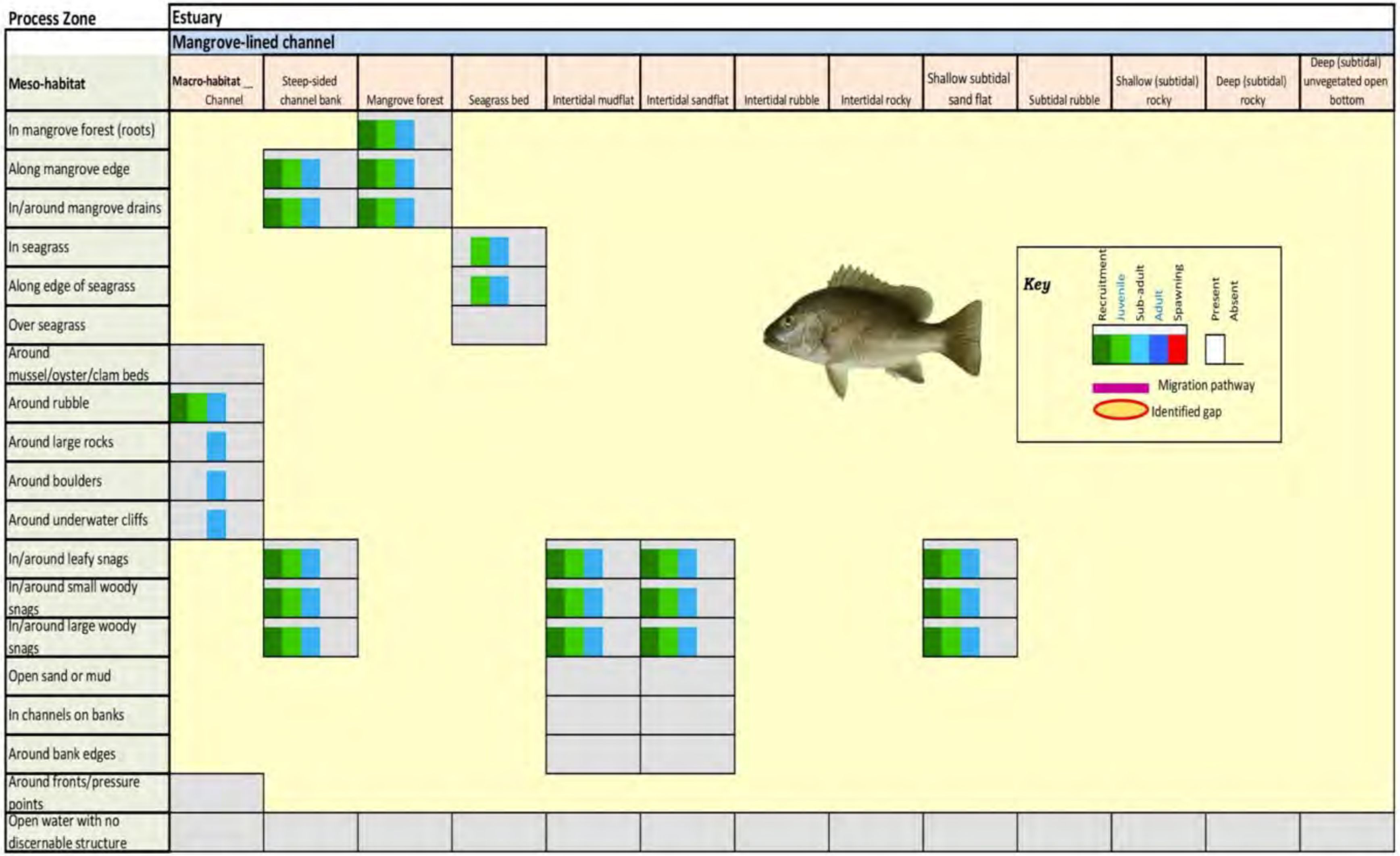


Image: Sheaves M., Barnett A., Bradley M, Abrantes K.G., Bryans M., James Cook University, 2016, *Life history specific habitat utilisation of tropical fisheries species*, Townsville, Australia, July. CC BY 3.0, available: http://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2013-046_DLD.pdf

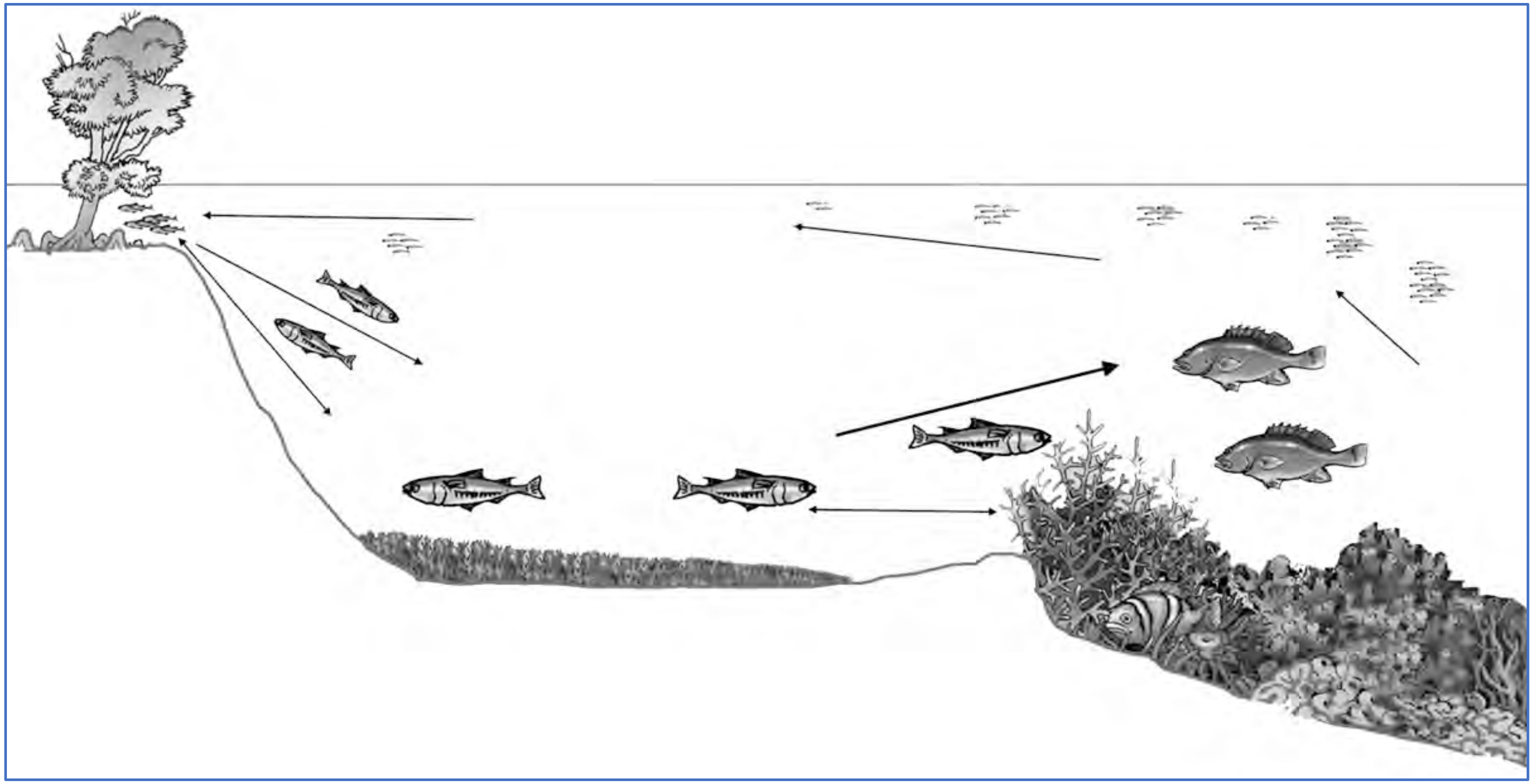
Summary

- Many species of fish, including many commercially important species, spend part of their lifecycle in mangroves, seagrass, estuaries or shallow coastal habitat.
- These habitats act as “nursery area” providing food, shelter and protection from predation. Fish migrate (ontogenetic migration) to different habitats as they mature.
- The level of dependence on different habitats varies between species and life-cycle stage.
- This has implications for the management of these species and design of marine parks.

Questions

1. Describe, with reference to a specific example, how fish lifecycles incorporate different habitats.

2. Interpret the fish life cycle diagram below in your own words



Further activities

See

https://coralwatch.org/index.php/education-2/curriculum-materials/marine-science/

by

CORALWATCH

Further activity

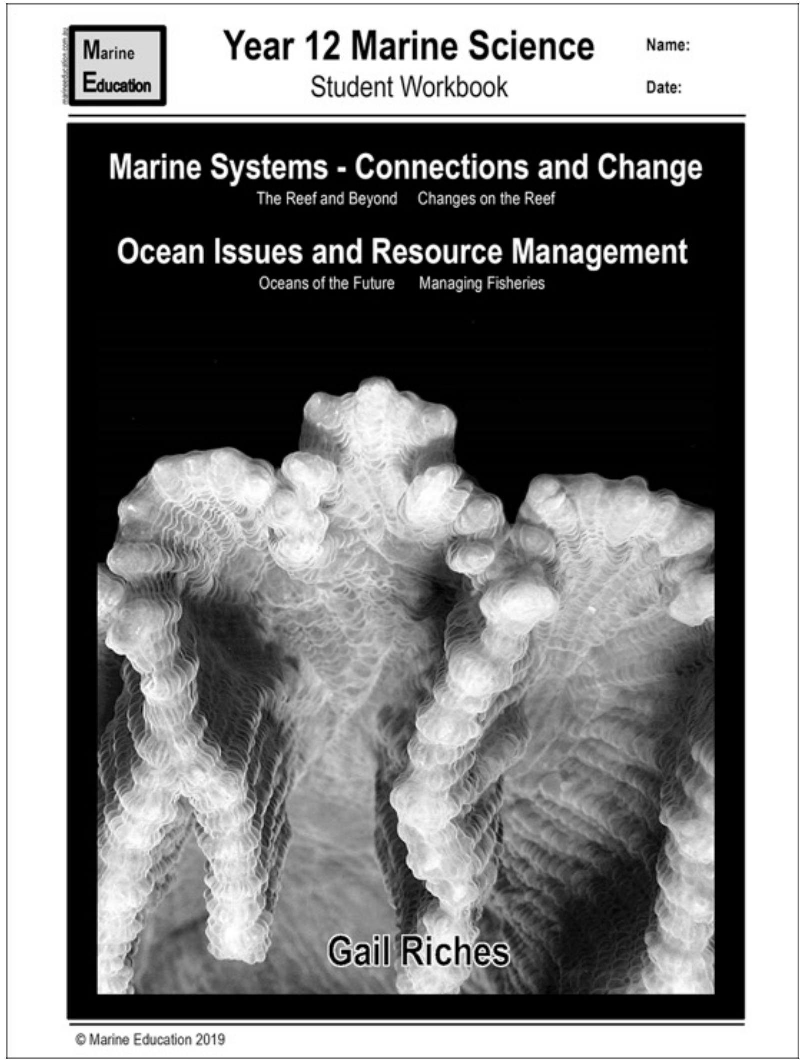
Worksheet –

Fish Moving Home

by

Gail Riches

www.marineeducation.com.au



T090 Fish reef benefits

Adam Richmond

Syllabus statement

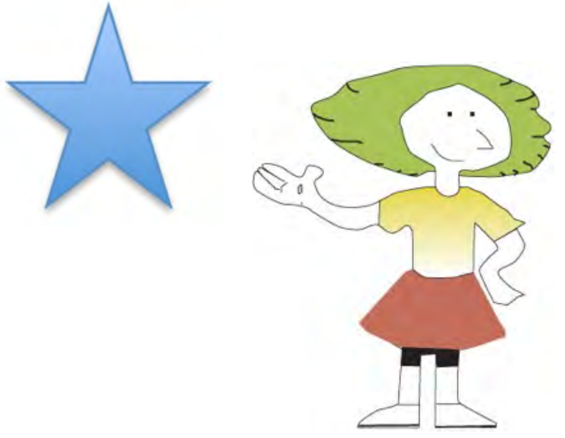
At the end of this topic you should be able to ...

Describe

how fish, particularly herbivore populations, benefit coral reefs

Describe

- give an account (written or spoken) of a situation, event, pattern or process, or of the characteristics or features of something



Objectives

Complete two sentences on how herbivores benefit coral reefs.

Fish play critical roles in the …….

Herbivorous reef fishes are particularly important in ………. ……….

Use an experiment to justify your answer.

Fish play critical roles in the functional ecology of coral reefs.

Herbivorous reef fishes are particularly important in preventing and reversing the development of stands of macroalgae.

Surgeonfish are among the most common of coral reef herbivores, often feeding in shoals.

"Plant-eating fish, or herbivores, remove seaweed from reefs.
In normal conditions, these fish act as nature's lawnmowers and keep seaweed levels under control by grazing close to the bottom of the reef."

Text from poster, GBRMPA

Download a pdf copy of this poster here:

http://www.gbrmpa.gov.au/__data/assets/pdf_file/0006/247848/Coral-Recovery-A4-Flyer_4Print.pdf

There are several ecological roles, or functional groups of herbivorous fish on reef systems.

- Scrapers/small excavators
- Large excavators/bioeroders
- Grazers/detritivores
- Browsers

This large male steephead parrotfish, *Chlorurus microrhinos* is a large excavator/bioeroder.

Image: Hectonichus [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)]

Reference:

Green, A., & Bellwood, D. *Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience- A practical guide for coral reef managers in the Asia Pacific region.*IUCN working group on Climate Change and Coral reefs. IUCN, Gland, Switzerland.

Available:
http://www.iucn.org/cccr/publications/

Scrapers and small excavators

The majority of parrotfish (*Hipposcarus* and *Scarus spp*), up to 35cm long, are scrapers.

Scrapers and small excavators limit the establishment and growth of macroalgae, whilst intensely grazing algal turf.

Images
(Fernando Herranz Martín [GPL (http://www.gnu.org/licenses/gpl.html)]
Albert Kok at Dutch Wikipedia(Original text: albert kok) [Public domain]

Reference:

Green, A., & Bellwood, D. *Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience- A practical guide for coral reef managers in the Asia Pacific region.*IUCN working group on Climate Change and Coral reefs. IUCN, Gland, Switzerland.

Available:
http://www.iucn.org/cccr/publications/

They also provide areas of clean substrate for the settlement, growth and survival of coralline algae and corals.

Images
(Fernando Herranz Martín [GPL (http://www.gnu.org/licenses/gpl.html)]
Albert Kok at Dutch Wikipedia(Original text: albert kok) [Public domain]

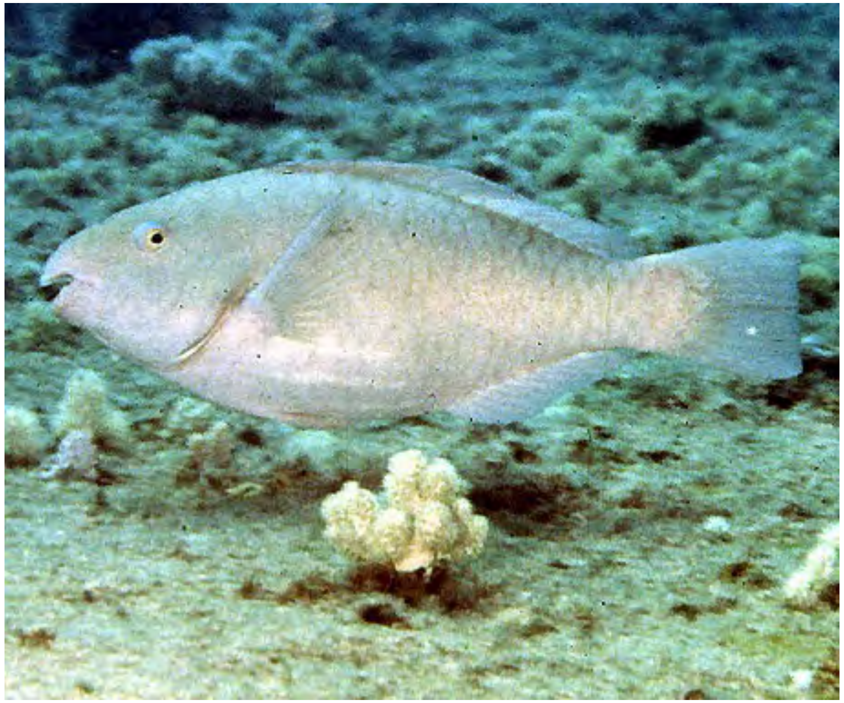
Parrotfish take non-excavating bites and remove algae, sediment and other material by closely cropping or scraping the reef surface, leaving shallow scrape marks on the reef substrate.

Parrotfish eating coral

Scrape marks left by parrotfish feeding

The rivulated parrotfish, *Scarus rivulatus* is a scraper/small excavator.

Smaller individuals (<35cm) scrape a larger area of substrate for their size, whilst larger (>35cm) individuals take a greater volume, excavating the substrate.



Small female (left) and large male *Scarus rivulatus*

Images: Randall, J.E., 1997 Randall's underwater photos. Fishbase.se CC-NC-3.0

Large excavators and bioeroders

Large excavators and bioeroders play a similar role as scrapers/small excavators, but also cause significant bioerosion.

Parrotfish, such as this *Chlorurus microrhinos* (right) make deeper “excavating” bites into the coral.

These bites expose hard reef substrate for settlement by coralline algae and corals- play a critical role in reef resilience.

The steephead parrotfish, *Chlorurus microrhinos*

The Humphead parrotfish, *Bolbometopon muricatum*, is one of the most important bioeroders on coral reefs. It can grow to 120 cm and consume 5 tonnes of reef carbonate per year.

Grazers/ detritivores

Grazers intensely graze epilithic (on the surface of rocks) algal turfs, which also limits the growth and establishment of macroalgae. They do not scrape or excavate the reef substrate as they feed.

The blue-lined rabbitfish, *Siganus doliatus*, is a grazing herbivore.

The golden-lined spinefoot, *Siganus lineatus*, is a detritivore.

By Graham Edgar / Reef Life Survey -
http://www.fishesofaustralia.net.au/images/image/SiganLineatRLS.jpg, CC BY 3.0,
https://commons.wikimedia.org/w/index.php?curid=40690155

Browsers

Browsers feed on macroalgae by selectively eating algal components and epiphytic material. Browsing fish significantly reduce coral overgrowth and shading by macroalgae.

The unicornfish, *Naso unicornis* (left), and batfish, *Platax teira*, are browsers

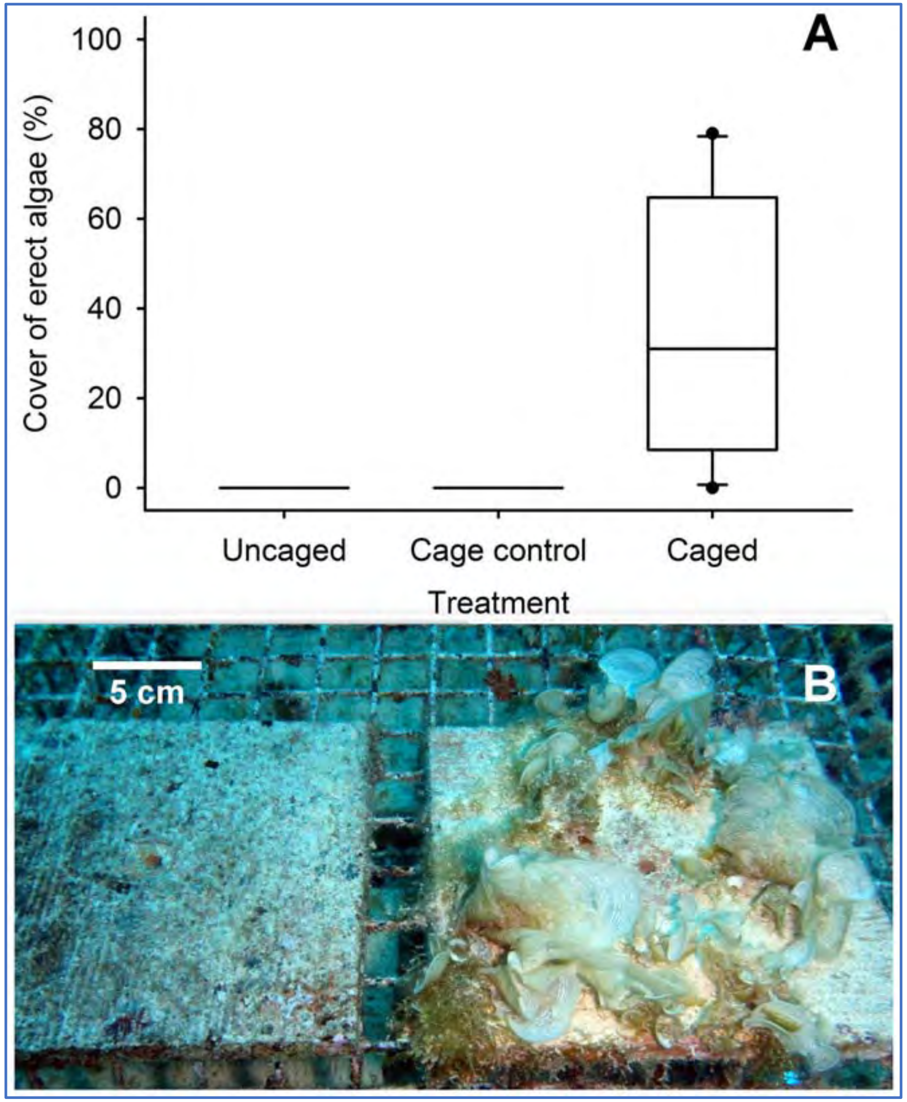
Image (left):Karelj [Public domain]; (right) Richard Ling [CC BY-SA 2.0 (https://creativecommons.org/licenses/by-sa/2.0)]

Herbivore exclusion experiments show the effect herbivorous fish have on coral reefs.

In control areas, where large herbivorous fish were abundant, algal cover remains low, and coral cover can increase.[1,2]

Exclusion of large herbivorous fishes causes an increase in macroalgae, which suppresses the fecundity, recruitment, and survival of corals. [1]

Reference: 1.Hughes, T., Rodrigues, M., Bellwood, D., Ceccarelli, D., Hoegh-Guldberg, O., & McCook, L. et al. (2007). Phase Shifts, Herbivory, and the Resilience of Coral Reefs to Climate Change. *Current Biology*, *17*(4), 360-365. doi: 10.1016/j.cub.2006.12.049\ Available : https://doi.org/10.1016/j.cub.2006.12.049
2. Adam TC, Schmitt RJ, Holbrook SJ, Brooks AJ, Edmunds PJ, et al. (2011) Herbivory, Connectivity, and Ecosystem Resilience: Response of a Coral Reef to aLarge-Scale Perturbation. PLoS ONE 6(8): e23717. doi:10.1371/journal.pone.0023717 Available: https://www.academia.edu/15019595/Herbivory_Connectivity_and_Ecosystem_Resilience_Response_of_a_Coral_Reef_to_a_Large-Scale_Perturbation



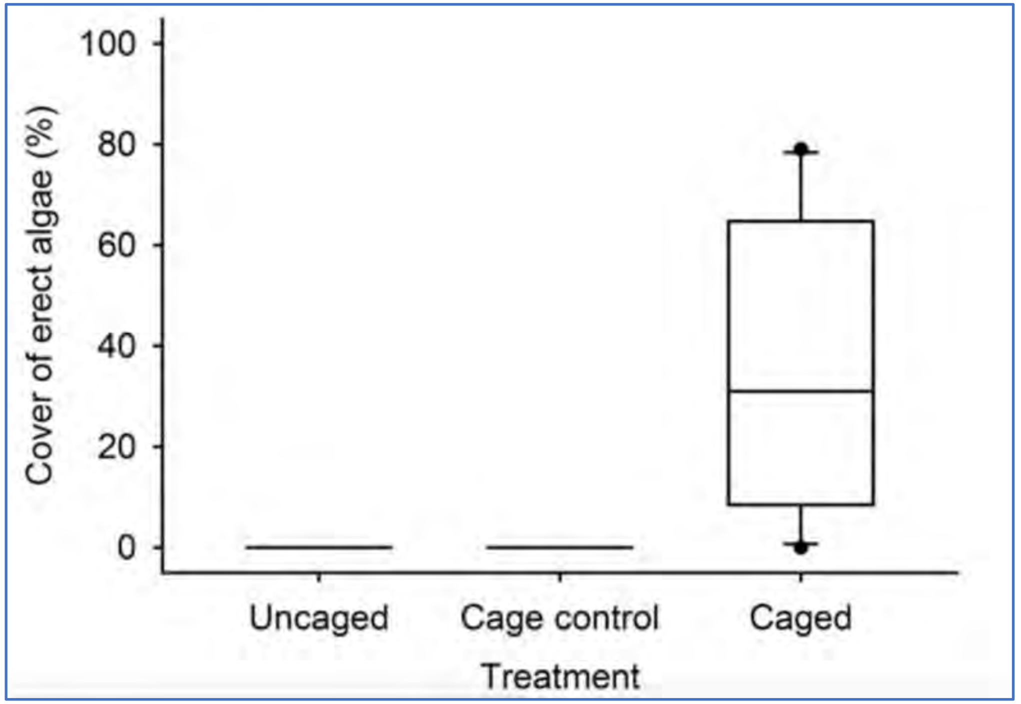
Questions

Complete these sentences to describe herbivores benefit coral reefs.

1. Fish play critical roles in the …….

2. Herbivorous reef fishes are particularly important in ……….. ……….

3. Use the experimental results in the graph opposite to justify your answer.



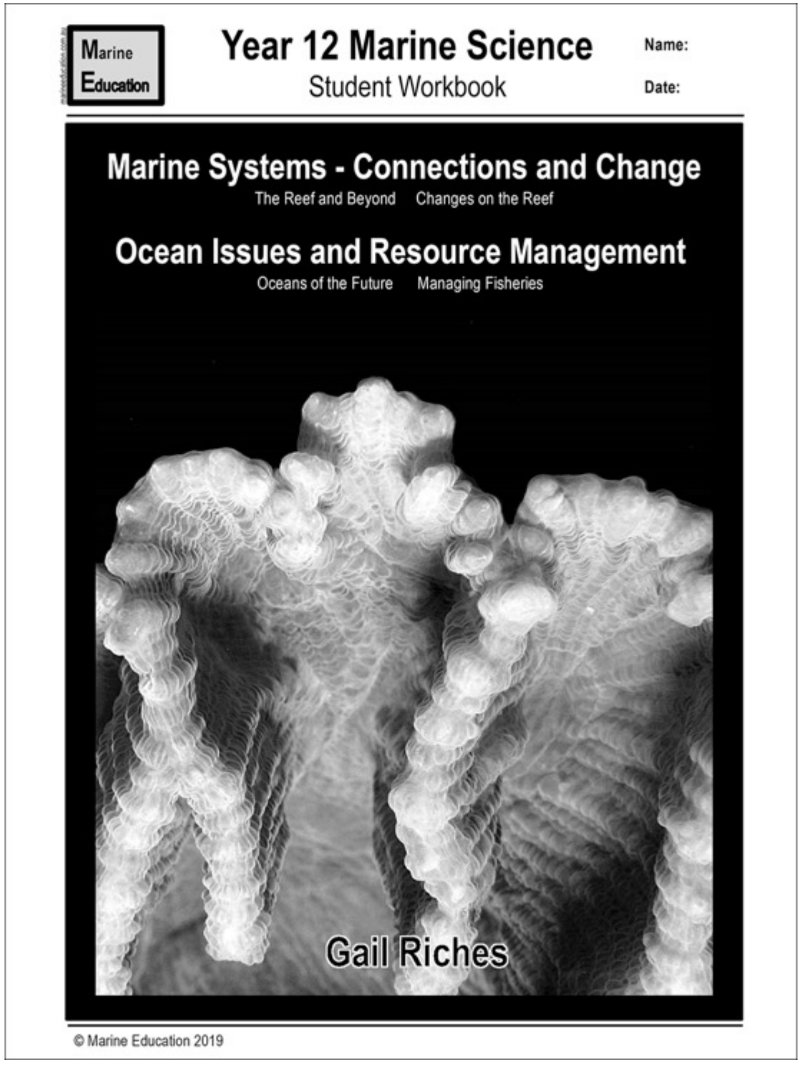
Further activity

Worksheet –

Heroic Herbivores

by
Gail Riches

www.marineeducation.com.au



Further activities

See

https://coralwatch.org/index.php/education-2/curriculum-materials/marine-science/

by

CORALWATCH


T091 Ecological tipping points
Adam Richmond

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Schools should be aware that these power points make extensive use of journal articles, which, in the scientific community, often need to be replicated and in some cases are often refuted. In addition marine park regulations and policies can change with changing governments, so teachers are advised to check acceptable answers with the relevant QCAA officer if in doubt.

June 2019

Syllabus statement

At the end of this topic you should be able to ...

Identify

ecological tipping points and how this applies to coral reefs

Identify

- distinguish;
- locate, recognise and name;
- establish or indicate who or what someone or something is;
- provide an answer from a number of possibilities;
- recognise and state a distinguishing factor or feature

Objective

Explain the concept of “tipping points” in your own words.

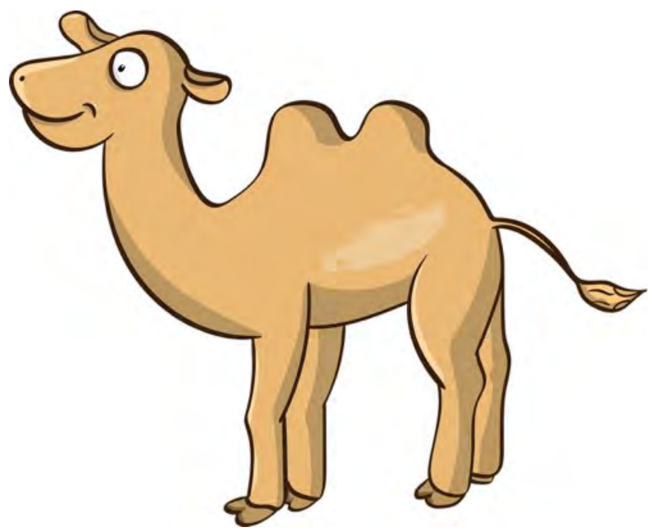
How do tipping points affect coral reef ecosystems?

Definition

Tipping points are the point at which an ecosystem can no longer cope with environmental change and the ecosystem rapidly (and often unexpectedly) shifts to a new state.

“Tipping point” is synonymous with ecosystem threshold- but ”tipping point” helps us visualise the dramatic change associated with thresholds.

Think of the straw that breaks a camel's back:
The poor camel can carry a lot of weight-
but at some stage, just one more tiny straw
will be too much!



Here's another example:
The tipping bucket at the water park gradually fills with water, until it reaches a critical threshold- then it suddenly tips over.

This analogy has limitations- the constant flow of water into the bucket represents gradually changing conditions- and the ecosystem state is the volume of water in the bucket.

There is no "desirable" or "undesirable" state: unless you are the kid waiting to get drenched!

Image: Shylah Anderson, flickr, CCBY2.0 https://flic.kr/p/chJYr9

This YouTube video on Climate tipping points provides a good overview of tipping points

Video link

https://youtu.be/UKD6m04PipU

Climate Tipping Points: The Point of No Return? A Quick Guide

YouTube video by Climate Tipping Points, available: https://youtu.be/UKD6m04PipU

Scientists have observed tipping points in many real world systems, such as marine fisheries, lake water quality and the world's climate.

With hindsight, we can identify tipping points that we have already crossed in real world systems.

For example, the volume of ice changes greatly between ice ages and warm periods.

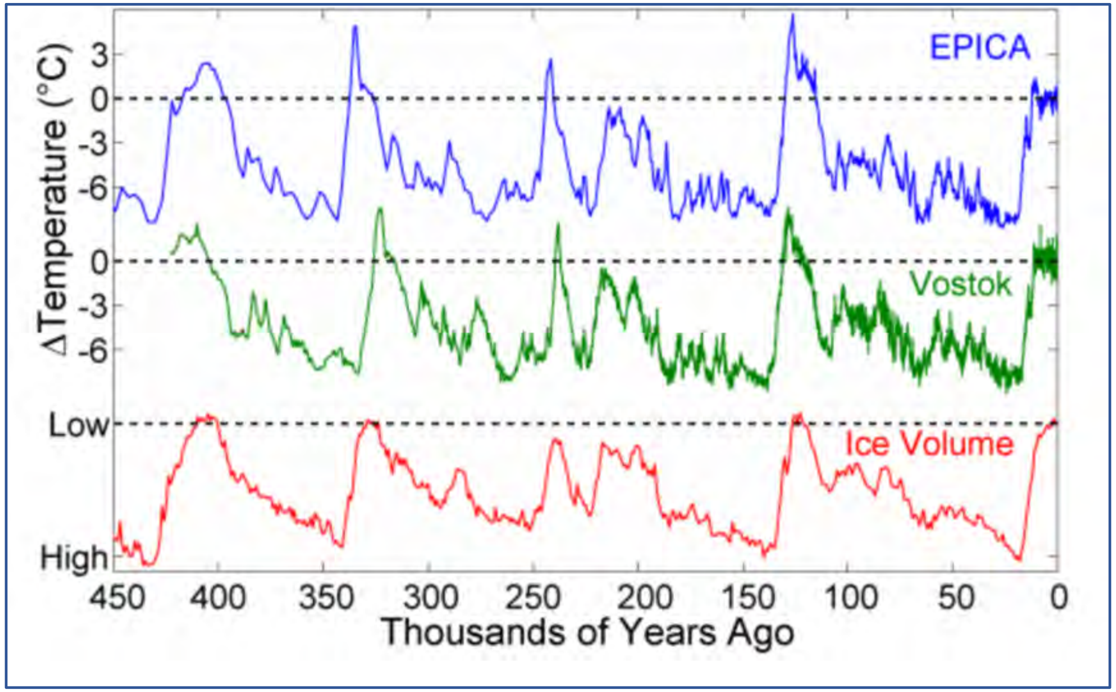


Image: Robert A. Rhode, Global warming Art project. CC 3.0
https://upload.wikimedia.org/wikipedia/commons/f/f8/Ice_Age_Temperature.png

Ecosystems respond to a changes in conditions in different ways.

Graph A shows a linear transition, where the ecosystem state changes smoothly in response to changing conditions.

Graph B shows a non linear transition, where there is a sudden, abrupt change in ecosystem state, when conditions approach a critical level.

Graph C shows that an ecosystem can have more than one stable state over a range of conditions (more about this next topic)

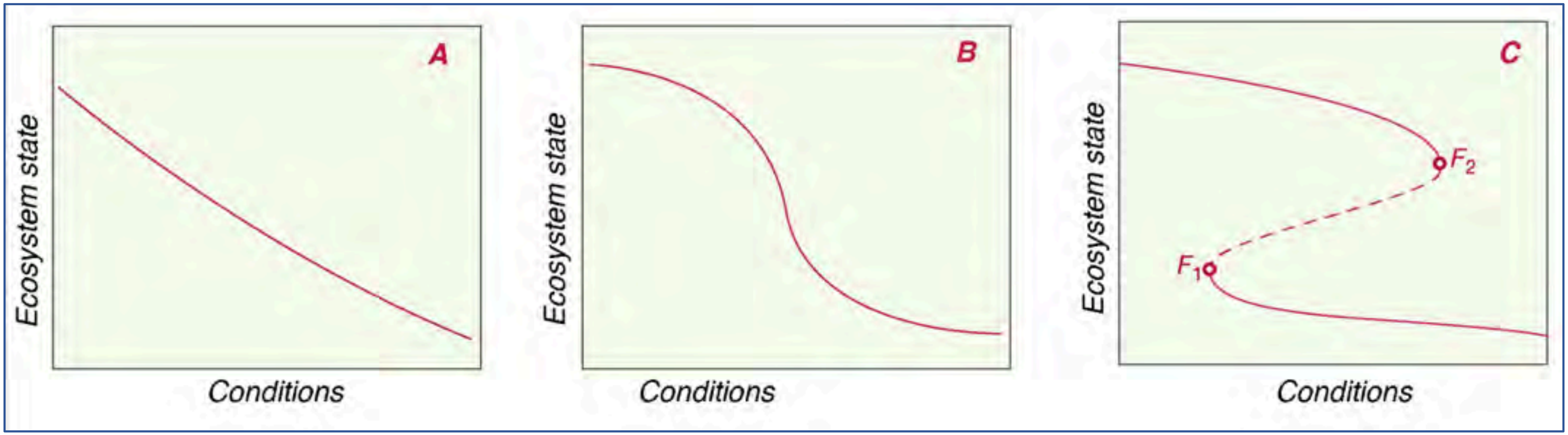


Image: Bob Moffatt CC 4.0 BY , after Scheffer, M., Carpenter, S., Foley, J., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(6856), 591-596. doi: 10.1038/35098000

Graph A represents a linear change in an ecosystem state in response to changing conditions.

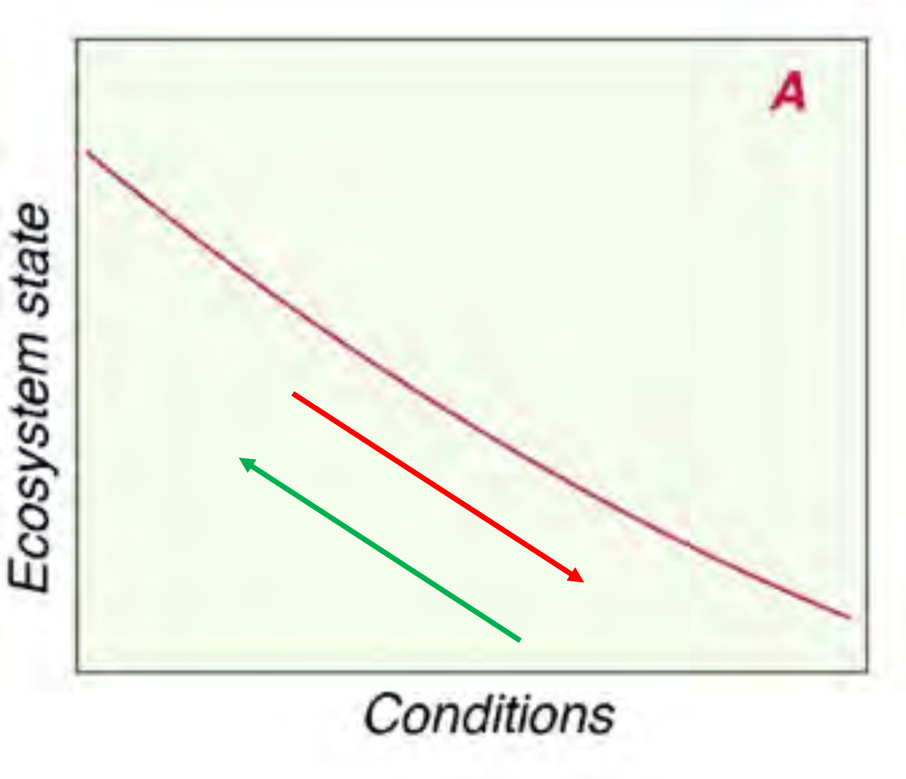


Image: Bob Moffatt, after Scheffer, M., Carpenter, S., Foley, J., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(6856), 591-596. doi: 10.1038/35098000

An example could be water quality in response to nutrient loading.

The water quality (Ecosystem State) gradually decreases with increased levels of nutrient loading (condition). (Red arrow)

Water quality can easily be improved if the nutrient loading is reduced. (Green Arrow)

The tipping point is somewhere in the zone between the arrows- it is difficult to pinpoint because of the continuous, gradual nature of the change.

Nutrient runoff and sediment pollution were the drivers for an ecosystem shift to a degraded ecosystem with poor water clarity, low oxygen and low diversity in Chesapeake Bay in the 1960-70s.

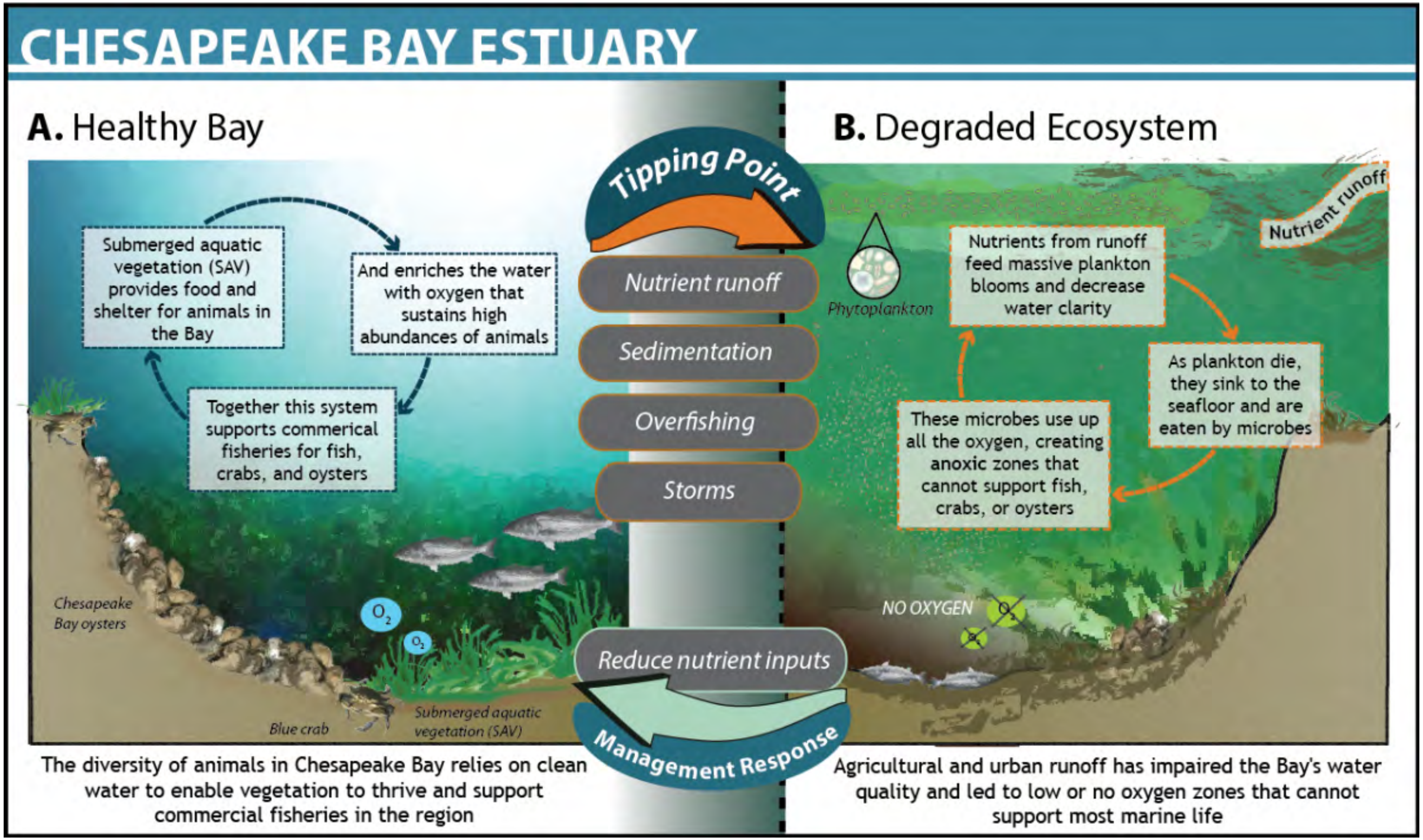
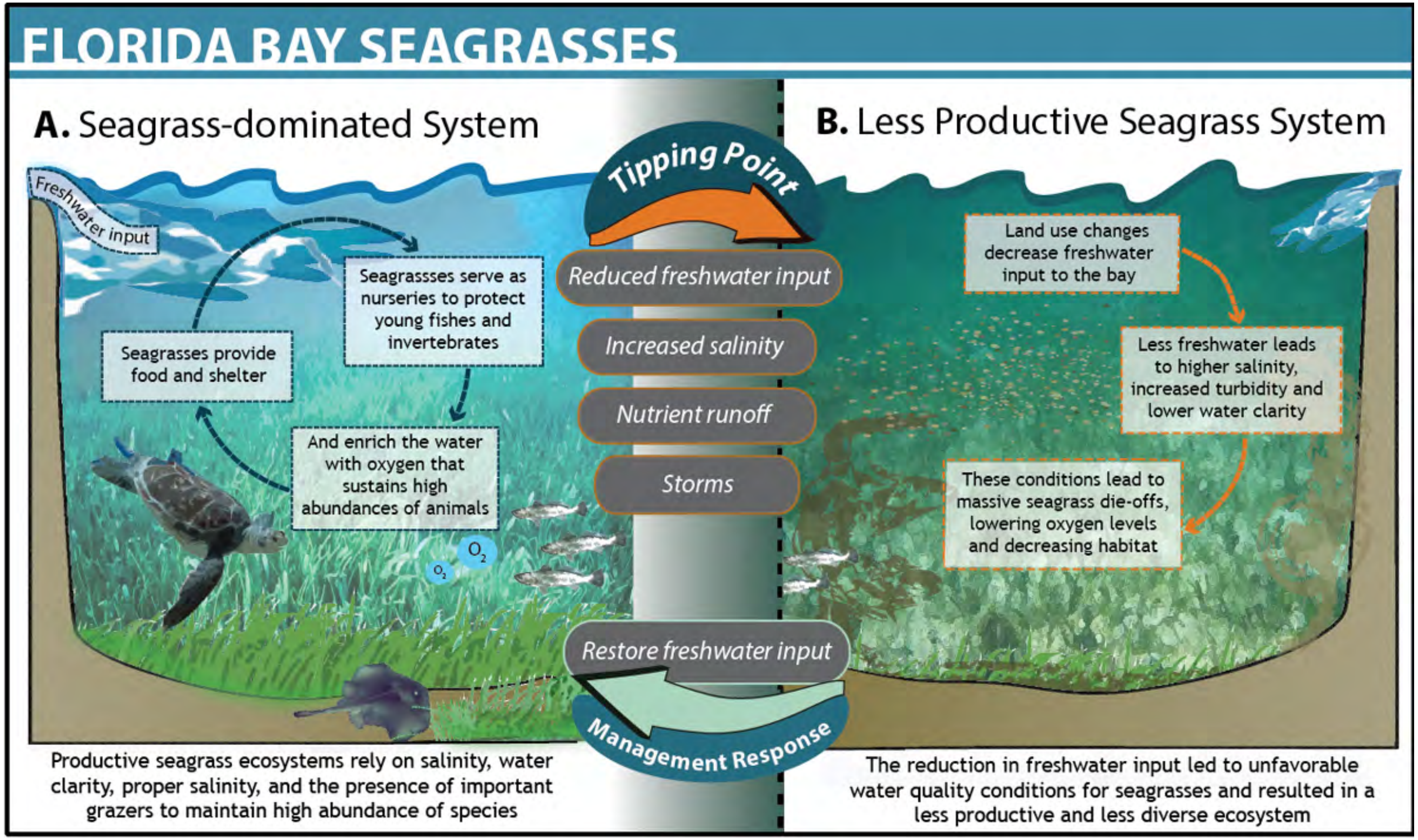


Image: Reproduced with permission, Oceantippingpoints.org,
Available: http://oceantippingpoints.org/sites/default/files/uploads/MRCS_Graphic_Chesapeake_0.png

A decrease in freshwater input led to increased salinity and decreased water circulation, which caused a non-linear reduction in water clarity and seagrass productivity in Florida Bay during the 1980s.



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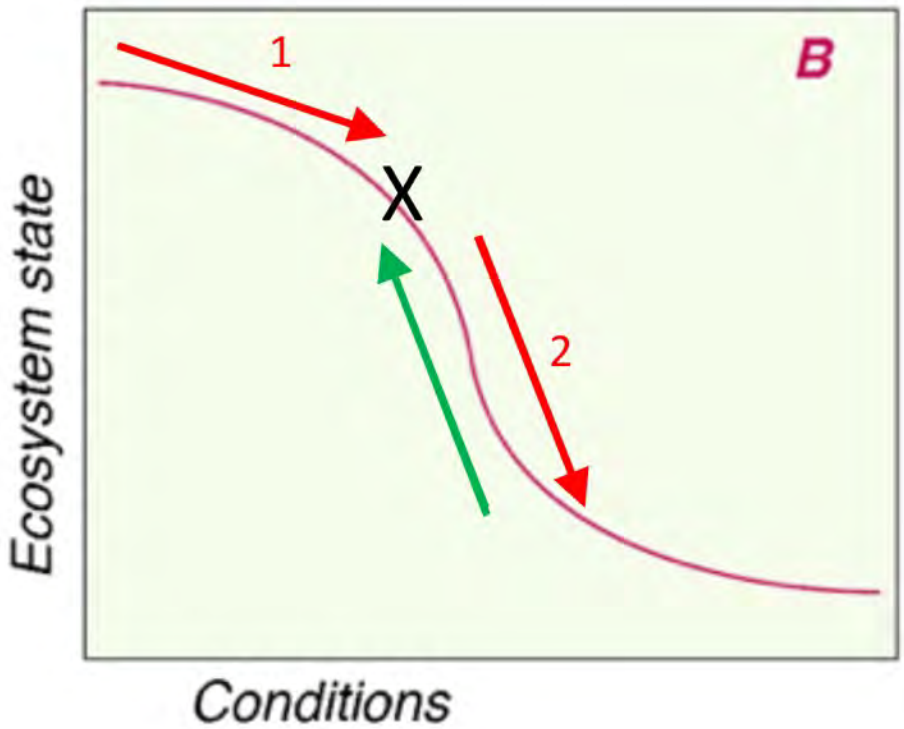
Graph B models a non linear transition, where there is a sudden, abrupt change in ecosystem state, when conditions approach a critical level- the threshold boundary or tipping point. (Marked X)



Water quality (Ecosystem state) gradually decreases with increasing nutrient loading (conditions) as before. (Red Arrow 1)

When the nutrient levels (conditions) reach a certain threshold, a small change in the water quality (ecosystem changes) causes a much larger change in the ecosystem state. (Red Arrow 2)

Water quality can still be improved by reducing nutrient loading (Green arrow), or in the seagrass example, reinstating freshwater inputs.

Image: Bob Moffatt. CC 4.0 BY , after Scheffer, M., Carpenter, S., Foley, J., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(6856), 591-596. doi: 10.1038/35098000

Was the “X” too high on the previous slide?

The better the data, the more confident scientists can be with their predictions.

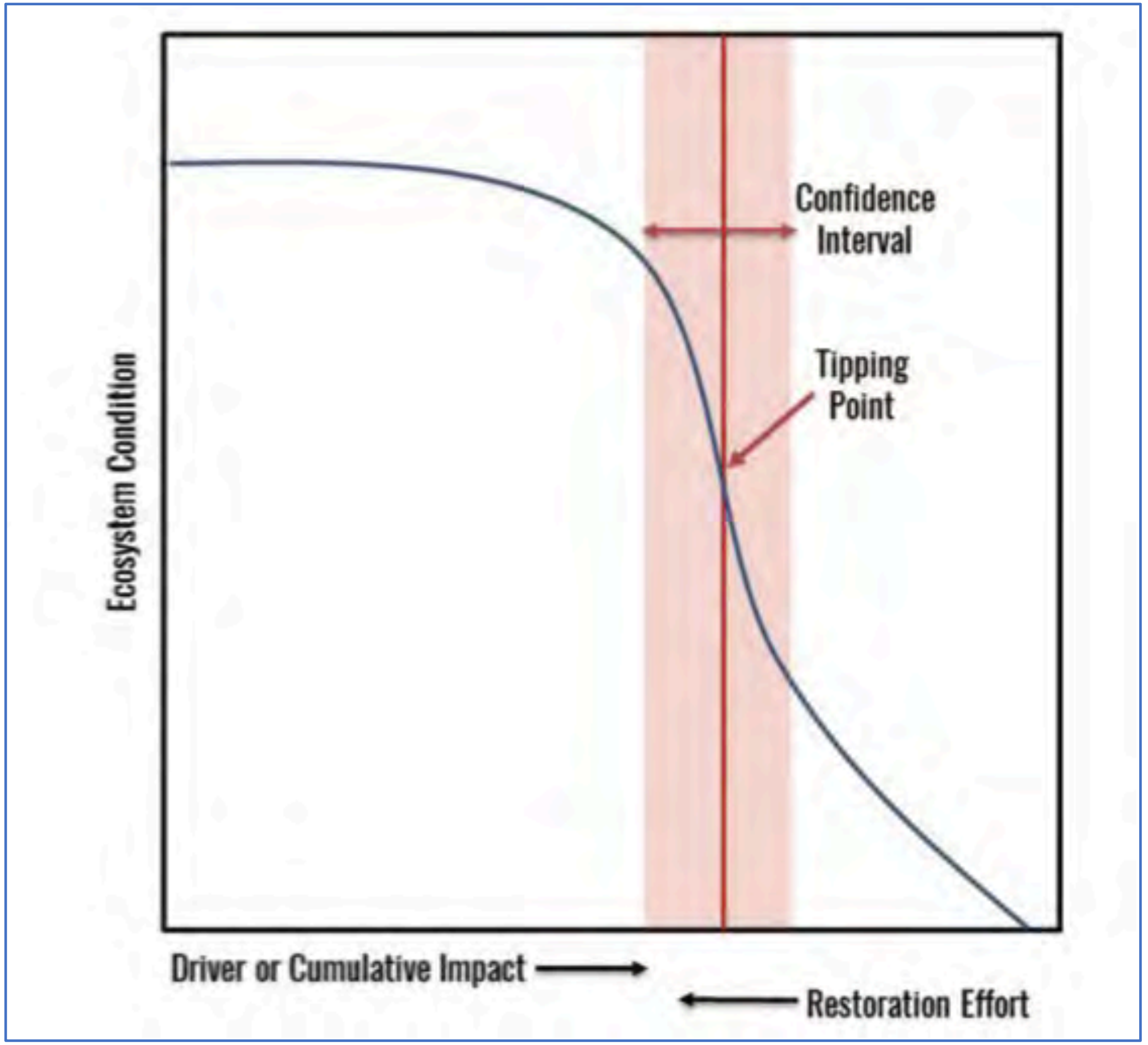


Image from: http://oceantippingpoints.org/sites/default/files/uploads/OTP_GUIDE_Final.pdf
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The next few slides refer to a group a animals called Pteropods.

Pteropoda

From Wikipedia, the free encyclopedia

Pteropoda (common name **pteropods**, are specialized free-swimming pelagic sea snails and sea slugs

(they are both pelagic, small, and transparent, and swim using wing-like flaps (parapodia) which protrude from their bodies) may reflect adaptation to their particular lifestyle.

Pteropoda

Scientific classification

Kingdom:	Animalia
Phylum:	Mollusca
Class:	Gastropoda
Subclass:	Heterobranchia
Informal group:	Opisthobranchia
Informal group:	**Pteropoda**

https://en.wikipedia.org/wiki/Pteropoda

This graph shows the non-linear relationship between the change in the mass of pteropod shells (ecosystem state), as a result of decreasing aragonite saturation (condition).

Can you identify a threshold or tipping point?

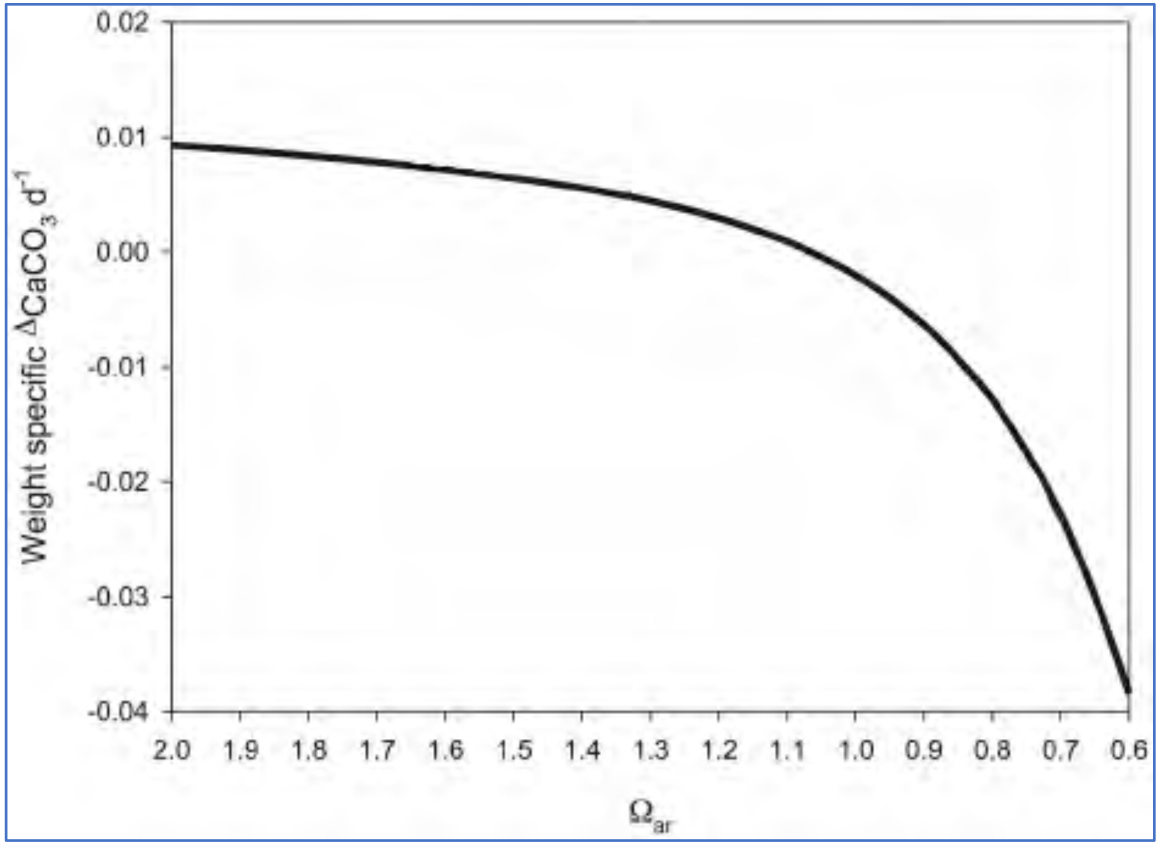


Image: Bednaršek, N., Tarling, G., Bakker, D., Fielding, S., & Feely, R. (2014). Dissolution Dominating Calcification Process in Polar Pteropods Close to the Point of Aragonite Undersaturation. *Plos ONE*, *9*(10), e109183. doi: 10.1371/journal.pone.0109183 Open access, https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0109183

Can you identify a threshold or tipping point?

- Somewhere between 1.0 and 0.7?
- Anywhere below 1.0 is bad news for a pteropod!

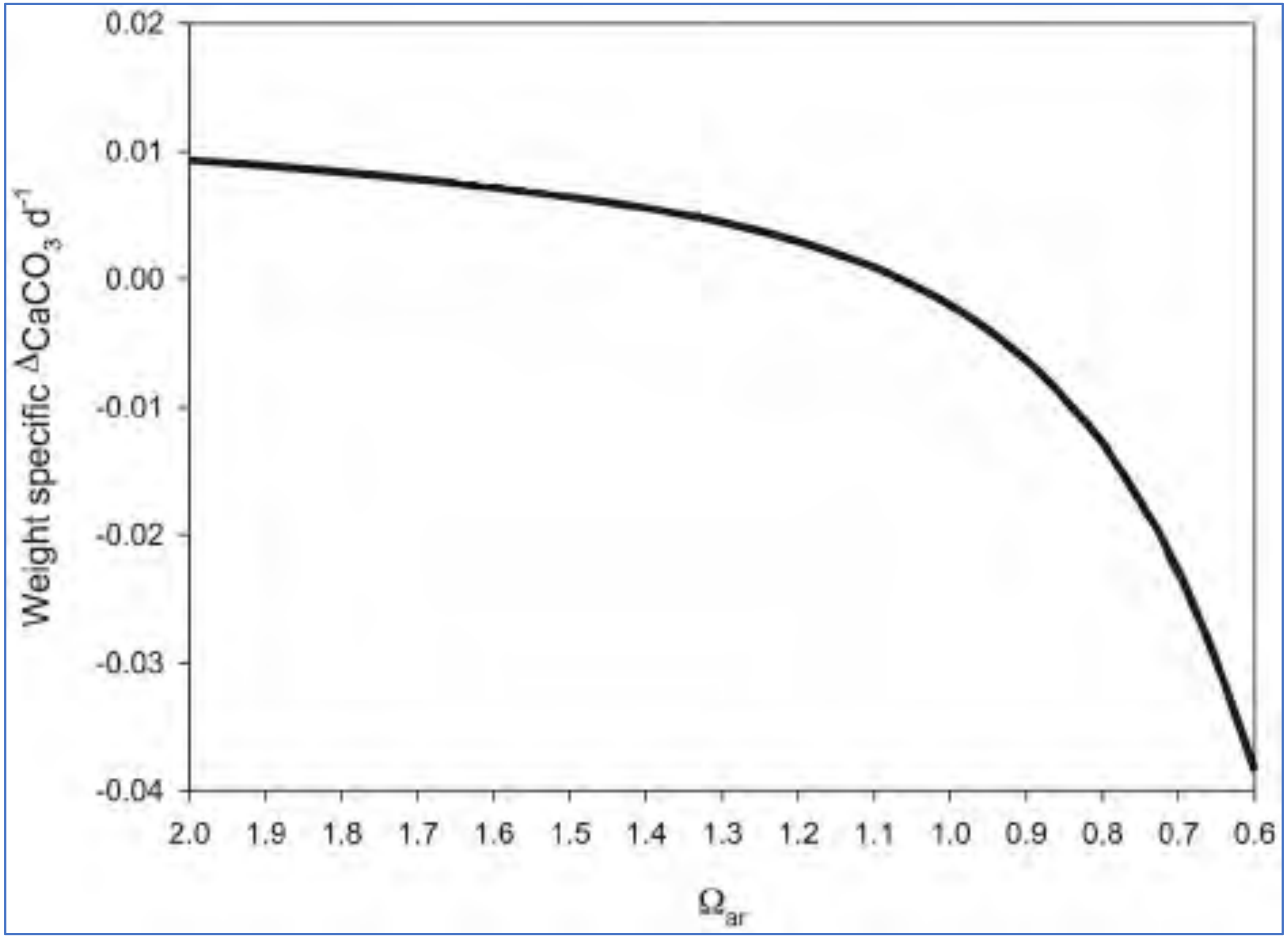
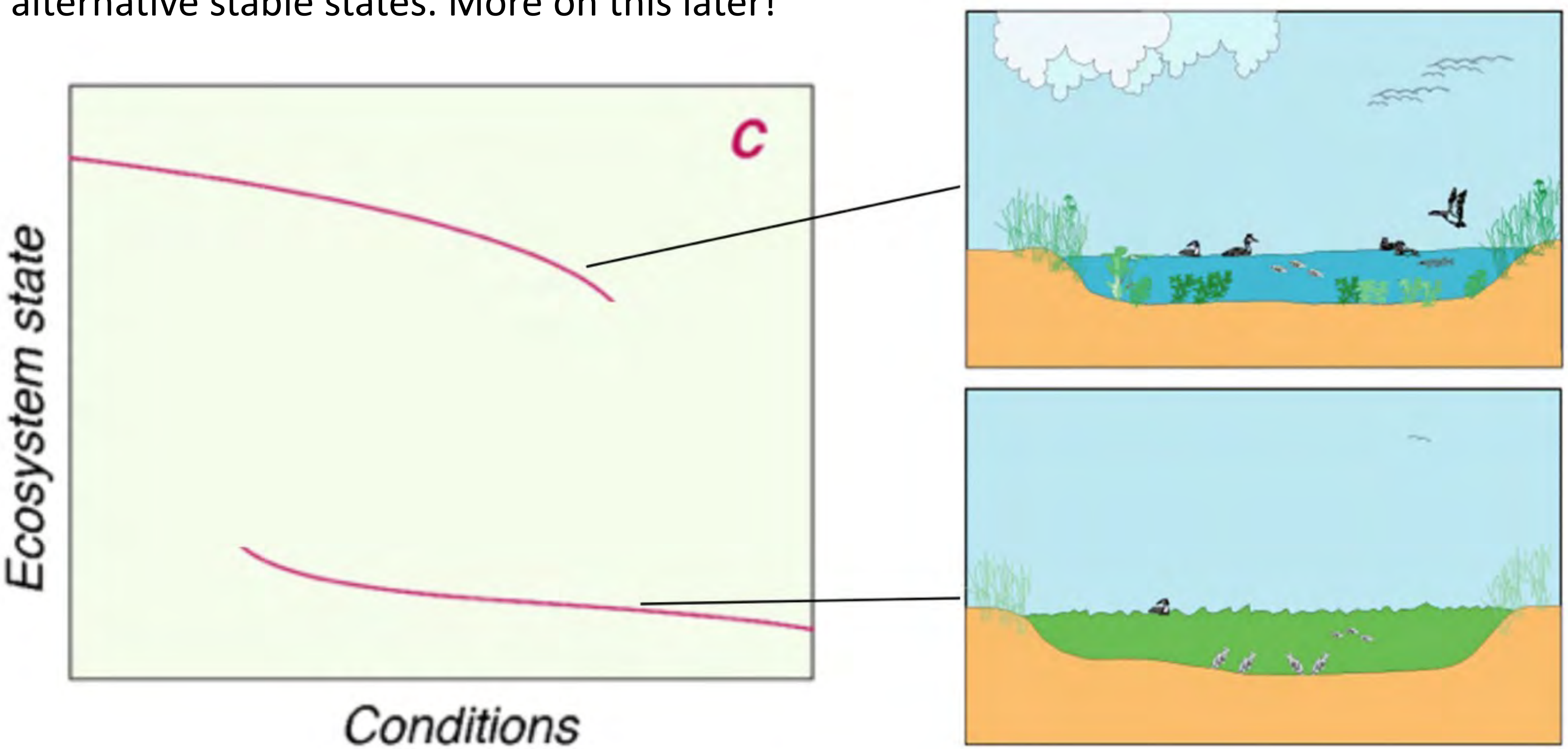


Image: Bednaršek, N., Tarling, G., Bakker, D., Fielding, S., & Feely, R. (2014). Dissolution Dominating Calcification Process in Polar Pteropods Close to the Point of Aragonite Undersaturation. *Plos ONE*, *9*(10), e109183. doi: 10.1371/journal.pone.0109183 Open access, https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0109183

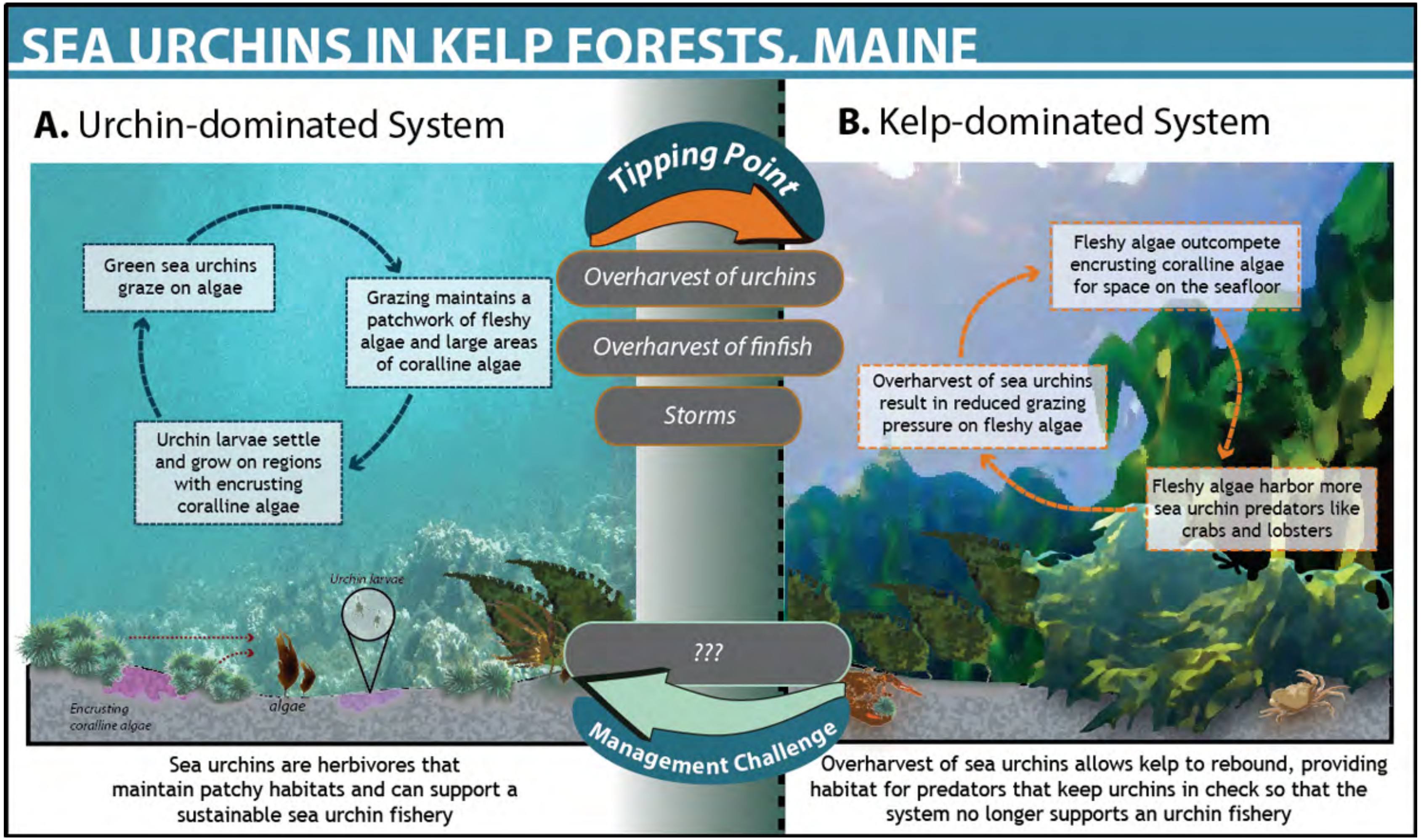
The two alternative ecosystem states (or regimes) can be quite different- a shallow lake could be clear with lots of aquatic vegetation, or turbid without submerged vegetation.

Graph C has been simplified here to show two alternative stable states. More on this later!



Graph Image: Bob Moffatt, after Scheffer, M., Carpenter, S., Foley, J., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(6856), 591-596. doi: 10.1038/35098000
Shallow lake Image: Scheffer, M. (2001). Alternative Attractors of Shallow Lakes. *The Scientific World JOURNAL*, *1*, 254-263. doi: 10.1100/tsw.2001.62, CC BY 3.0

Overfishing of sea urchins in Maine resulted in a tipping point, shifting an urchin-dominated patchy kelp forest to a dense kelp forest with no sea urchins.



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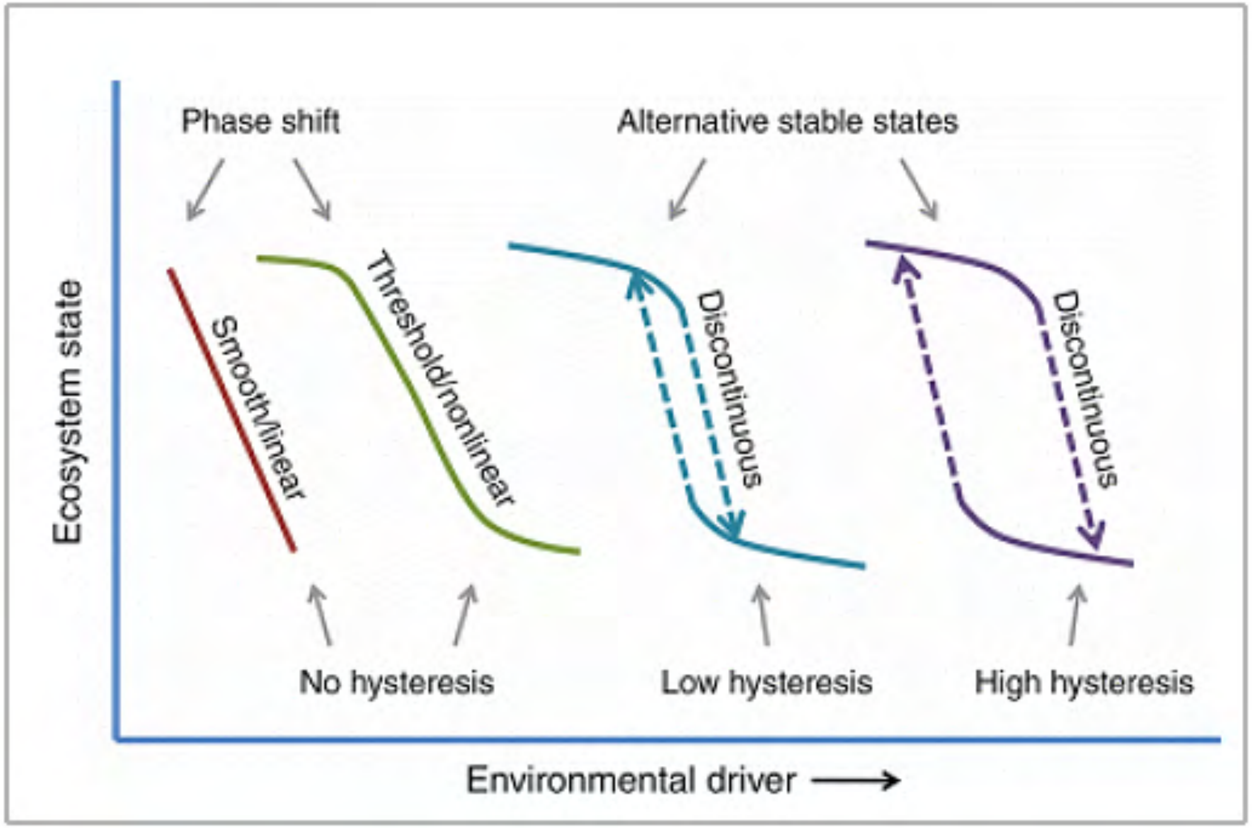
http://oceantippingpoints.org/sites/default/files/uploads/MRCS_Graphic_Maine_CS2.png

The change between ecosystem states is known as a regime shift, or phase shift.
As we have already seen they can be shifts can be smooth or nonlinear.



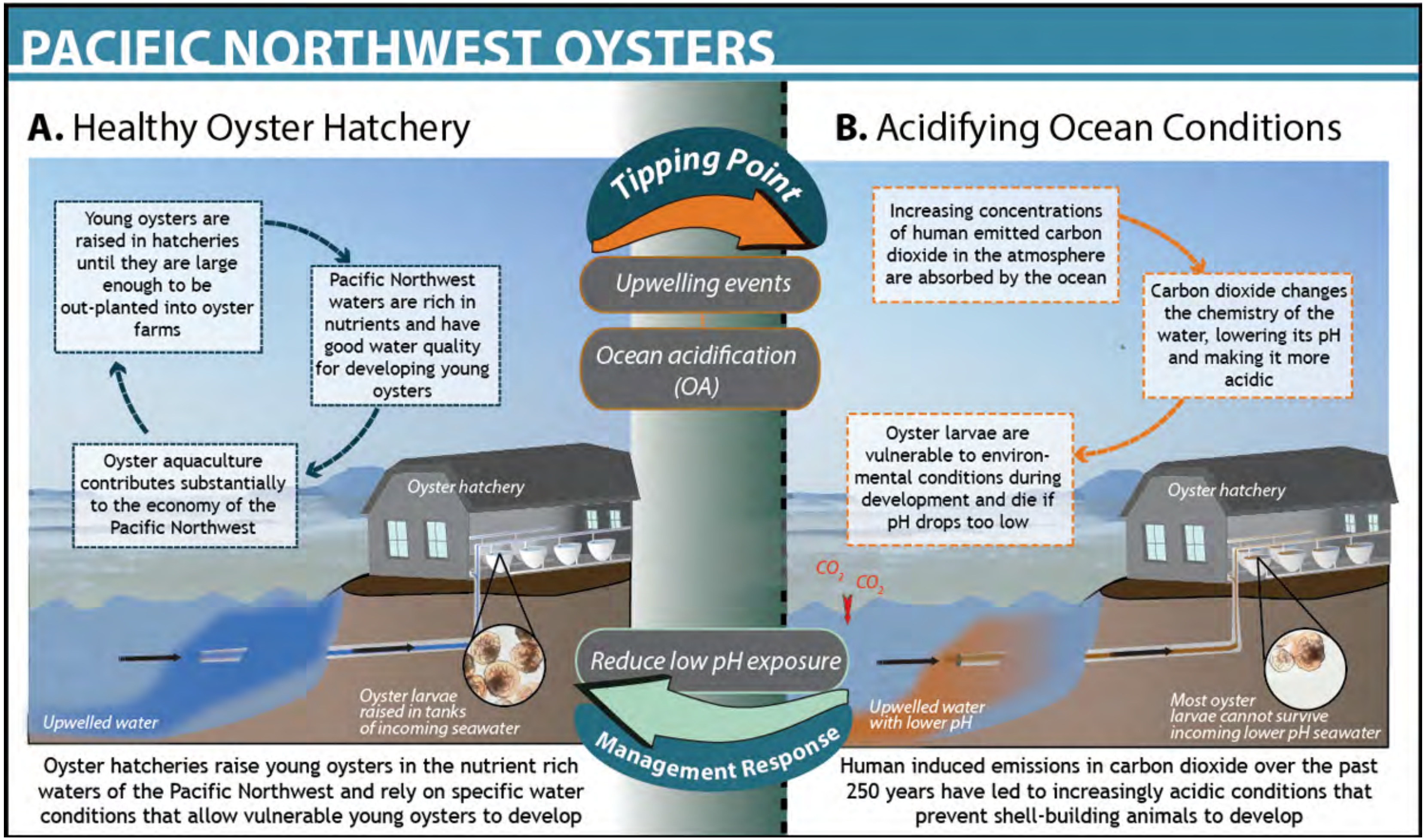
Selkoe, K., Blenckner, T., Caldwell, M., Crowder, L., Erickson, A., & Essington, T. et al. (2015). Principles for managing marine ecosystems prone to tipping points. *Ecosystem Health And Sustainability*, *1*(5), 1-18. doi: 10.1890/ehs14-0024.1, Open Access article distributed under the terms of the Creative Commons Attribution License

In this graph, the conditions are known as environmental drivers.

Drivers are events or activities that cause the change in state.

(Alternative stable states show hysteresis- more on this next topic)

Ocean acidification has led to changed seawater chemistry, resulting in an ocean pH too low for oyster larvae to survive, preventing successful oyster aquaculture in the Pacific Northwest.



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An ecosystem threshold is is a relatively rapid change from one ecological state to another. In this image, the threshold is marks the transition from a coral dominated ecosystem to an algae dominates system.

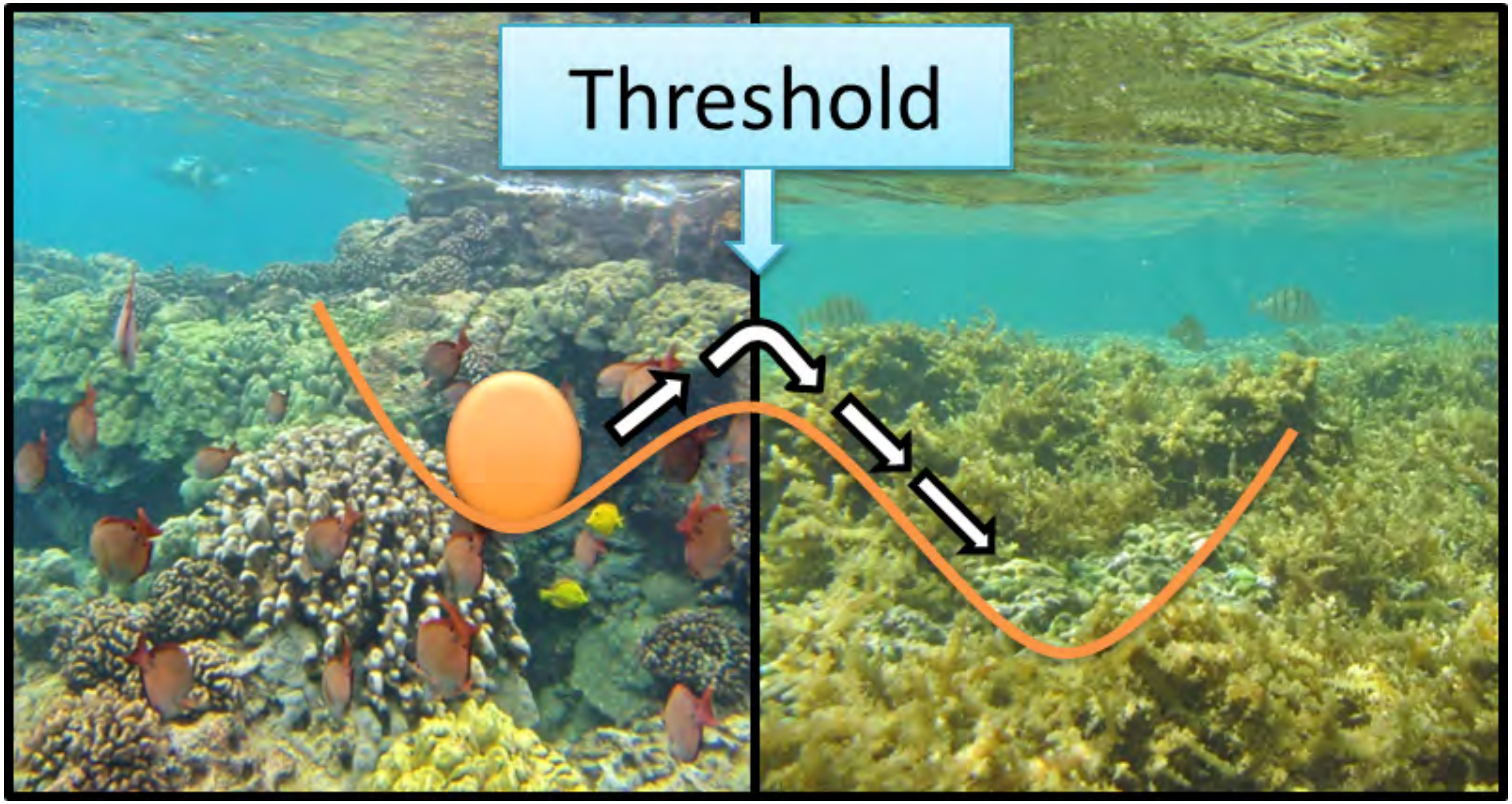


Image: Reproduced with permission, oceantippingpoints.org, available: http://oceantippingpoints.org/our-work/glossary

We will look at the W" shaped graphs in the next topic- as they relate to resilience.

Coral bleaching occurs when the water temperature is too hot for too long.
Zooxanthellae are expelled when the temperature induced stress reaches a threshold.

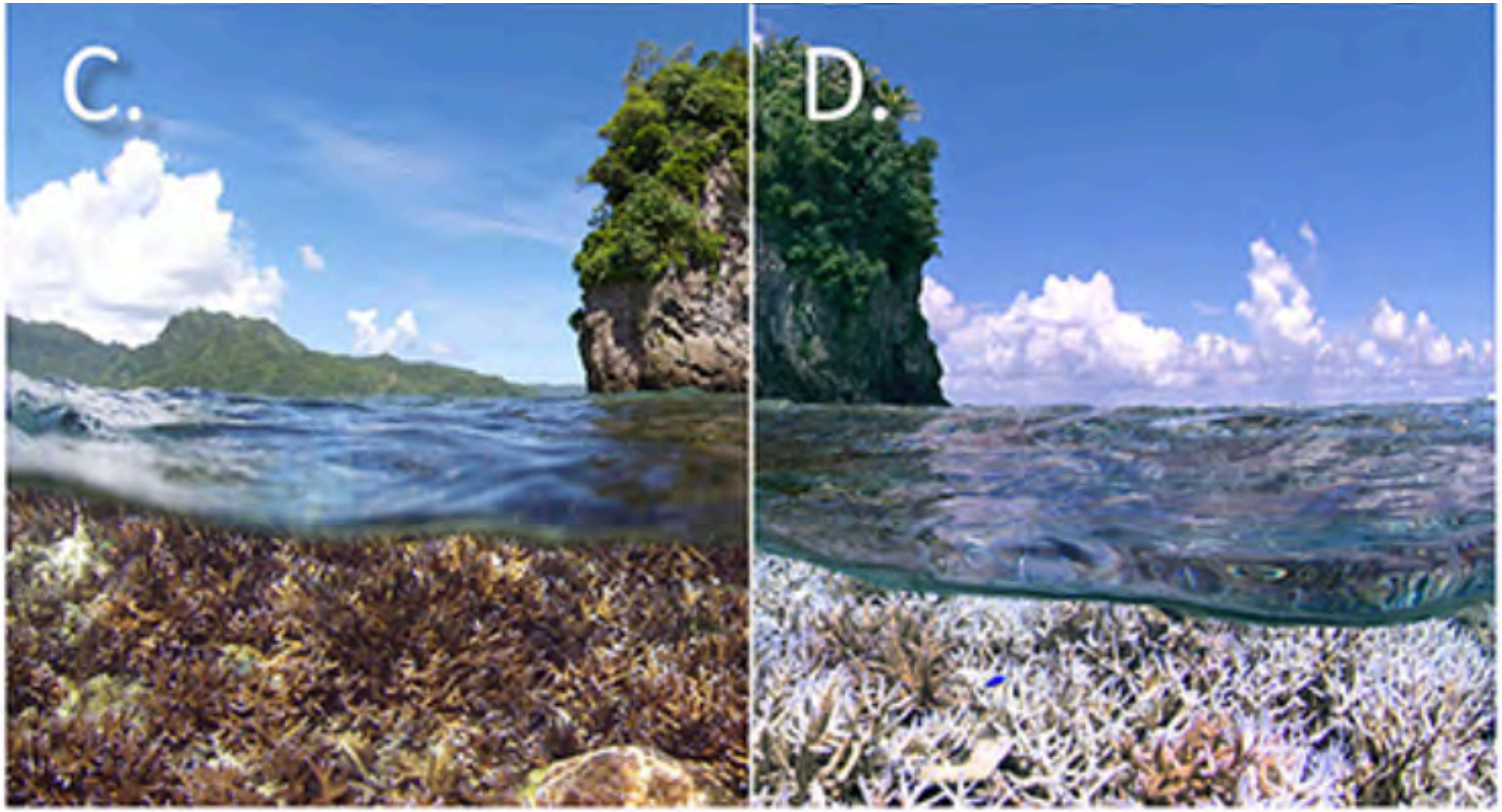
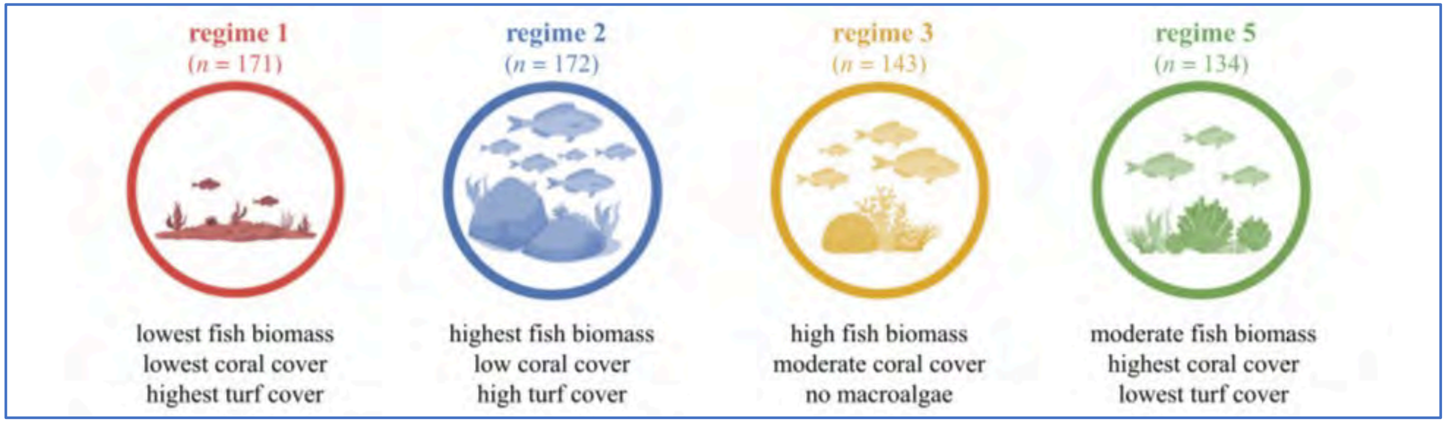
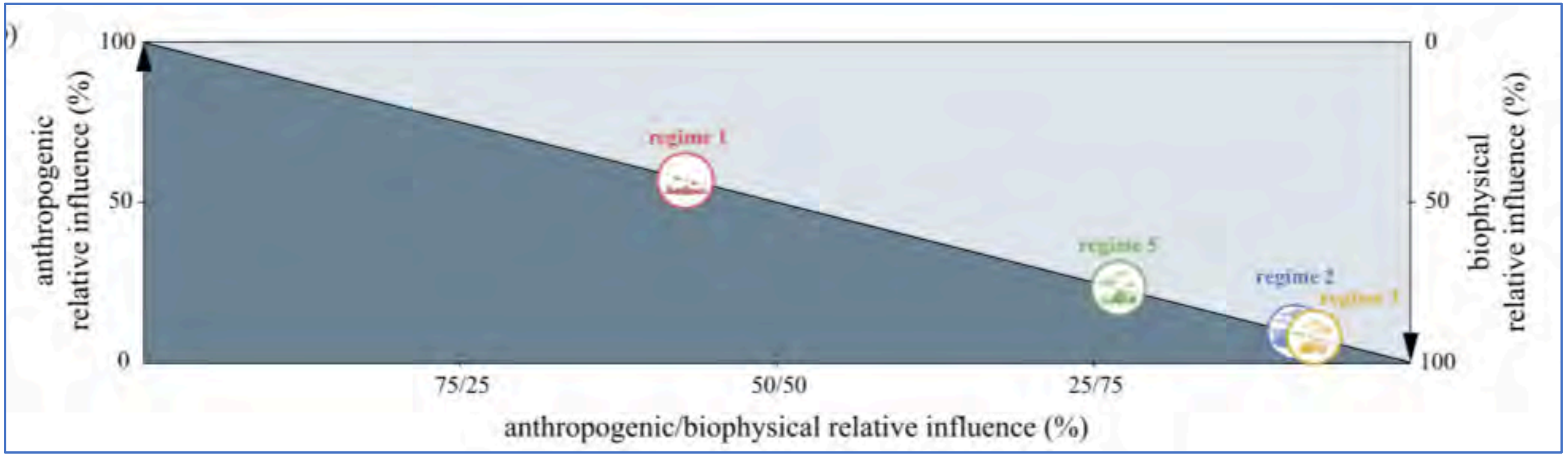


Image: Richard Vevers, The Ocean Agency, as used in Hoegh-Guldberg, O., Poloczanska, E., Skirving, W., & Dove, S. (2017). Coral Reef Ecosystems under Climate Change and Ocean Acidification. *Frontiers In Marine Science*, *4*. doi: 10.3389/fmars.2017.00158 Open access, CCBY 4 available: https://www.frontiersin.org/articles/10.3389/fmars.2017.00158/full

Jouffray et al recognised four distinct stable regimes (or ecosystem states) on Hawaiian reefs (Regime 4 was highly variable and transitional).

Drivers include overfishing, reduced water quality and climate change, as well as structural complexity (rugosity), depth, wave energy and sea surface temperature.

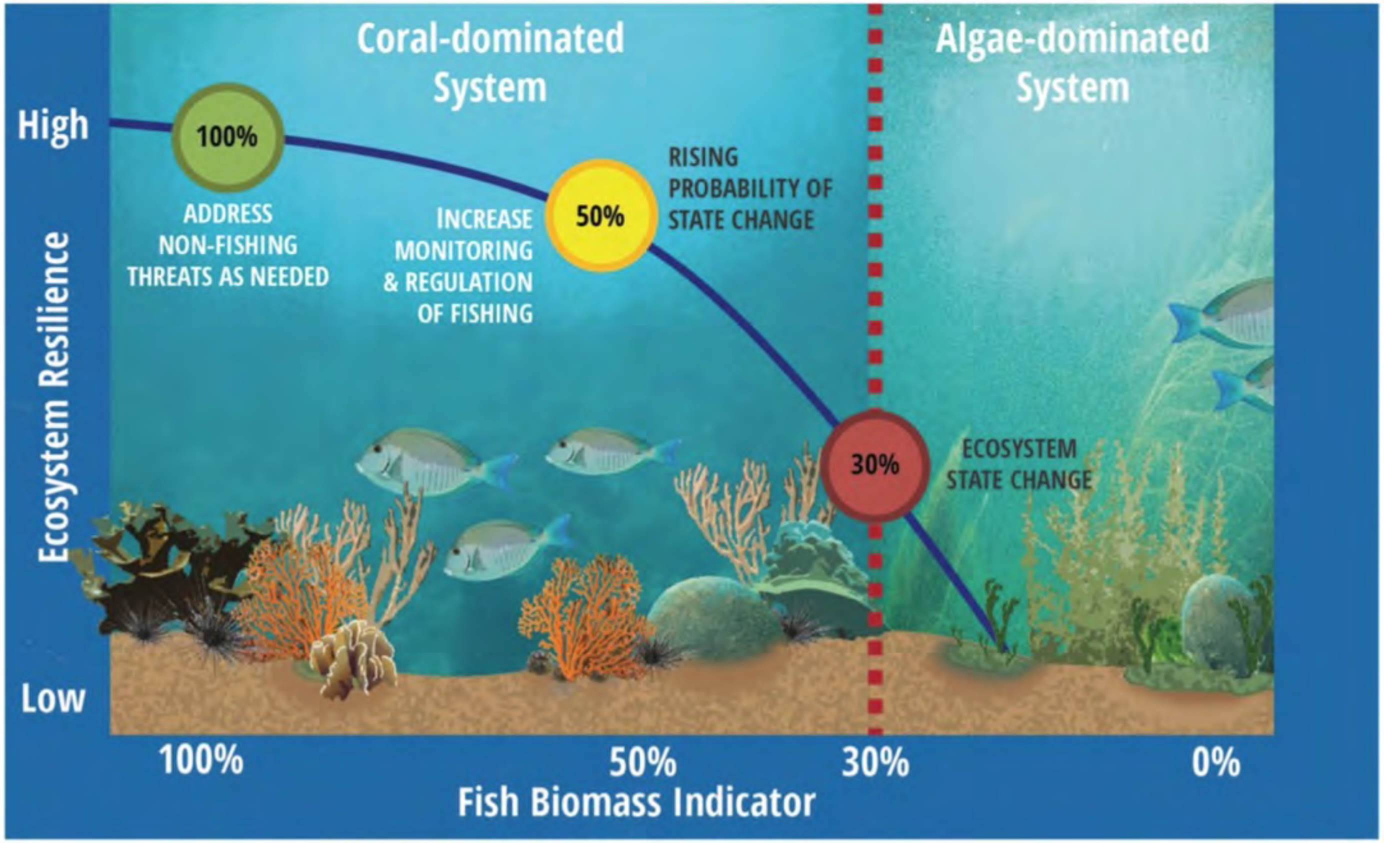




Jouffray J-B et al. 2019 Parsing human and biophysical drivers of coral reef regimes. Proc. R. Soc. B 286: 20182544. http://dx.doi.org/10.1098/rspb.2018.2544. Open access, CCBY 4 available:

Shifts in ecosystem state on coral reefs are often away from coral and towards macro-algae. Some reefs recover from disturbances quickly, and do not shift states.

Knowing how close a system is to a tipping point is critical to our ability to manage resilience and sustain ecosystem services.



Ref: Holbrook, S., Schmitt, R., Adam, T., & Brooks, A. (2016). Coral Reef Resilience, Tipping Points and the Strength of Herbivory. *Scientific Reports*, *6*(1). doi: 10.1038/srep35817. CCBY4. Image: "Ocean Tipping Points Guide", based on Karr *et al,* 2015, Reproduced with permission K Selkoe, http://oceantippingpoints.org/sites/default/files/uploads/OTP_GUIDE_Final.pdf

Caribbean coral reefs have undergone a phase shift from coral reef to algae dominated ecosystems. A major driver is the overfishing of herbivorous fish.

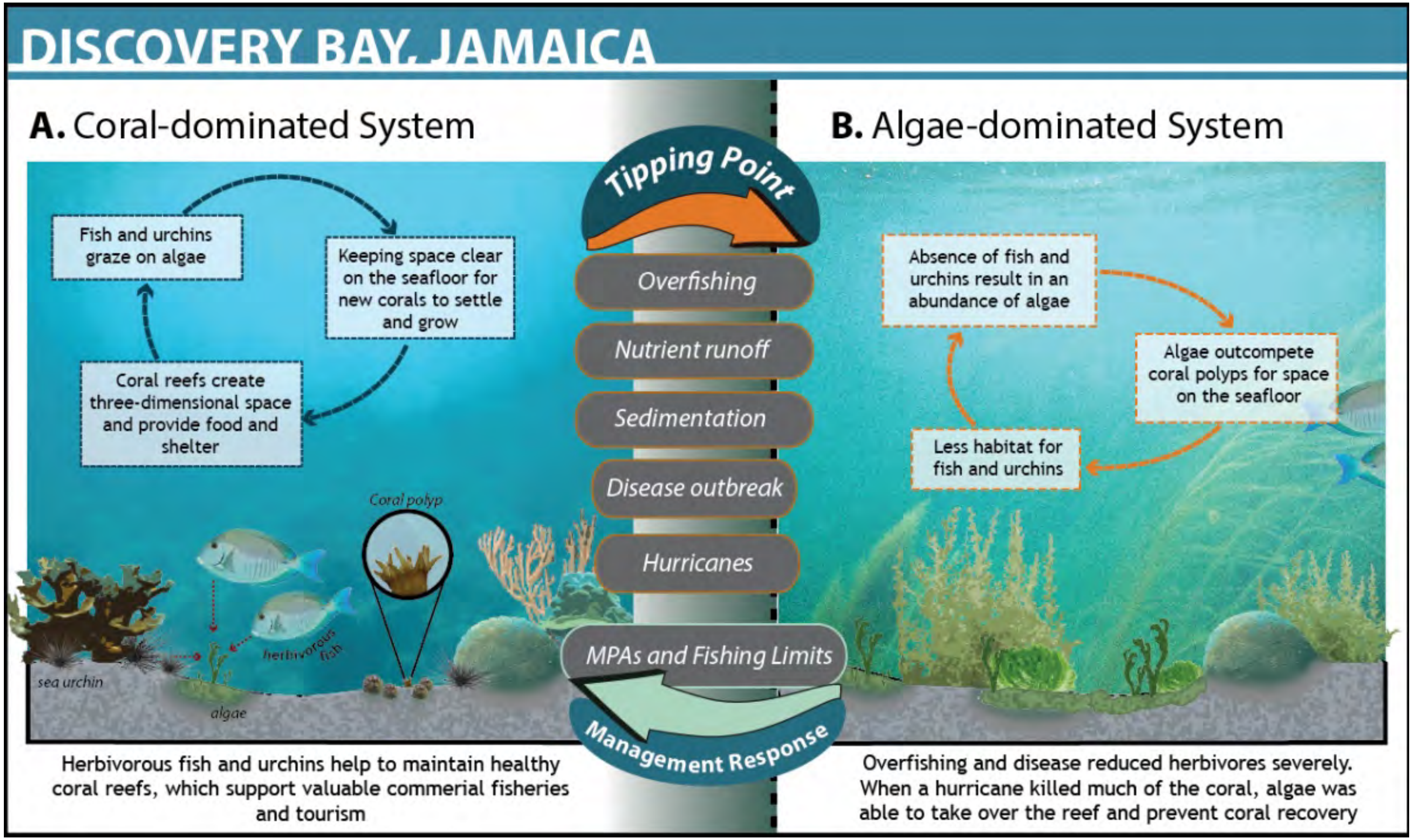
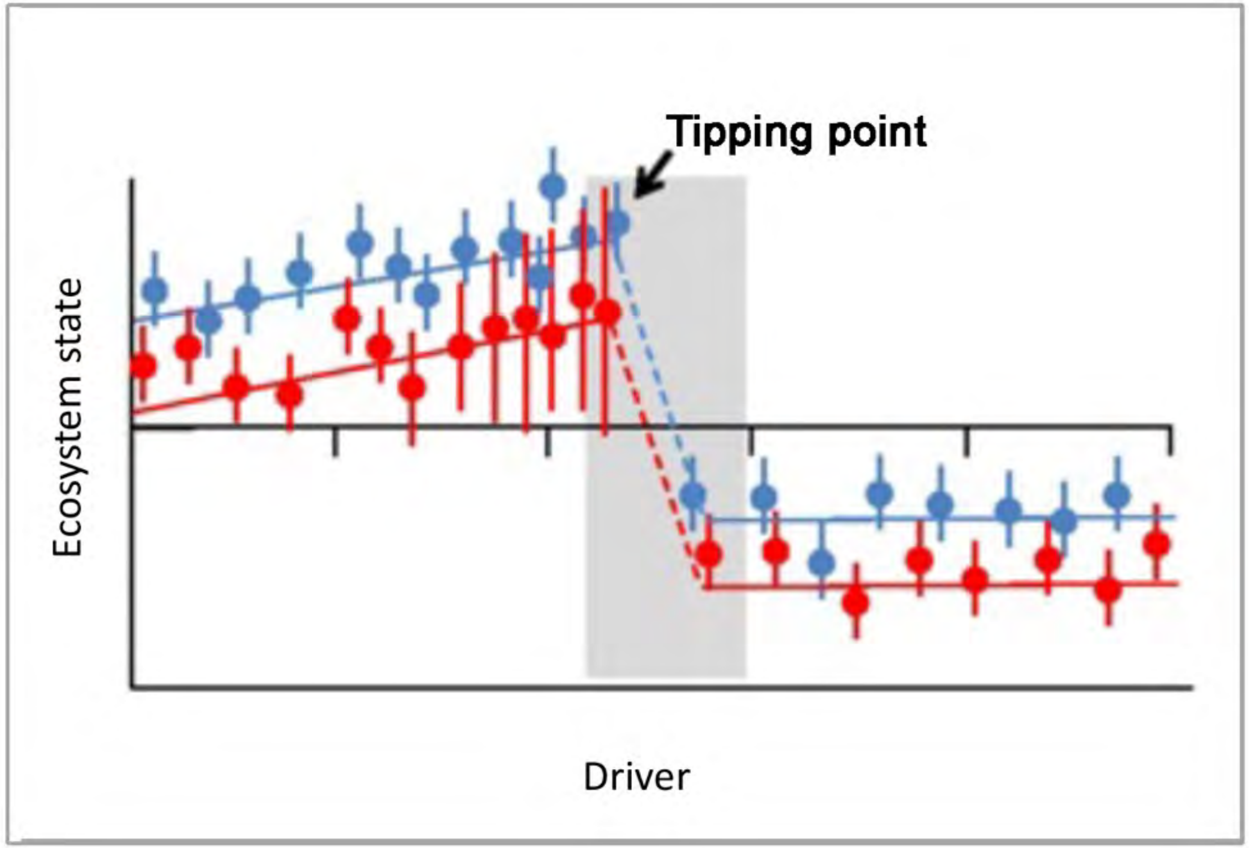


Image: Jackie Mandoske, reproduced with permission from K Selkoe, available: http://oceantippingpoints.org/sites/default/files/uploads/Jamaica.png

Tipping points and regime shifts in the future are difficult to predict.

This graph shows an external driver gradually changing the state of the blue and red ecosystem until a tipping point is reached, after which the ecosystems transition to new states.

The increased variability (around the mean state) of the red ecosystem can provide an early warning that the system is approaching a tipping point. The blue ecosystem shows no early warning.

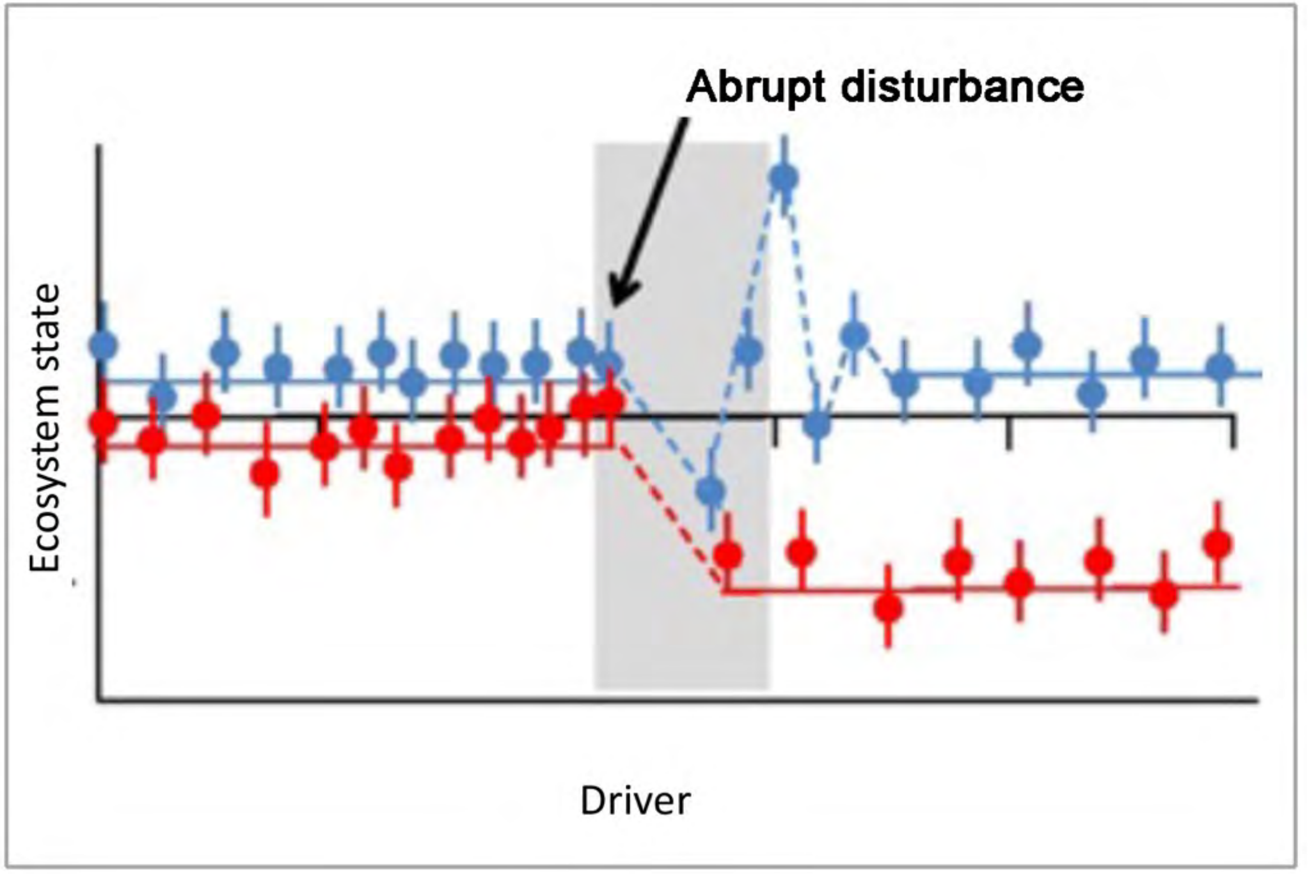


Moore, J. (2018). Predicting tipping points in complex environmental systems. *Proceedings Of The National Academy Of Sciences*, *115*(4), 635-636. doi: 10.1073/pnas.1721206115. PNAS CCBY open access

This graph shows both red and blue ecosystems in a relatively stable states until an abrupt disturbance occurs.

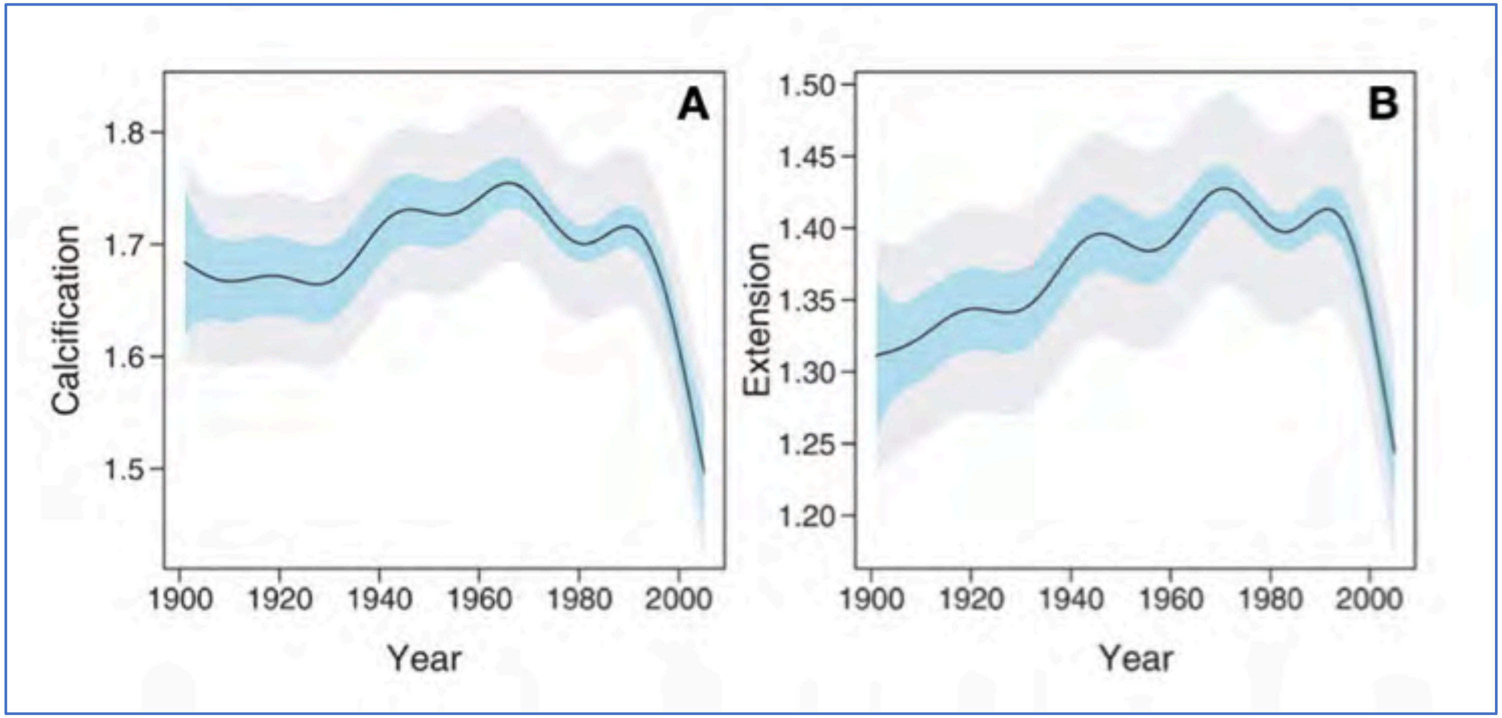
This disturbance initially alters their state of both ecosystems.

The blue ecosystem recovers from the disturbance and returns to its original state, while the red ecosystem is pushed beyond a tipping point and transitions to an alternate state.



Moore, J. (2018). Predicting tipping points in complex environmental systems. *Proceedings Of The National Academy Of Sciences*, *115*(4), 635-636. doi: 10.1073/pnas.1721206115. PNAS CCBY open access

"Long-term records show that this severe and sudden decline in coral growth is unprecedented in at least the last 400 years, and that 1990 may have been a 'tipping point' for coral calcification rates on the Reef."



The calcification rate of Porites colonies in the Great Barrier Reef show a non-linear response to sea surface temperature.

Ref: AIMS; https://www.aims.gov.au/docs/research/climate-change/declining-coral-growth.html
Image: Cropped but unmodified from original figure from Hoegh-Guldberg, O., Poloczanska, E., Skirving, W., & Dove, S. (2017). Coral Reef Ecosystems under Climate Change and Ocean Acidification. *Frontiers In Marine Science*, *4*. doi: 10.3389/fmars.2017.00158 Open access, CCBY 4 available: https://www.frontiersin.org/articles/10.3389/fmars.2017.00158/full

The atmospheric CO_2 concentration will continue increasing in the near future. A carbonate threshold of 480 ppm will cause an ecosystem shift towards non-carbonate reef communities.

A simultaneous temperature increase of 2°C is predicted to cause an ecosystem shift to reefs not dominated by corals.

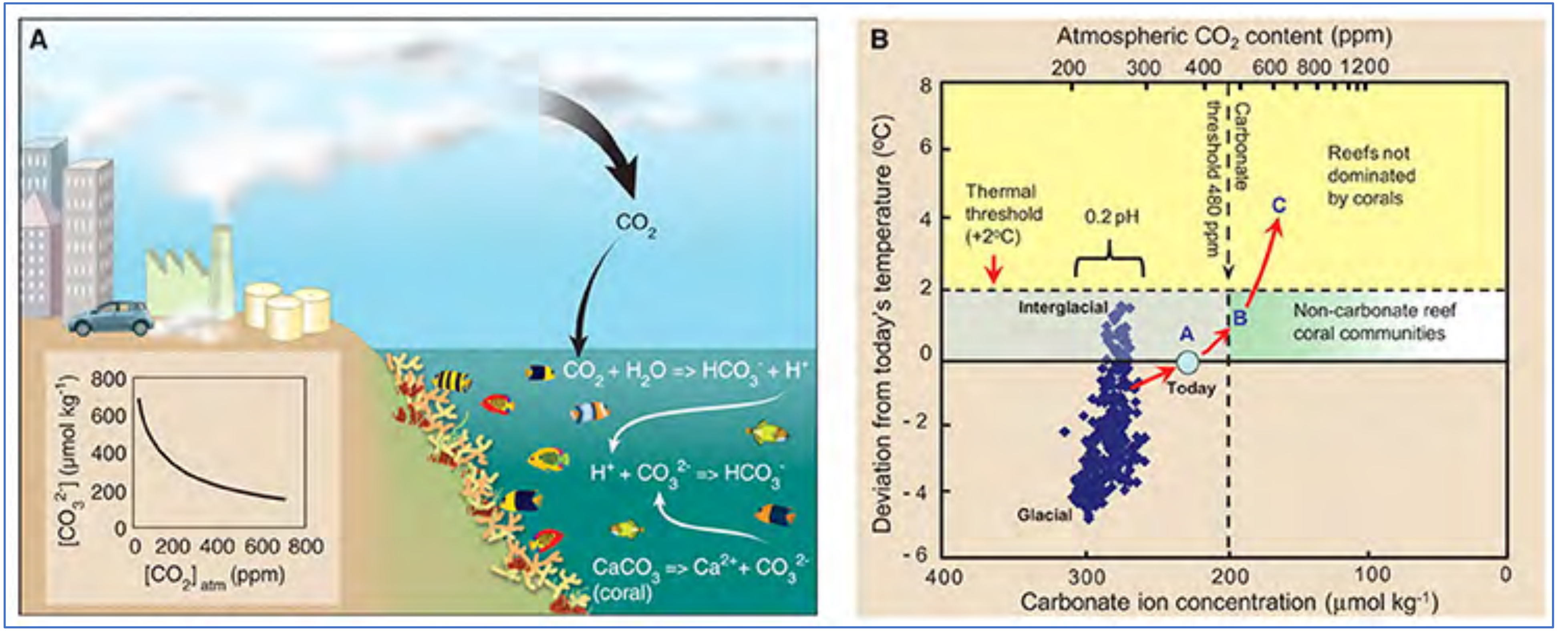
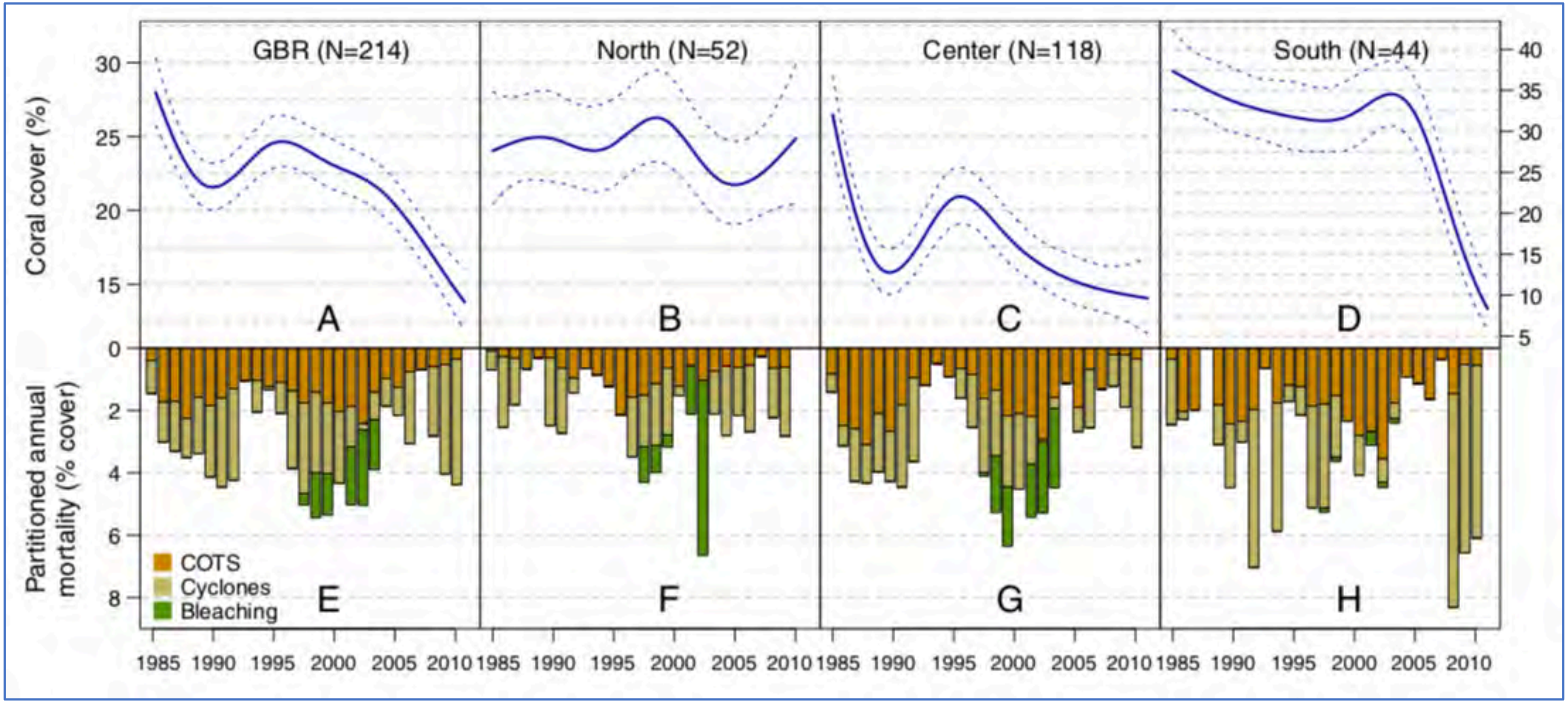


Image: Hoegh-Guldberg, O., Poloczanska, E., Skirving, W., & Dove, S. (2017). Coral Reef Ecosystems under Climate Change and Ocean Acidification. *Frontiers In Marine Science*, *4*. doi: 10.3389/fmars.2017.00158 Open access, CCBY 4 available: https://www.frontiersin.org/articles/10.3389/fmars.2017.00158/full

These graphs show trends in % coral cover (A-D) and % of mortality caused by COTS, cyclones and bleaching on the Great Barrier Reef.

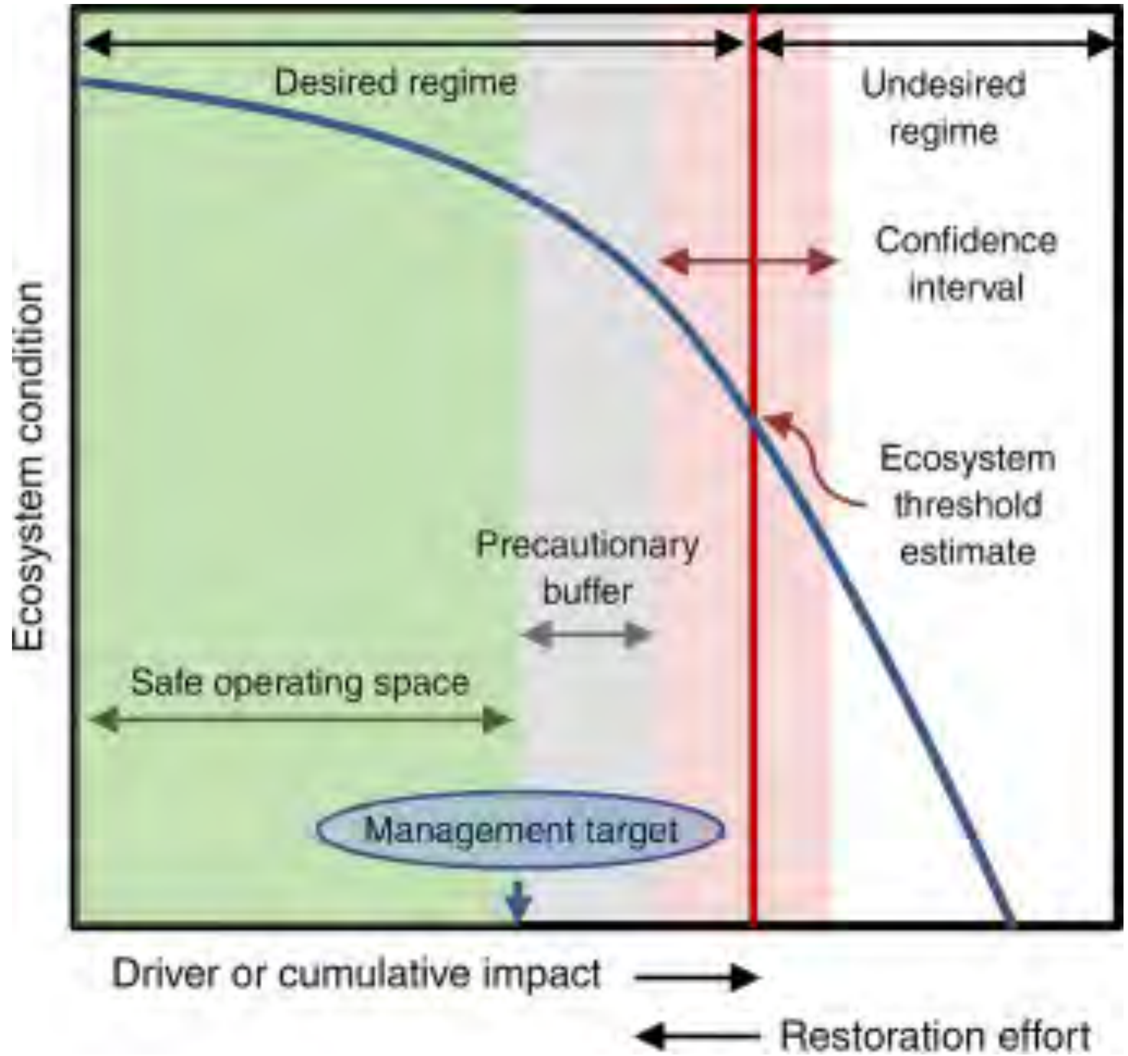


De'ath, G., Fabricius, K., Sweatman, H., & Puotinen, M. (2012). The 27-year decline of coral cover on the Great Barrier Reef and its causes. *Proceedings Of The National Academy Of Sciences*, *109*(44), 17995-17999. doi: 10.1073/pnas.1208909109, PNAS CCBY open access

Detailed knowledge of tipping points can be used to inform management decisions, so that the transition to undesired ecosystem regimes may be avoided.

This provides a "safe operating space" for drivers such as fisheries yields.

The size of the precautionary buffer depends on the confidence limits of the threshold.



Selkoe, K., Blenckner, T., Caldwell, M., Crowder, L., Erickson, A., & Essington, T. et al. (2015). Principles for managing marine ecosystems prone to tipping points. *Ecosystem Health And Sustainability*, *1*(5), 1-18. doi: 10.1890/ehs14-0024.1, Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/)

High resolution models such as these are used to help scientists predict bleaching events.

Graph A shows the relationship between monthly sea surface temperature (SST) and the probability of coral bleaching.

Graph D shows the relationship between degree heating weeks (1 degree higher than normal, for 1 week= I degree heating week) and the probability of coral bleaching

The dotted vertical line shows the bleaching threshold.

The grey areas are the 95% confidence limits.

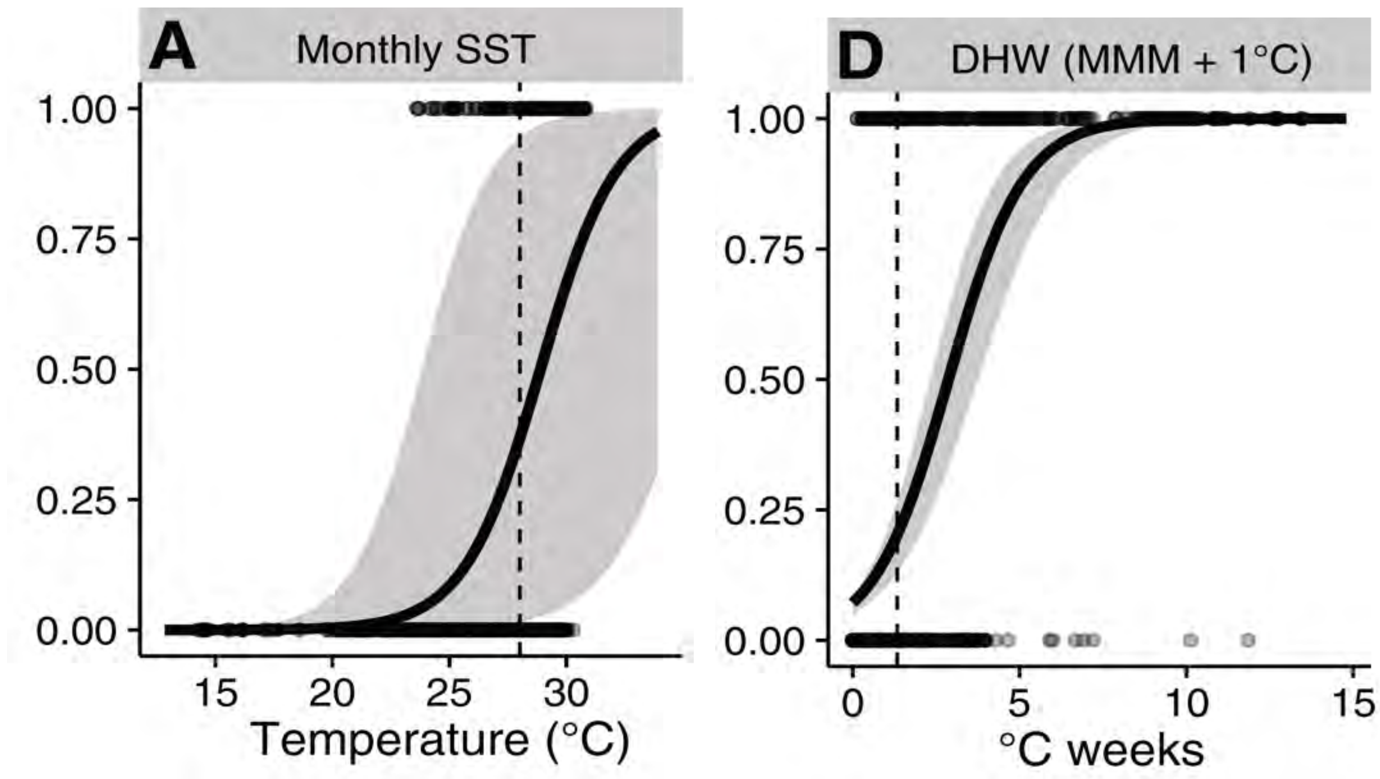
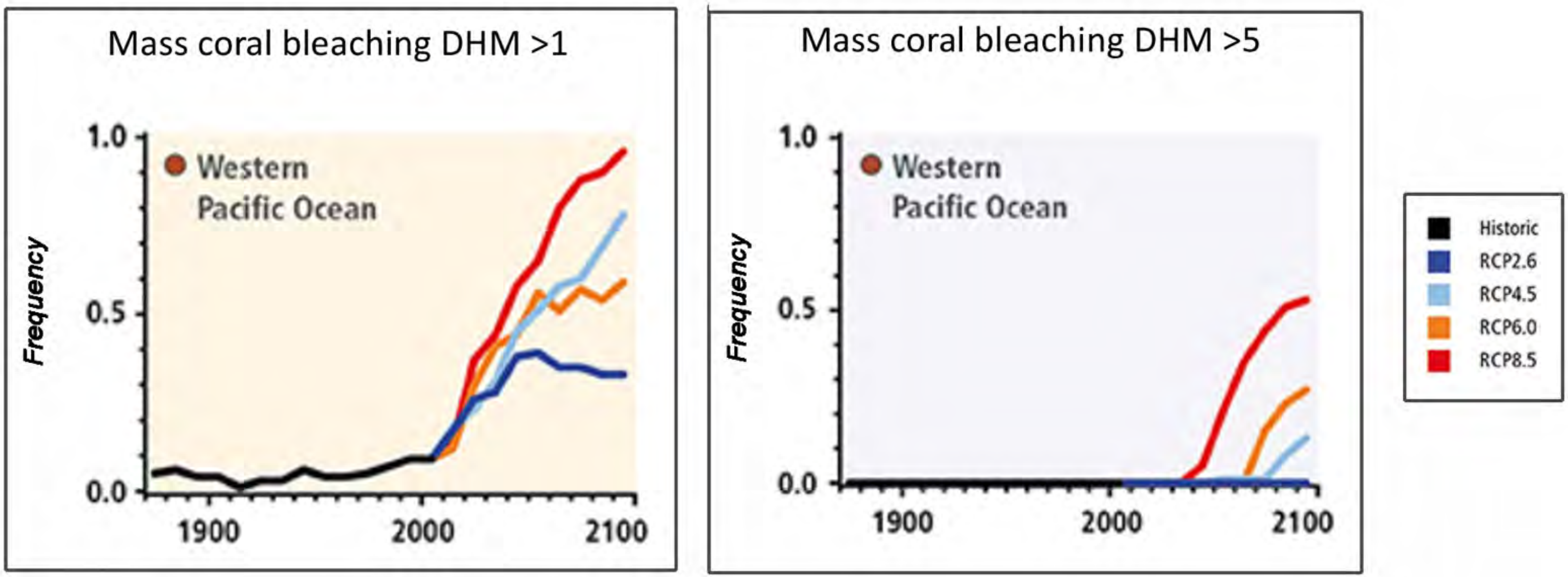


Image: Kumagai, N., & Yamano, H. (2018). High-resolution modeling of thermal thresholds and environmental influences on coral bleaching for local and regional reef management. *Peerj*, *6*, e4382. doi: 10.7717/peerj.4382

These graphs show future projections of coral bleaching and coral mortality for coral reefs in the Western Pacific Ocean (where the Great Barrier Reef is), based on degree heating months.

Can you see any tipping points?



Images: The Western Pacific Ocean section only of Figure 7 from Hoegh-Guldberg, O., Poloczanska, E., Skirving, W., & Dove, S. (2017). Coral Reef Ecosystems under Climate Change and Ocean Acidification. *Frontiers In Marine Science*, *4*. doi: 10.3389/fmars.2017.00158 Open access, CCBY 4 available: https://www.frontiersin.org/articles/10.3389/fmars.2017.00158/full

In this video, six leading ocean thinkers discuss rapid, potentially irreversible shifts in our oceans.

https://www.youtube.com/watch?v=8NWmagRlArI

YouTube video posted by Phillip Levin, available: https://youtu.be/8NWmagRlArI

Question

Explain the concept of “tipping points” in your own words.

How do tipping points affect coral reef ecosystems?

Further activities

See

https://coralwatch.org/index.php/education-2/curriculum-materials/marine-science/

by

CORALWATCH

Further activity

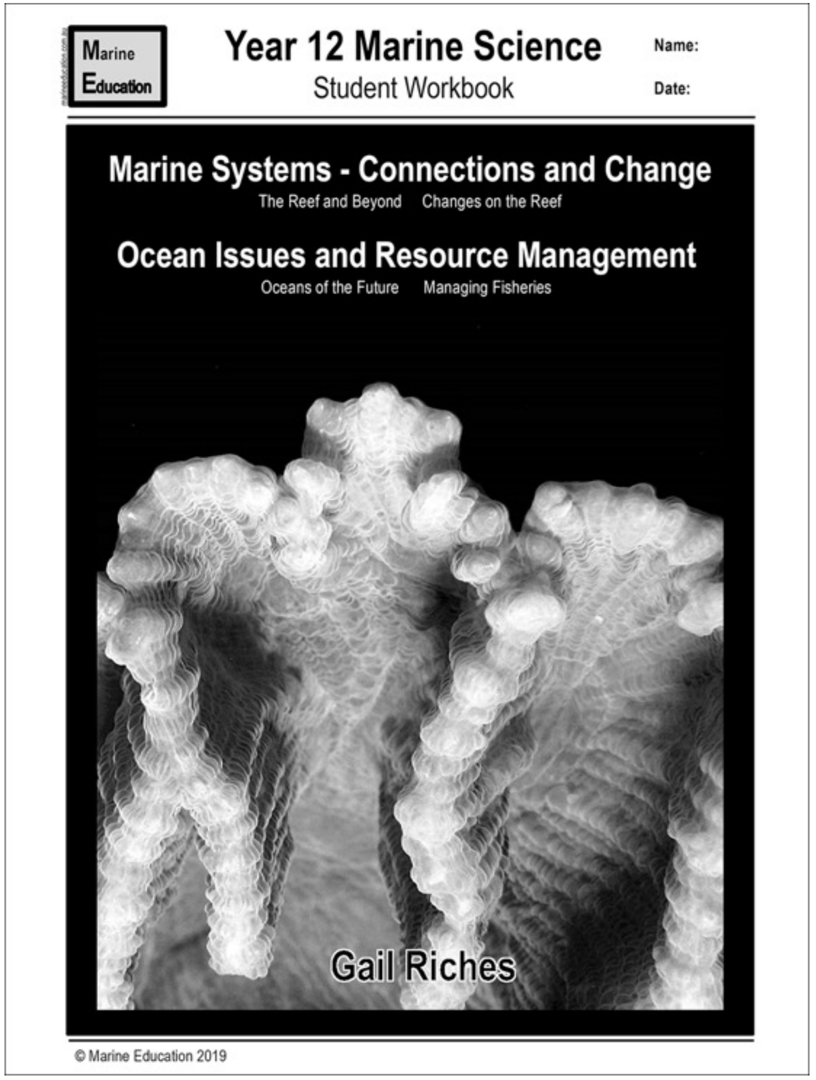
Worksheet –

Tipping over the edge

by

Gail Riches

www.marineeducation.com.au



T092 Reef hysteresis

Adam Richmond

Syllabus statement

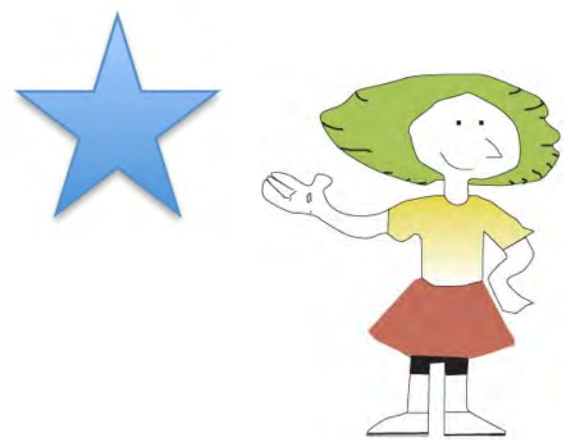
At the end of this topic you should be able to ...

Describe

Describe hysteresis and how this applies to the concept of reef resilience

Describe

- give an account (written or spoken) of a situation, event, pattern or process, or of the characteristics or features of something



Objective

Recall a definition for resilience
Explain the idea of "reef resilience"

Explain how a model can represent hysteresis
Explain how hysteresis affects the resilience of a coral reef ecosystem

Definitions

Refer back to topic 44: important ecosystem definitions for more information about these terms.

From the syllabus:

Ecosystem resilience: the capacity of an ecosystem to recover from a disturbance or withstand ongoing pressures.

So you also need to know:

Ecosystem disturbance: a temporary change in environmental conditions that alters physical structures or arrangements of biotic and abiotic elements within an ecosystem; can also occur over larger temporal scales and affect diversity; can be natural or anthropogenic

Ecosystem recovery: the return of a damaged ecological system and associated ecosystem services to a stable state.

Hysteresis: When the return pathway to ecosystem, recovery differs from the original pathway of degradation.

Check out the Reef Resilience network website: https://reefresilience.org/resilience/ for a good overview of coral reef resilience and more resources.

The Reef Resilience Network define resilience as
"the ability of a system to maintain key functions and processes in the face of stresses or pressures by resisting to and then recovering or adapting to change"

Resilience includes three components:
1) resistance: refers to the ability to absorb or resist impacts
2) recovery: refers to the ability to recover from impacts
3) transformation: refers to changes that affect the function of the ecosystem

Reference: What is resilience? Reef Resilience Network, The Nature Conservancy, https://reefresilience.org/resilience/what-is-resilience/

The previous topic explained that ecosystem disturbances, stressors or drivers are impacting on coral reef ecosystems, that can lead to a shift to an alternate ecosystem state.

Image: Reproduced with permission, oceantippingpoints.org

Reference for the next few slides:

http://oceantippingpoints.org/our-work/glossary

This diagram shows the transition between two stable states- a reef dominated by coral and a reef dominated by fleshy macroalage.

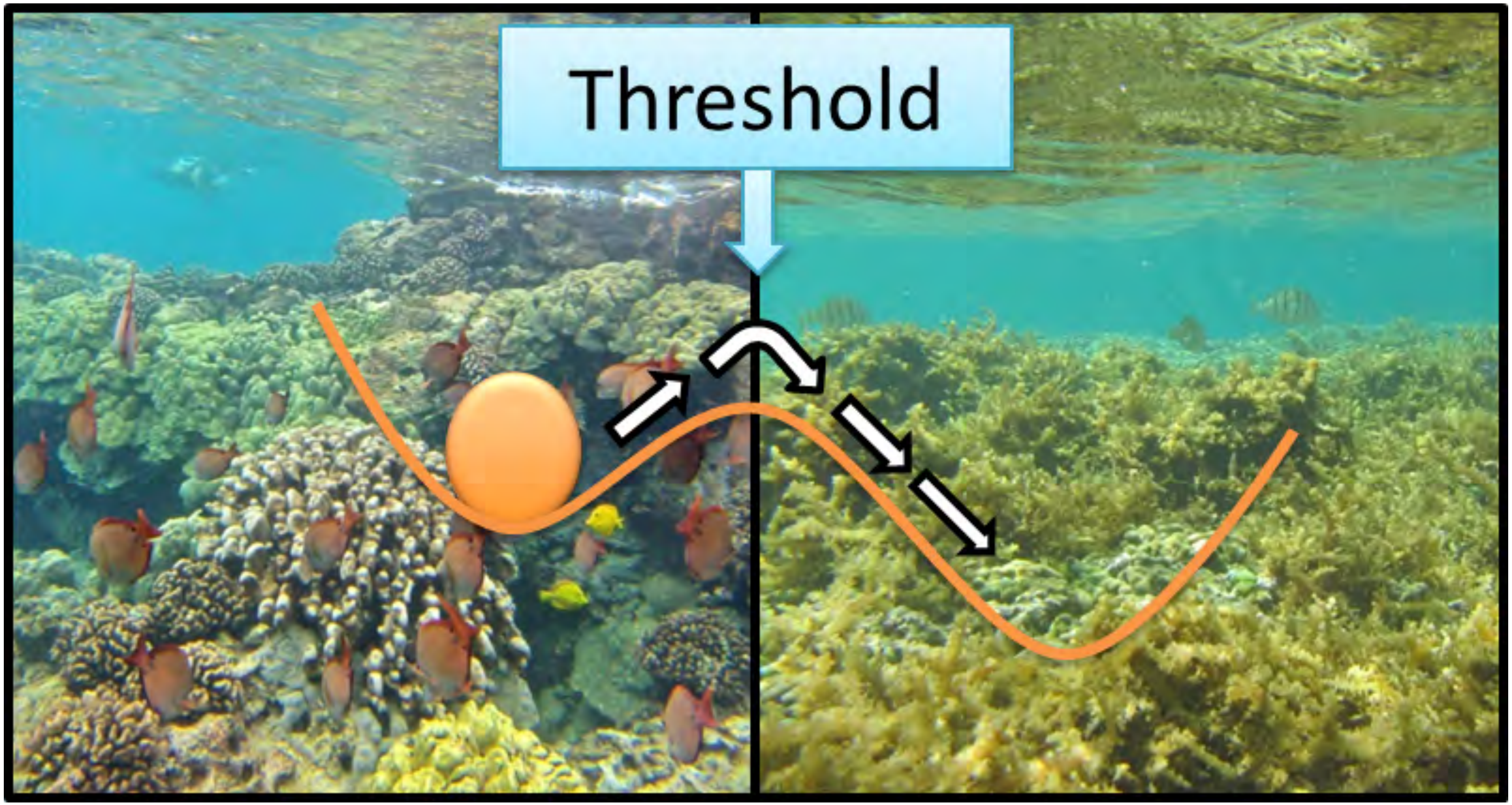


Image: Reproduced with permission, oceantippingpoints.org

The ball and cup (or landscape) model provides an analogy to describe the changes in an ecosystem.

- The ball represents the current state of the ecosystem.
- The lines, or landscape (think of hills and valleys), represent all the possible states of the ecosystem.

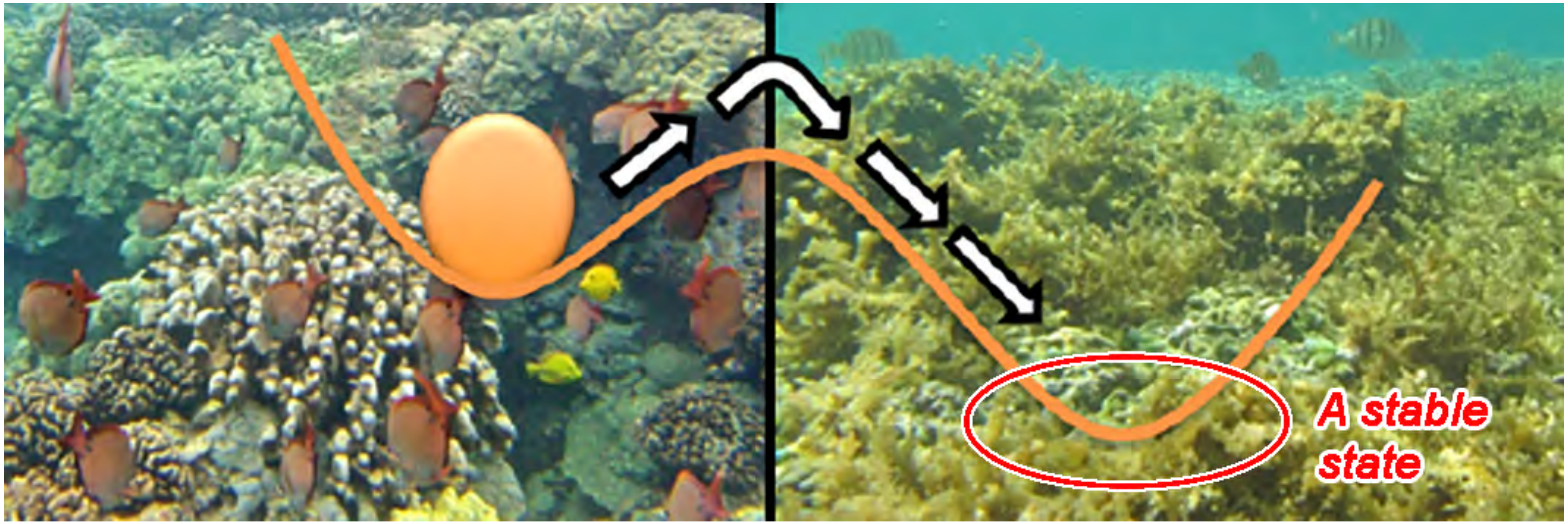


Image: Reproduced with permission, oceantippingpoints.org, available: http://oceantippingpoints.org/our-work/glossary

The ball will naturally roll downhill to a valley (or cup)- which is a stable state.
An external force (or driver, or disturbance) is required to move the ball from the stable point.

If the valley or cup is large or deep the ball can be pushed a long way up the hill, but will always roll back into the valley or cup.

The steep sides allow the ball to return quickly.

This represents an ecosystem that has a high level of resilience- as the ecosystem usually recovers quickly from a small disturbance to the same stable state.

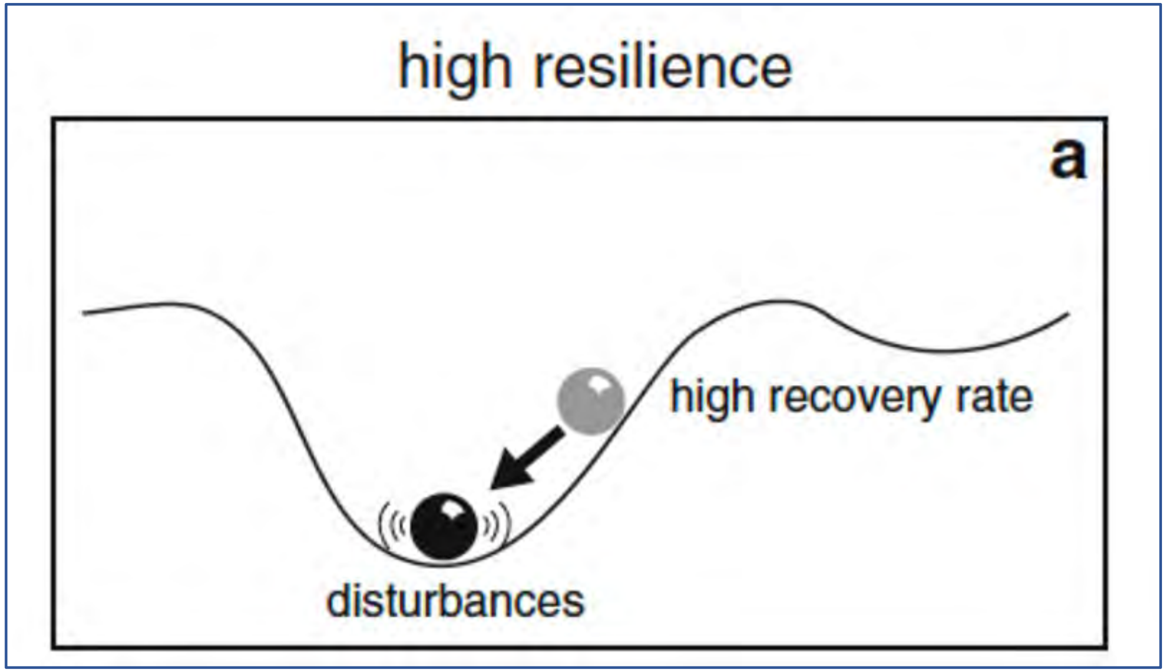


Image: Dakos, V., van Nes, E., Donangelo, R., Fort, H., & Scheffer, M. (2009). Spatial correlation as leading indicator of catastrophic shifts. *Theoretical Ecology*, *3*(3), 163-174. doi: 10.1007/s12080-009-0060-6 open access. Reproduced under the terms and conditions at https://link.springer.com/termsandconditions

If the valley is small or shallow the ball can only be pushed a short distance up the hill, or it won't roll back into the same valley or cup.

The flat slope means the ball returns slowly.

This represents an ecosystem with a low level of resilience- as the ecosystem can only recover to the same stable state from a very small disturbance.

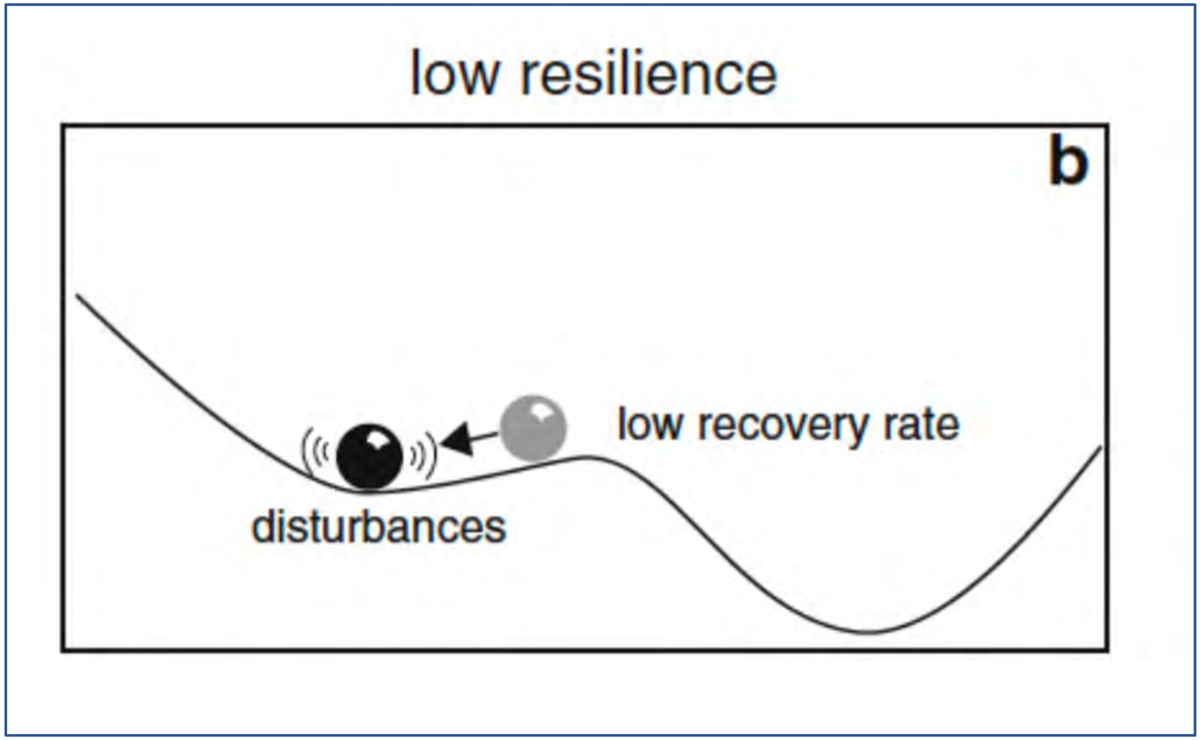


Image: Dakos, V., van Nes, E., Donangelo, R., Fort, H., & Scheffer, M. (2009). Spatial correlation as leading indicator of catastrophic shifts. *Theoretical Ecology*, *3*(3), 163-174. doi: 10.1007/s12080-009-0060-6 open access. Reproduced under the terms and conditions at https://link.springer.com/termsandconditions

If the push provided by the disturbance is be large enough to push the ball over the tipping point or “hill”, the ecosystem will transition from from one stable state (valley) to another.

These changes in an ecosystem- where the ball is moved sideways- are caused by changes in ecosystem state are those that directly affect communities, such as fishing pressure or disease.

The urchin-kelp and coral-algae phase shifts from the last topic could be caused by these types of variables.

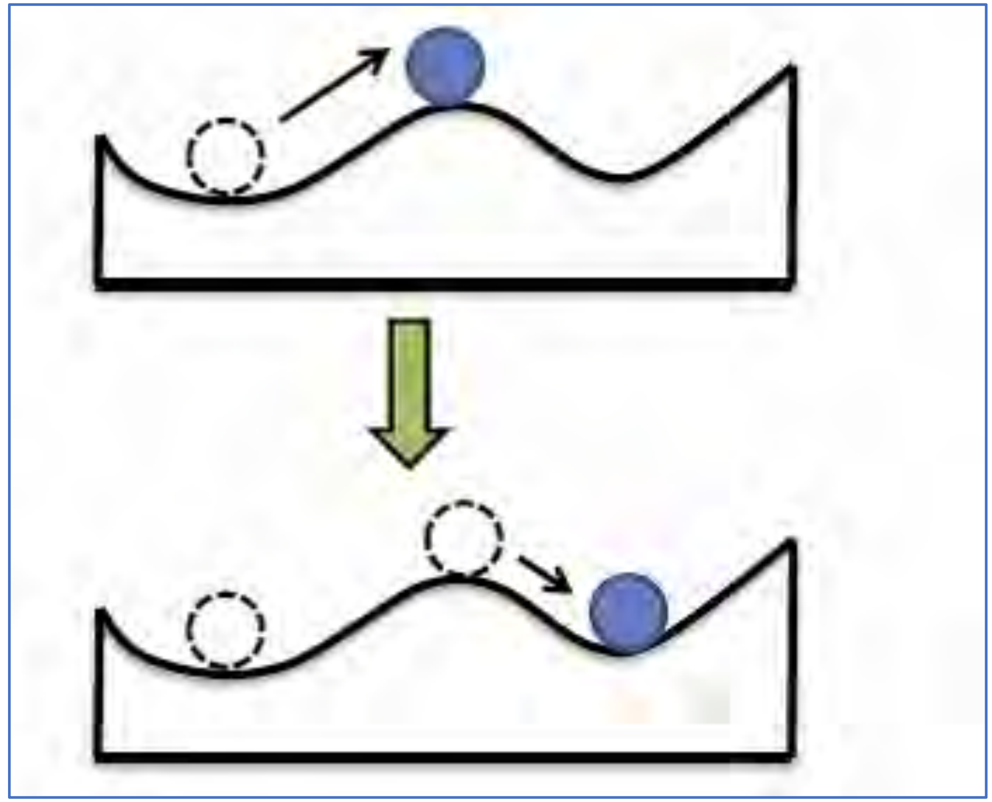


Image: Beisner, B., Haydon, D., & Cuddington, K. (2003). Alternative Stable States in Ecology. *Frontiers In Ecology And The Environment*, *1*(7), 376. doi: 10.2307/3868190, free access: Reproduced under the terms and conditions at https://esajournals.onlinelibrary.wiley.com/doi/epdf/10.1890/1540-9295%282003%29001%5B0376%3AASSIE%5D2.0.CO%3B2

Another way that the ball can move is if the shape of the landscape changes- which then caused the ball to roll downwards.

This kind of change in ecosystem state may occur if environmental parameters change- which then causes a change in the community.

The changes to ecosystems caused by parameters such as water input, oxygen availability, ocean pH, atmospheric CO2 and aragonite saturation would be due to changes in the “landscape”.

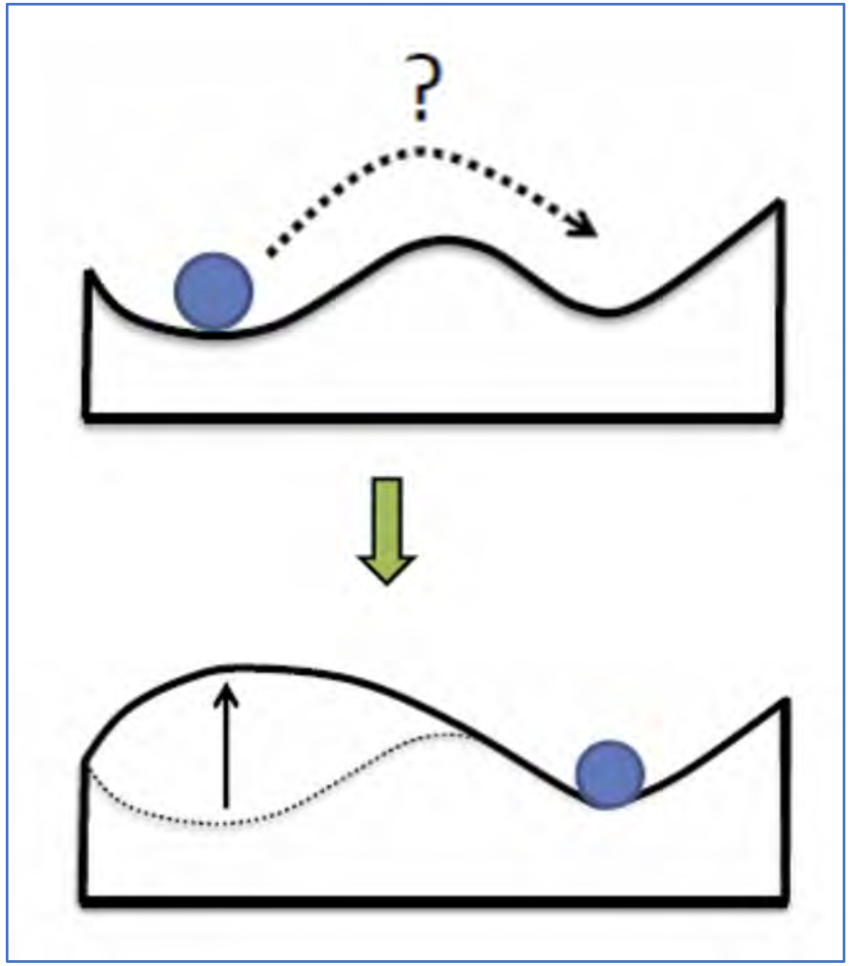
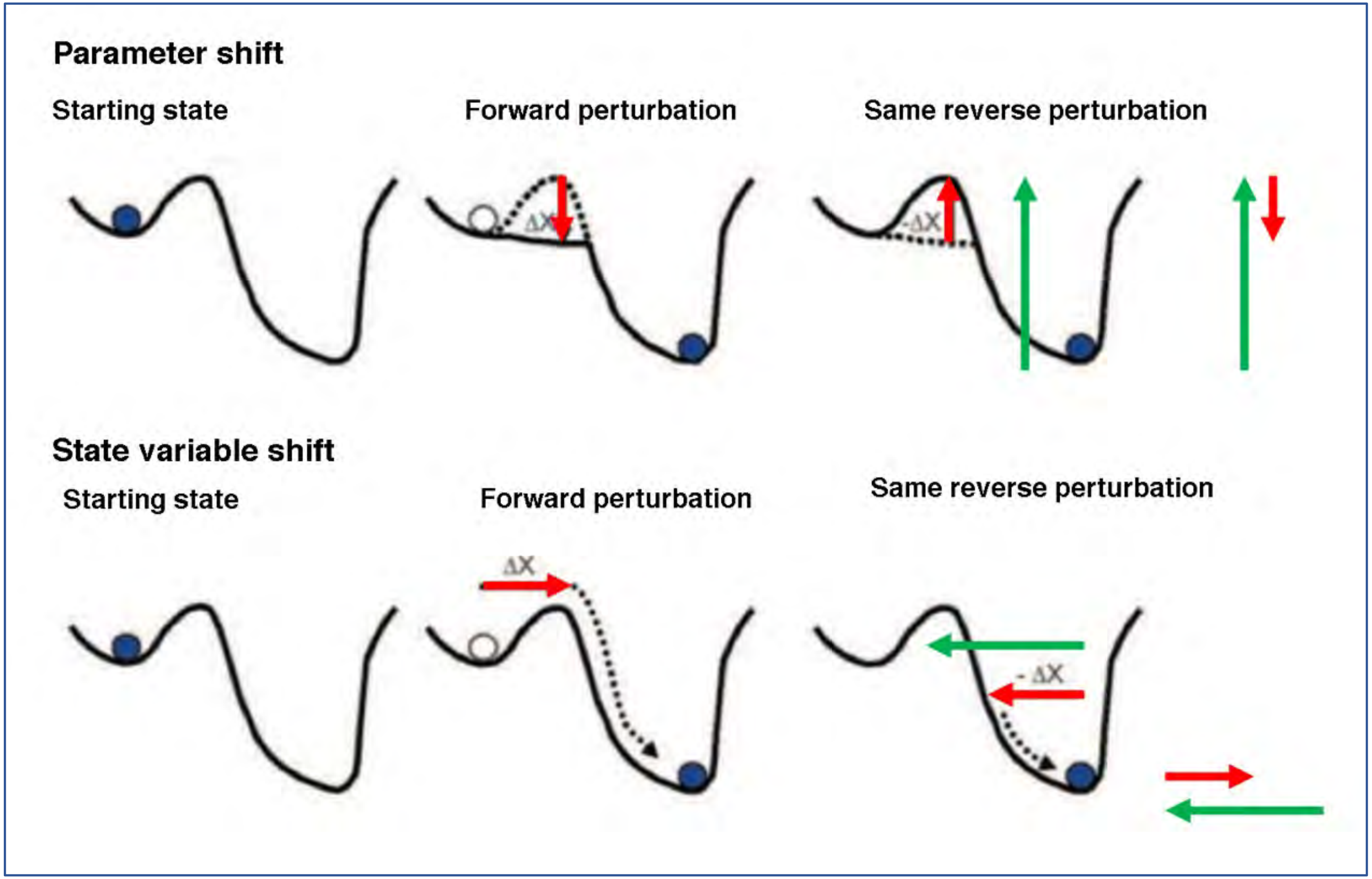


Image: Beisner, B., Haydon, D., & Cuddington, K. (2003). Alternative Stable States in Ecology. *Frontiers In Ecology And The Environment*, *1*(7), 376. doi: 10.2307/3868190, free access: Reproduced under the terms and conditions at https://esajournals.onlinelibrary.wiley.com/doi/epdf/10.1890/1540-9295%282003%29001%5B0376%3AASSIE%5D2.0.CO%3B2

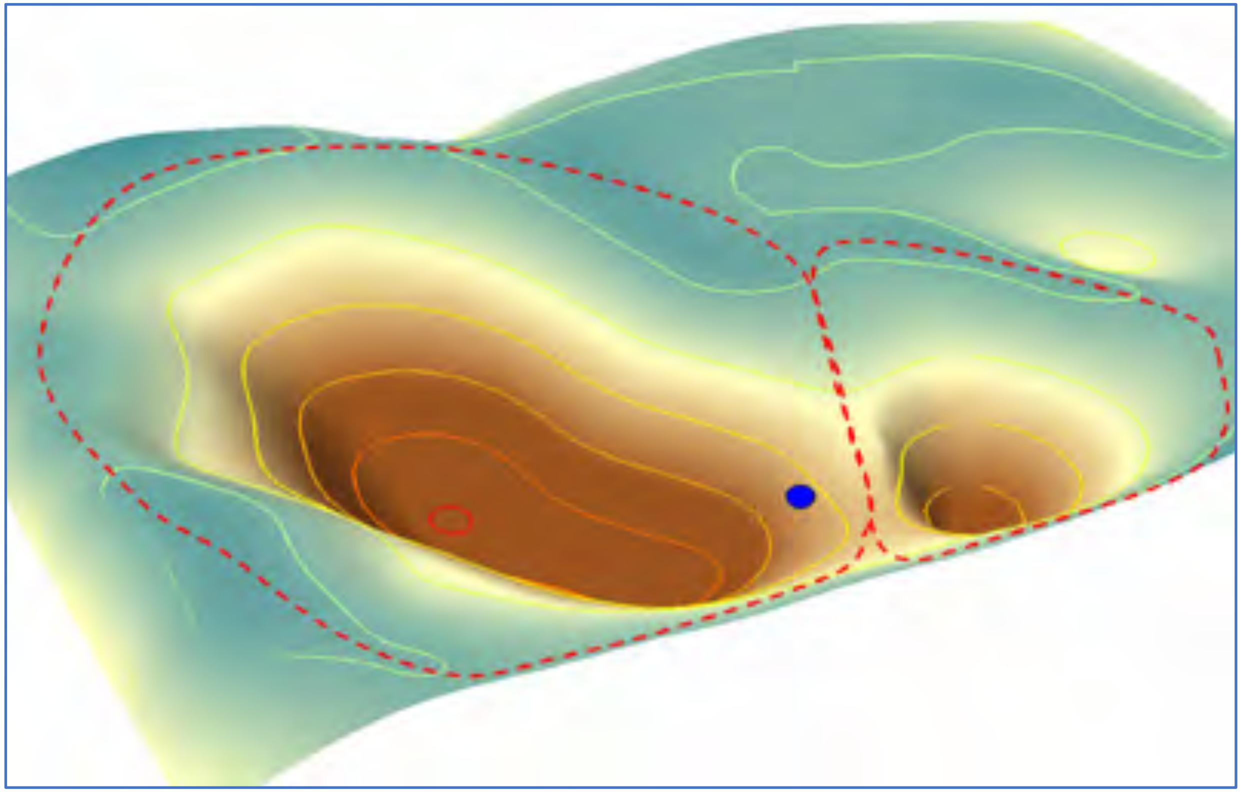
Regardless of whether a variable or parameter causes the change in ecosystem state, sometimes it is harder for the ball to return to its original stable state as shown below:



Beisner, B., Haydon, D., & Cuddington, K. (2003). Alternative Stable States in Ecology. *Frontiers In Ecology And The Environment*, *1*(7), 376. doi: 10.2307/3868190, free access: Reproduced under the terms and conditions at https://esajournals.onlinelibrary.wiley.com/doi/epdf/10.1890/1540-9295%282003%29001%5B0376%3AASSIE%5D2.0.CO%3B2

Ecosystem stability landscape models for determining the response of coral reef ecosystems to change can become really complex!

These models can consider pulse-type stressors, press-type stressors, changes in variables or parameters and whether the ecosystem responds in a linear or non-linear way.



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A 3-dimensional landscape - note the blue "ball" is not in a stable state.

Recall these ecosystems state models from the last topic:

Graph B shows a non linear transition in ecosystem state, like that which occurs on the Great Barrier Reef. There is only one possible ecosystem state for any given condition.

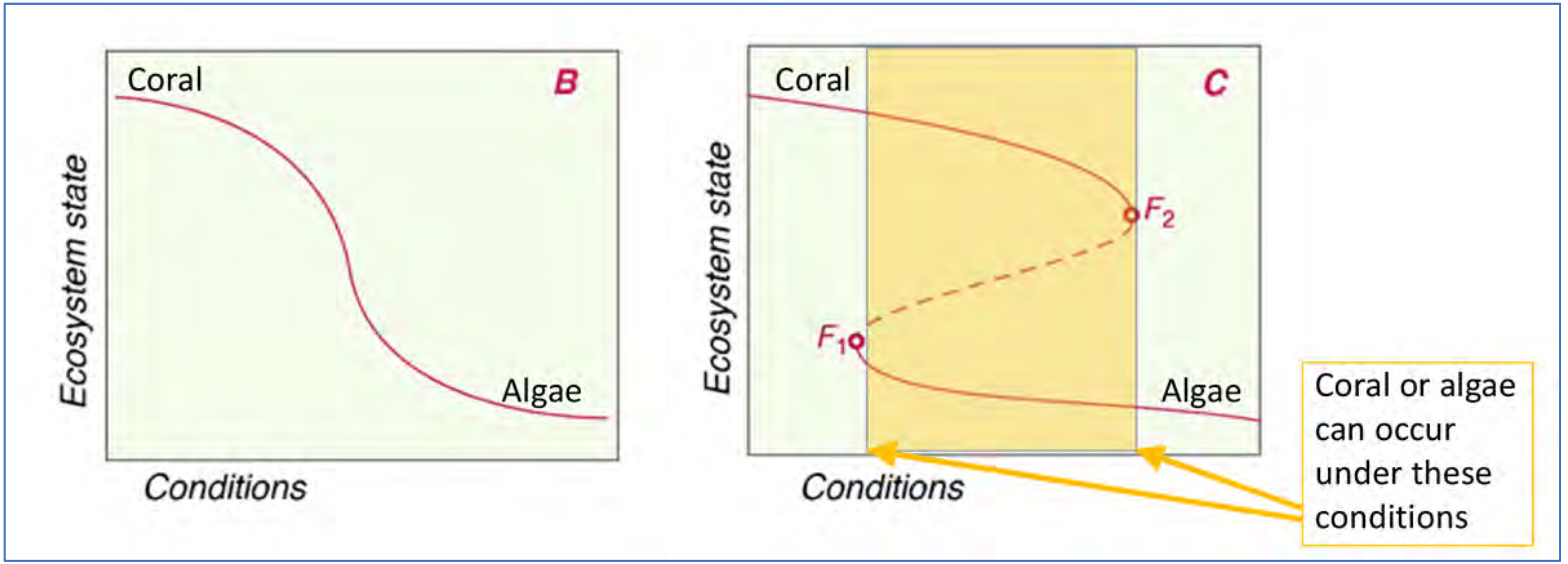
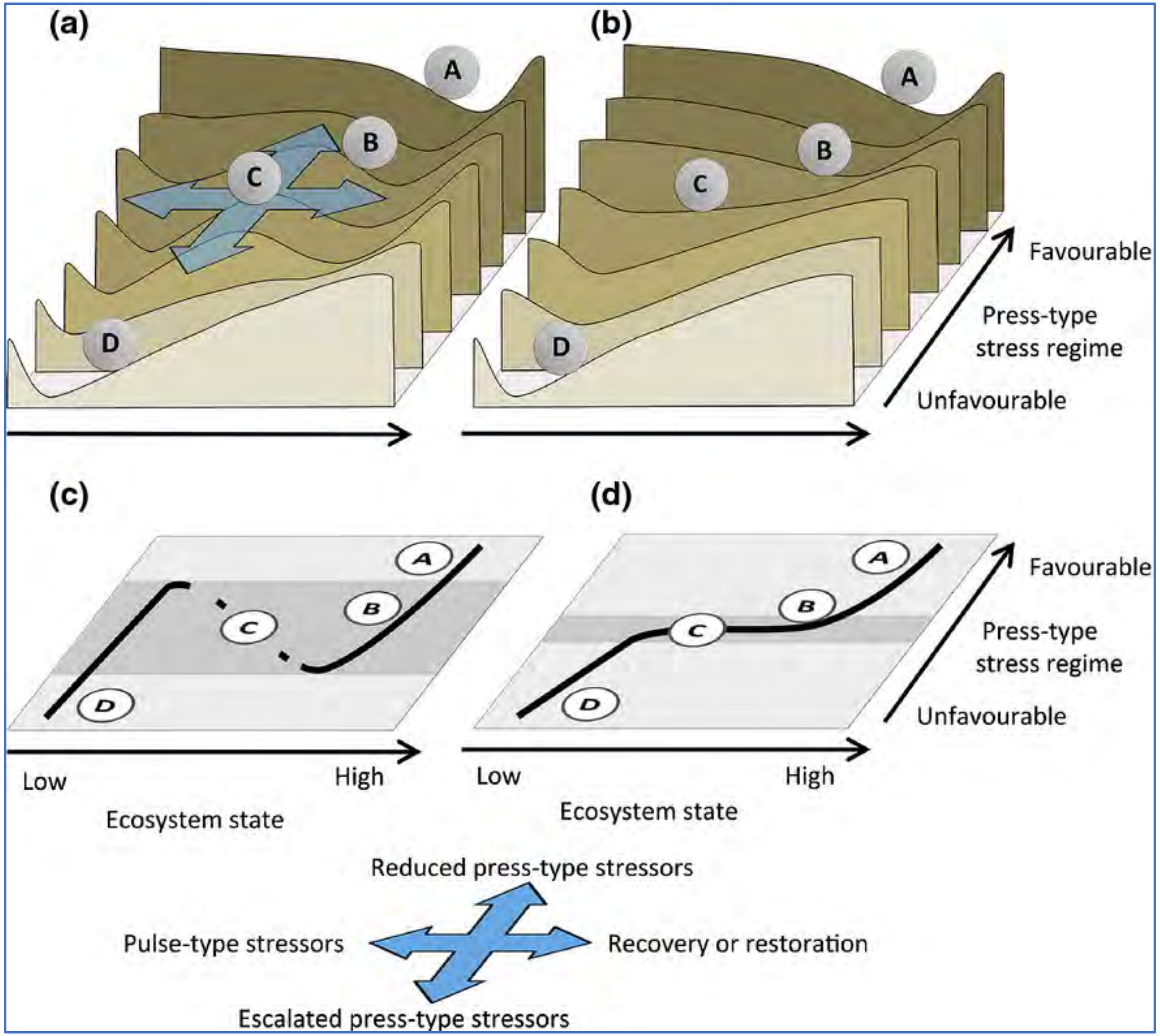


Image: Bob Moffatt, after Scheffer, M., Carpenter, S., Foley, J., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(6856), 591-596. doi: 10.1038/35098000

Graph C shows that an ecosystem can have more than one stable state over a range of conditions. This occurs in the Caribbean reef systems- where coral dominated reefs or algal dominated reefs can exist under the same conditions.

The landscape models in this topic interact with the ecosystem state models introduced in the previous topic.



Images from Anthony, K., Marshall, P., Abdulla, A., Beeden, R., Bergh, C., & Black, R. et al. (2014). Operationalizing resilience for adaptive coral reef management under global environmental change. *Global Change Biology*, *21*(1), 48-61. doi: 10.1111/gcb.12700, Accessed terms and conditions: https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.12700

In this ecosystem model, a coral-dominated ecosystem (represented by Ball 1) only requires a small change in conditions (red arrow) to pass a tipping point (F2) to transition to an algal-dominated ecosystem (Ball 2).

In order for the ecosystem to return from an algae-dominated state, conditions need to change a lot more (green arrow) to reach the tipping point (F1) to transition back to a coral –dominated ecosystem.

These discontinuous models are sometimes called “catastrophic fold bifurcations” or “critical transitions” as the ecosystem state shift is difficult if not impossible to reverse.

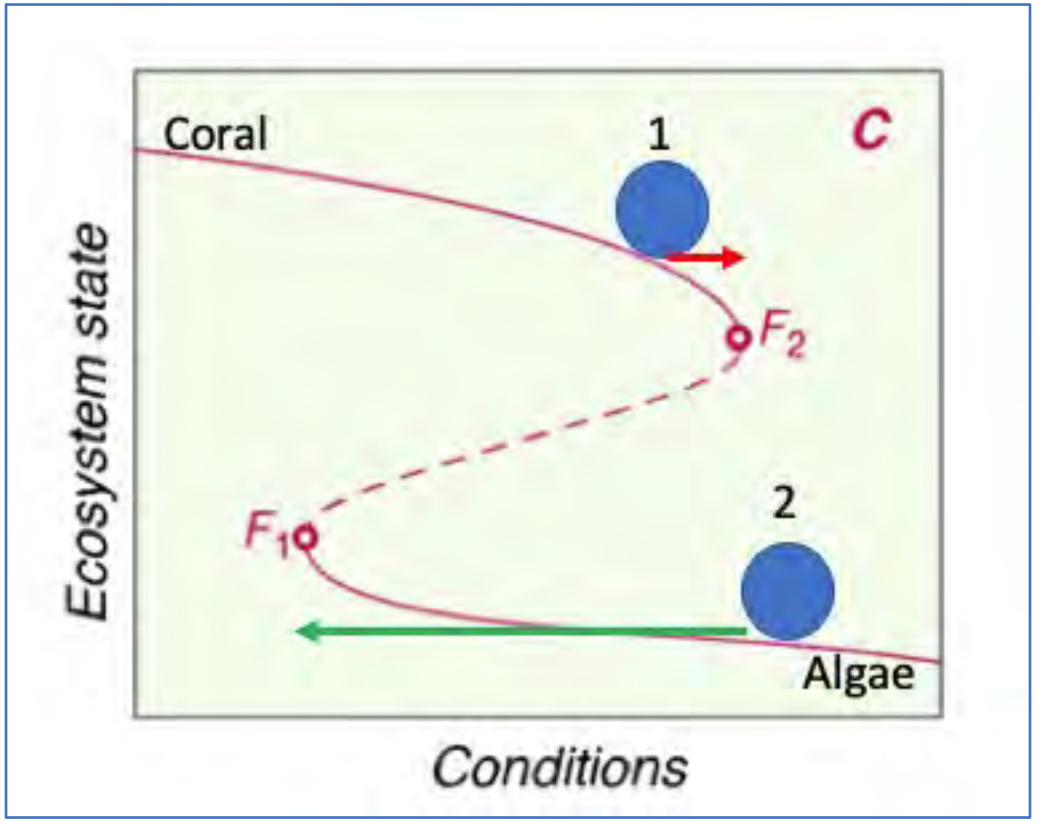


Image: Bob Moffatt, after Scheffer, M., Carpenter, S., Foley, J., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(6856), 591-596. doi: 10.1038/35098000

Positive and negative feedback loops allow ecosystems to persist over a range of conditions.

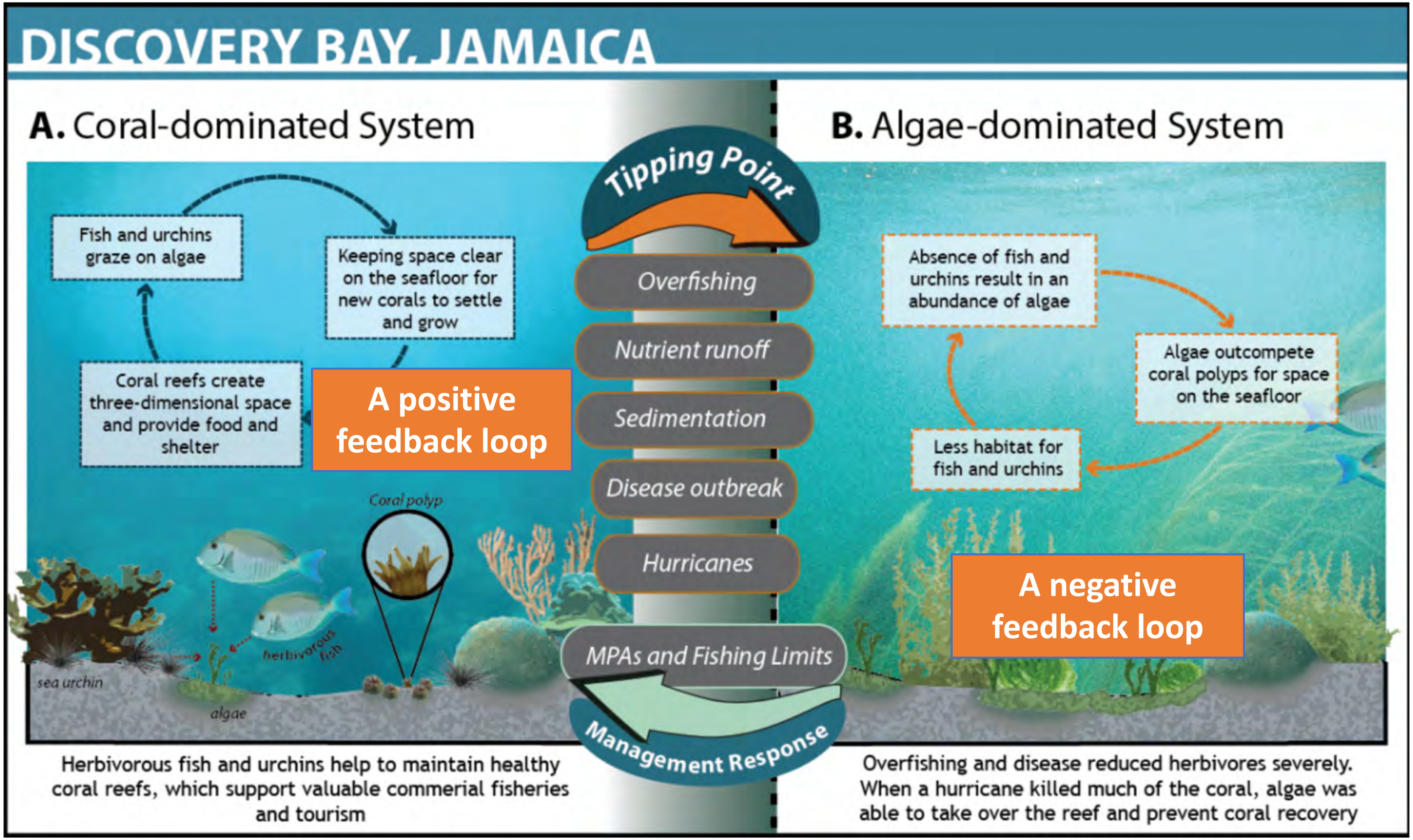


Image: Jackie Mandoske, reproduced with permission from K Selkoe, available: http://oceantippingpoints.org/sites/default/files/uploads/Jamaica.png

We have now seen two models showing that sometimes the pathway for an ecosystem to return to its original stable state is different to the pathway it went through to arrive at an alternate state.

This is hysteresis.

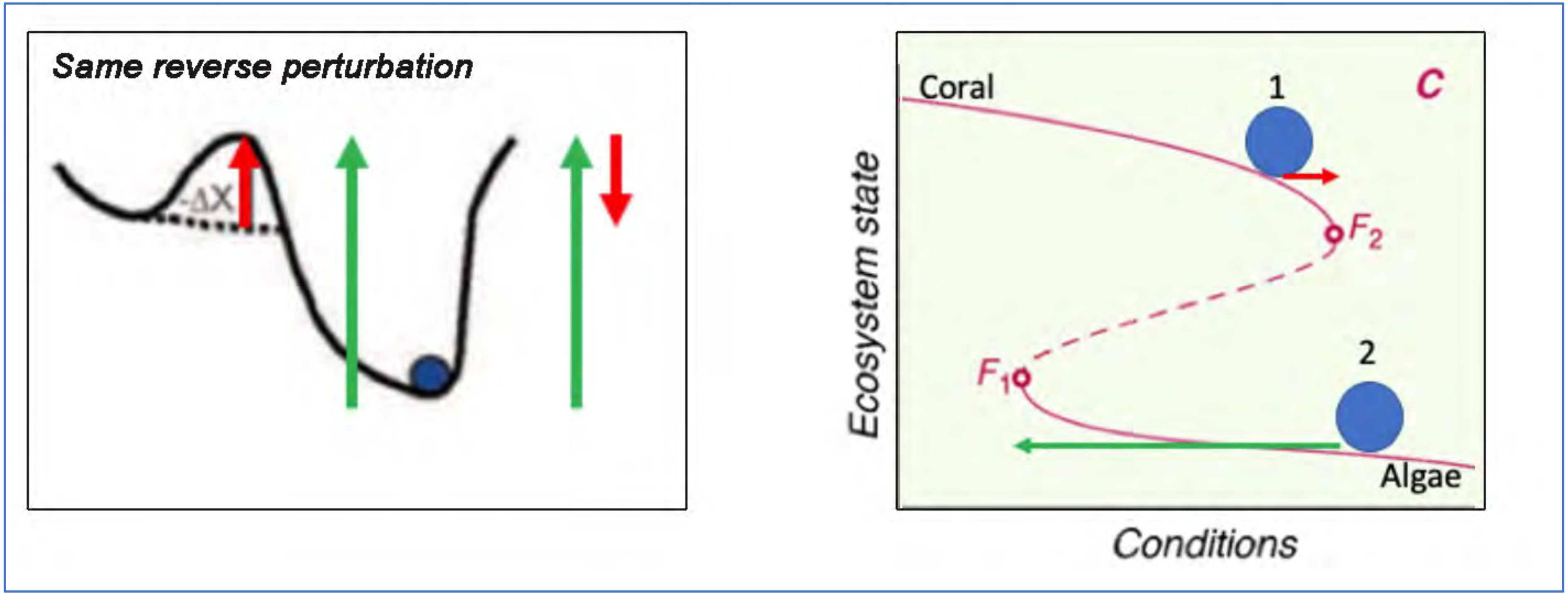


Image: (left, centre) Beisner, B., Haydon, D., & Cuddington, K. (2003). Alternative Stable States in Ecology. *Frontiers In Ecology And The Environment*, *1*(7), 376. doi: 10.2307/3868190, free access: https://esajournals.onlinelibrary.wiley.com/doi/epdf/10.1890/1540-9295%282003%29001%5B0376%3AASSIE%5D2.0.CO%3B2
(Right) Bob Moffatt, after Scheffer, M., Carpenter, S., Foley, J., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(6856), 591-596. doi: 10.1038/35098000

An ecosystem can exhibit high levels of low levels of hysteresis.

Hysteresis is a problem when the pressure that caused a system to degrade past a threshold is removed, the system still does not recover.

So even when pre-threshold conditions return, the system remains in its alternate state.

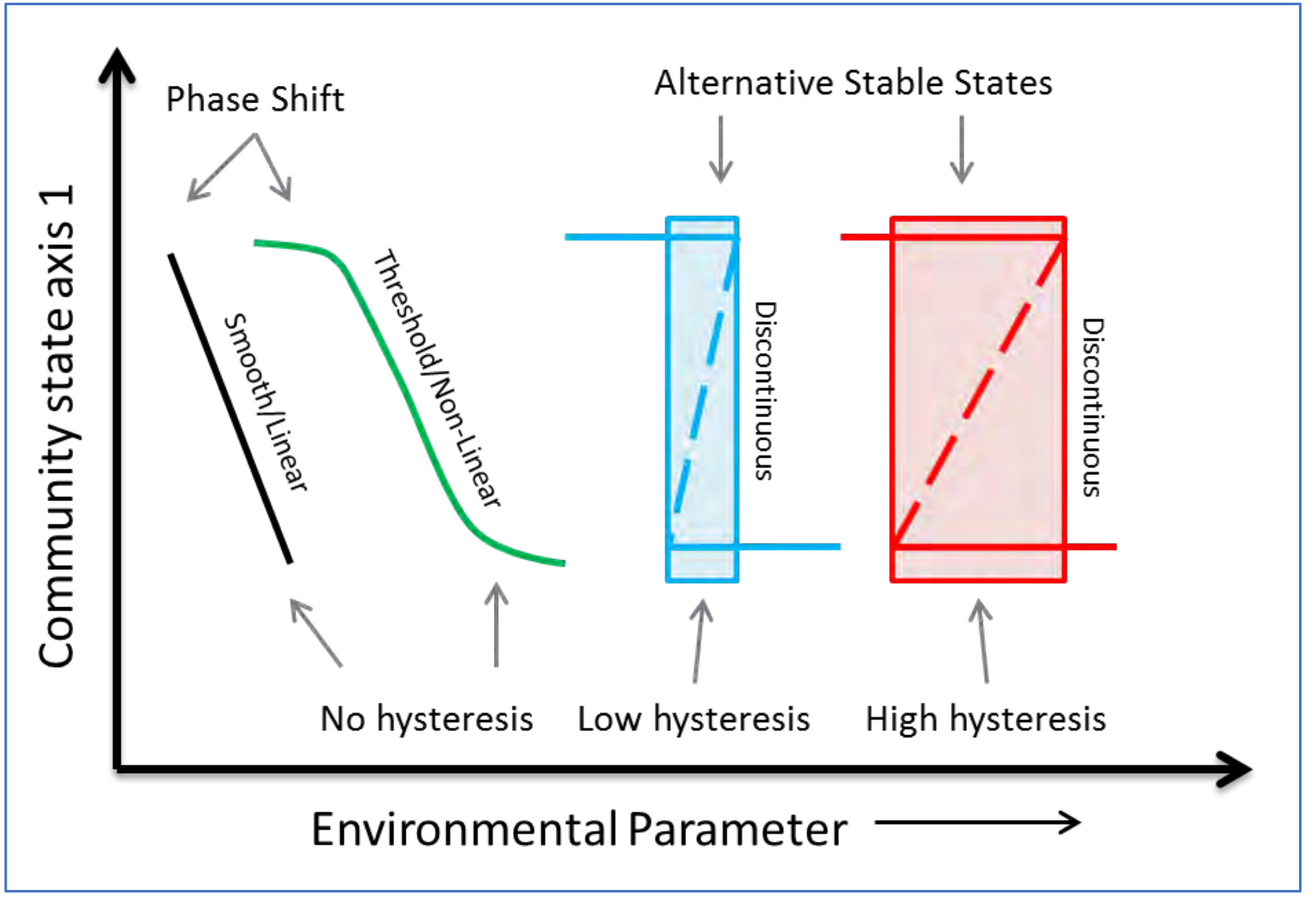


Image: Reproduced with permission, oceantippingpoints.org, av
Cited work based on Dudgeon et al. 2010.

If the coral-dominated reef ecosystem close to bifurcation point F2 , an incremental change in conditions (such as a reduction in parrot fish population) may induce an discontinuous shift to the alternative algal-dominated reef (down arrow).

To restore a coral-dominated reef ecosystem by reversing the conditions, the system shows hysteresis.

A return shift only occurs if conditions are reversed (such as increasing parrot fish populations) far enough to reach the other bifurcation point, B2 (up arrow).

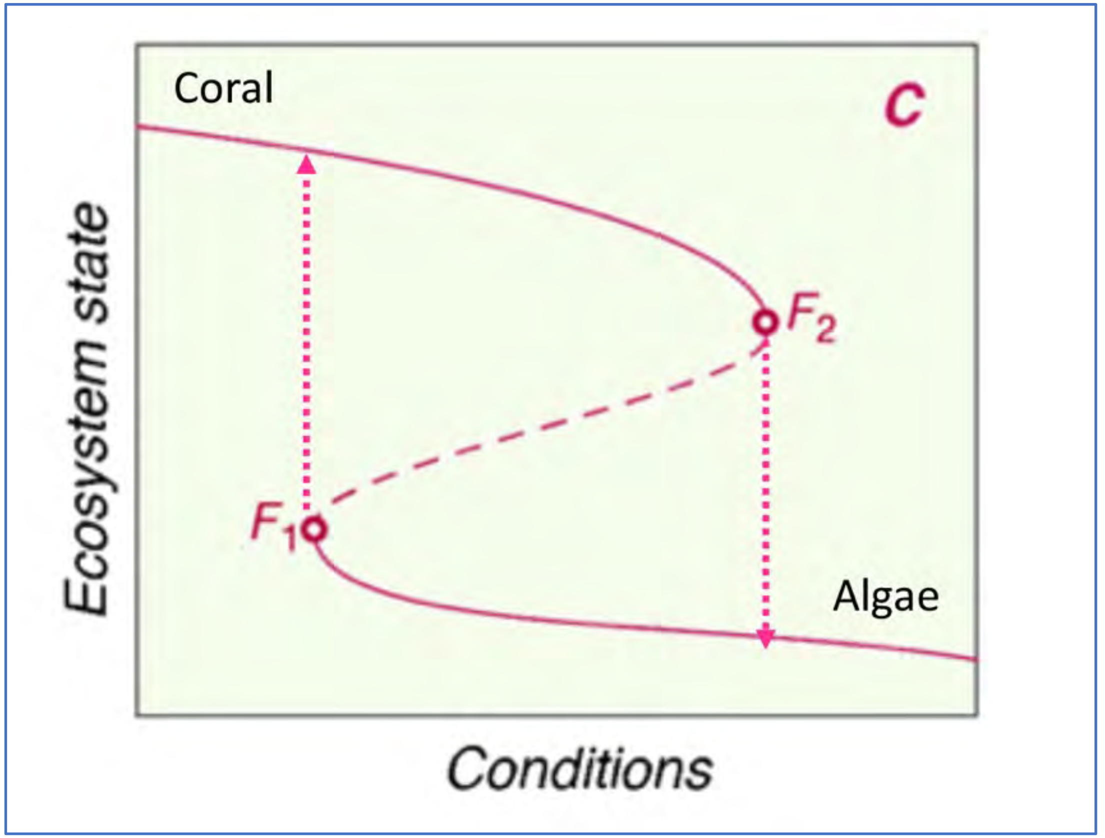


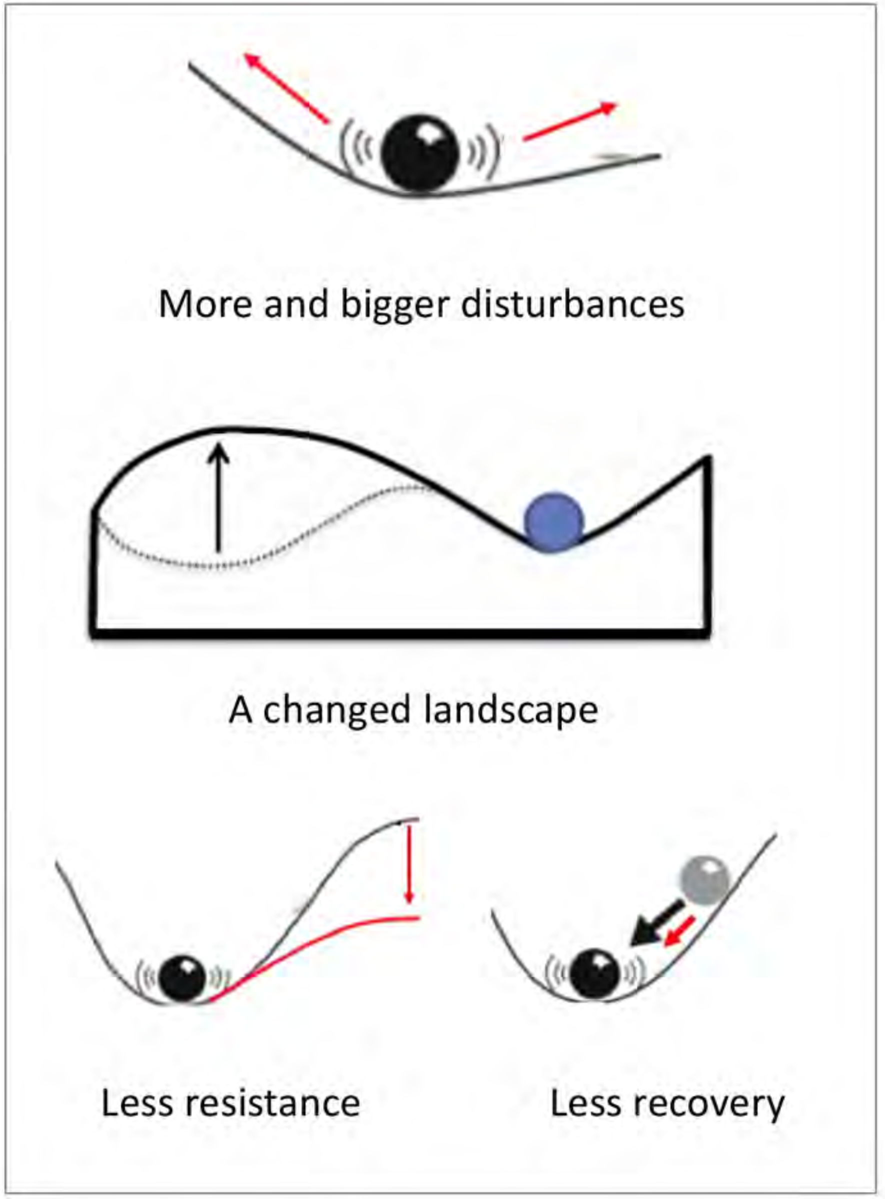
Image: Bob Moffatt, after Scheffer, M., Carpenter, S., Foley, J., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(6856), 591-596. doi: 10.1038/35098000

Summary

Coral reefs are increasingly threatened by storms, bleaching events, crown-of-thorns starfish outbreaks and other acute stressors, that increase the need for resilience.

At the same time, resilience is threatened by stressors such as: pollution, sedimentation, overfishing, ocean warming and acidification.

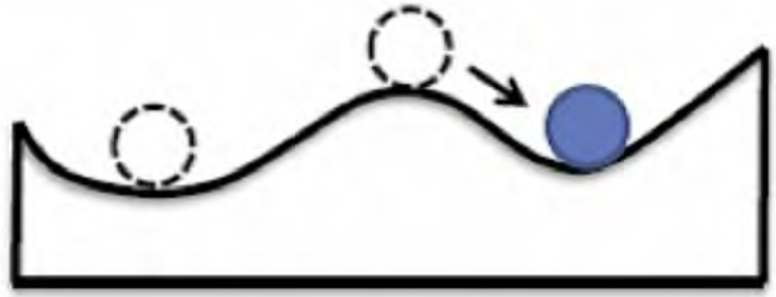
These stressors affect processes (such as larval recruitment, populations of herbivores) that are essential for resistance and recovery.



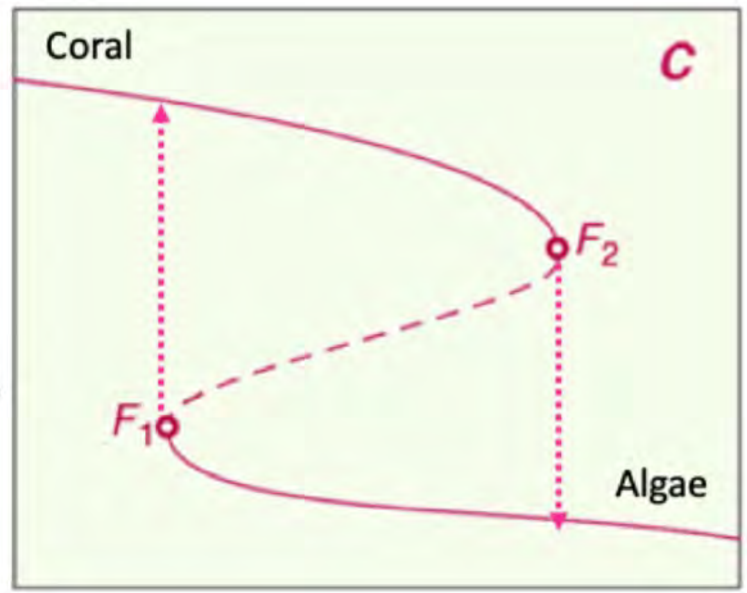
Images modified from: Dakos, V., van Nes, E., Donangelo, R., Fort, H., & Scheffer, M. (2009). Spatial correlation as leading indicator of catastrophic shifts. *Theoretical Ecology*, *3*(3), 163-174. doi: 10.1007/s12080-009-0060-6 open access. and Beisner, B., Haydon, D., & Cuddington, K. (2003). Alternative Stable States in Ecology. *Frontiers In Ecology And The Environment*, *1*(7), 376. doi: 10.2307/3868190, free access: Reproduced under the terms and conditions at https://esajournals.onlinelibrary.wiley.com/doi/epdf/10.1890/1540-9295%282003%29001%5B0376%3AASSIE%5D2.0.CO%3B2

So corals, in a stressed state, are increasingly vulnerable to phase shifts.

And hysteresis means that an equal and opposite improvement (or removals of stressors) may not cause an equivalent improvement in ecosystem state.



Phase shifts



Images: Beisner, B., Haydon, D., & Cuddington, K. (2003). Alternative Stable States in Ecology. *Frontiers In Ecology And The Environment*, *1*(7), 376. doi: 10.2307/3868190, Reproduced under the terms and conditions at free access: https://esajournals.onlinelibrary.wiley.com/doi/epdf/10.1890/1540-9295%282003%29001%5B0376%3AASSIE%5D2.0.CO%3B2 and Bob Moffatt, after Scheffer, M., Carpenter, S., Foley, J., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(6856), 591-596. doi: 10.1038/35098000

For more about phase shifts, see

Scheffer, M., Carpenter, S., Foley, J., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(6856), 591-596. doi: 10.1038/35098000

https://www.researchgate.net/publication/200033509_Catastrophic_shifts_in_ecosystems

Download this article:

Bellwood, D., Hughes, T., Folke, C., & Nyström, M. (2004). Confronting the coral reef crisis. *Nature*, *429*(6994), 827-833. doi: 10.1038/nature02691 Available: https://www.reefresilience.org/pdf/Bellwood_etal_2004.pdf

This paper reviews "the ecological roles of critical functional groups (for both corals and reef fishes) that are fundamental to understanding resilience and avoiding phase shifts from coral dominance to less desirable, degraded ecosystems"

Questions

1. Recall a definition for resilience
2. Explain the idea of “reef resilience”
3. Explain how a model can represent hysteresis
4. Explain how hysteresis affects the resilience of a coral reef ecosystem

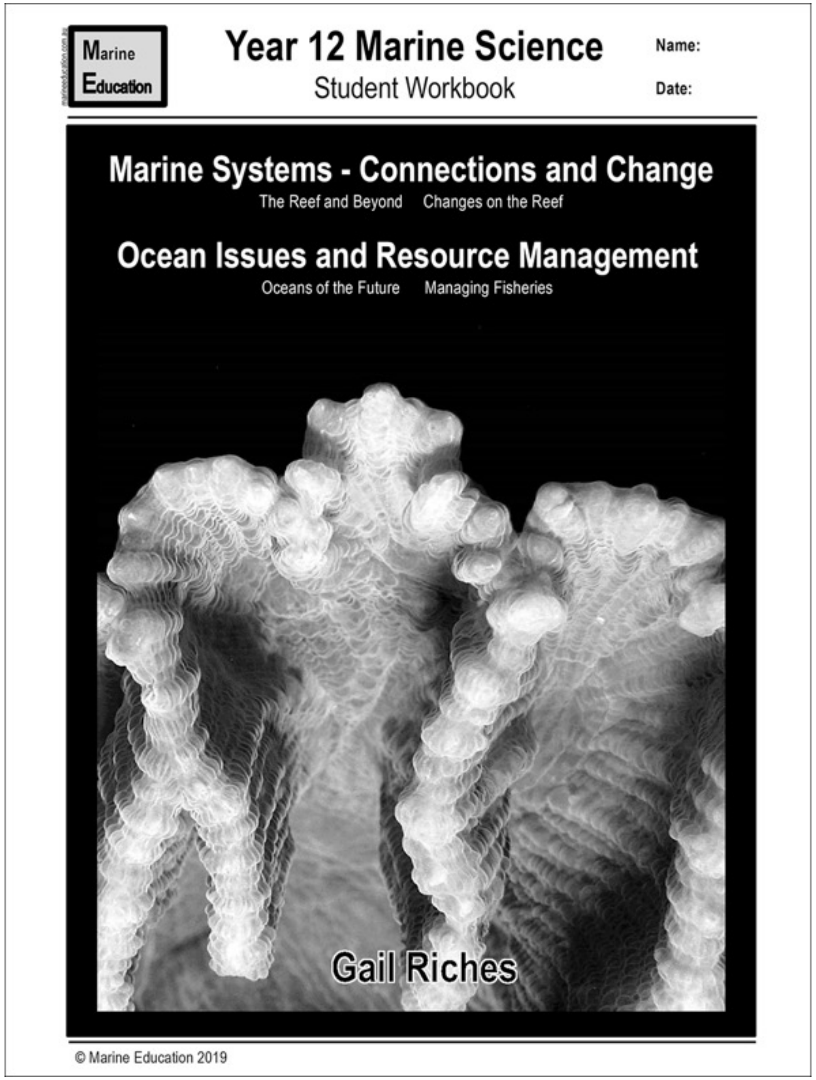
Worksheet

Recovery road blocks

by

Gail Riches

www.marineeducation.com.au



T093 Assess reef diversity

Adam Richmond

Syllabus statement

At the end of this topic you should be able to ...

Assess

the diversity of a reef system using a measure that could include (but is not limited to) line intercept transects, quadrats and fish counts using underwater video survey techniques, benthic surveys, invertebrate counts and rugosity measurements

Assess

- measure, determine, evaluate, estimate or make a judgment about the value, quality, outcomes, results, size, significance, nature or extent of something

Objective

Measure the diversity of a reef system using data collected in the field or virtual data.

Diversity

The Great Barrier Reef is internationally recognised for its outstanding biodiversity, with:

- 1625 species of fish
- 3000 species of molluscs
- 600 species of corals
- 630 species of echinoderm
- 14 breeding species of sea snakes
- 215 species of birds
- Six of the world's seven species of marine turtle
- 30 species of whales and dolphins
- One of the world's most important dugong populations
- 134 species of sharks and rays

Seaview Science Video: Biodiversity

Available:
https://youtu.be/TVAH4CAtfAk

References:
http://www.gbrmpa.gov.au/the-reef/animals
http://www.gbrmpa.gov.au/__data/assets/pdf_file/0014/21731/gbrmpa-VA-Sharks_Rays-11-7-12.pdf

Why do we measure diversity?

We need a good knowledge of "what is out there" to provide a baseline for future changes in biodiversity.

Marine biodiversity

YouTube video by Australian Institute of Marine Science,
Available: https://youtu.be/KPn3lAJyG7A

Available:

https://youtu.be/KPn3lAJyG7A

The next three slides show links to the University of Queensland's diversity on coral reefs videos.

Species diversity: Tropical coastal ecosystems organisms

YouTube video by UQx Tropic101x Tropical Coastal Ecosystems,
Available: https://youtu.be/BM3TpWGk5eo

Available:

https://youtu.be/BM3TpWGk5eo

Species diversity: Lower invertebrates

YouTube video by UQx Tropic101x Tropical Coastal Ecosystems, available:
https://youtu.be/xxuEgALdOuw

Available:

https://youtu.be/xxuEgALdOuw

Species diversity: Complex organisms

YouTube video by UQx Tropic101x Tropical Coastal Ecosystems, available:
https://youtu.be/bjcw2mToGgI

Available:

https://youtu.be/bjcw2mToGgI

How do we measure diversity?

This freely downloadable book presents standardised surveying and monitoring methodologies, how to select an appropriate scale and technique for your investigation, and how to record and analyse data.

Hill, J., & Wilkinson, C. (2004). *Methods for ecological monitoring of coral reefs. Version 1*. Townsville, Qld: Australian Institute of Marine Science.

Available: https://www.cbd.int/doc/case-studies/tttc/tttc-00197-en.pdf

Note:
All images in the next few pages from

https://www.cbd.int/doc/case-studies/tttc/tttc-00197-en.pdf

The scale of the survey determines the techniques used.

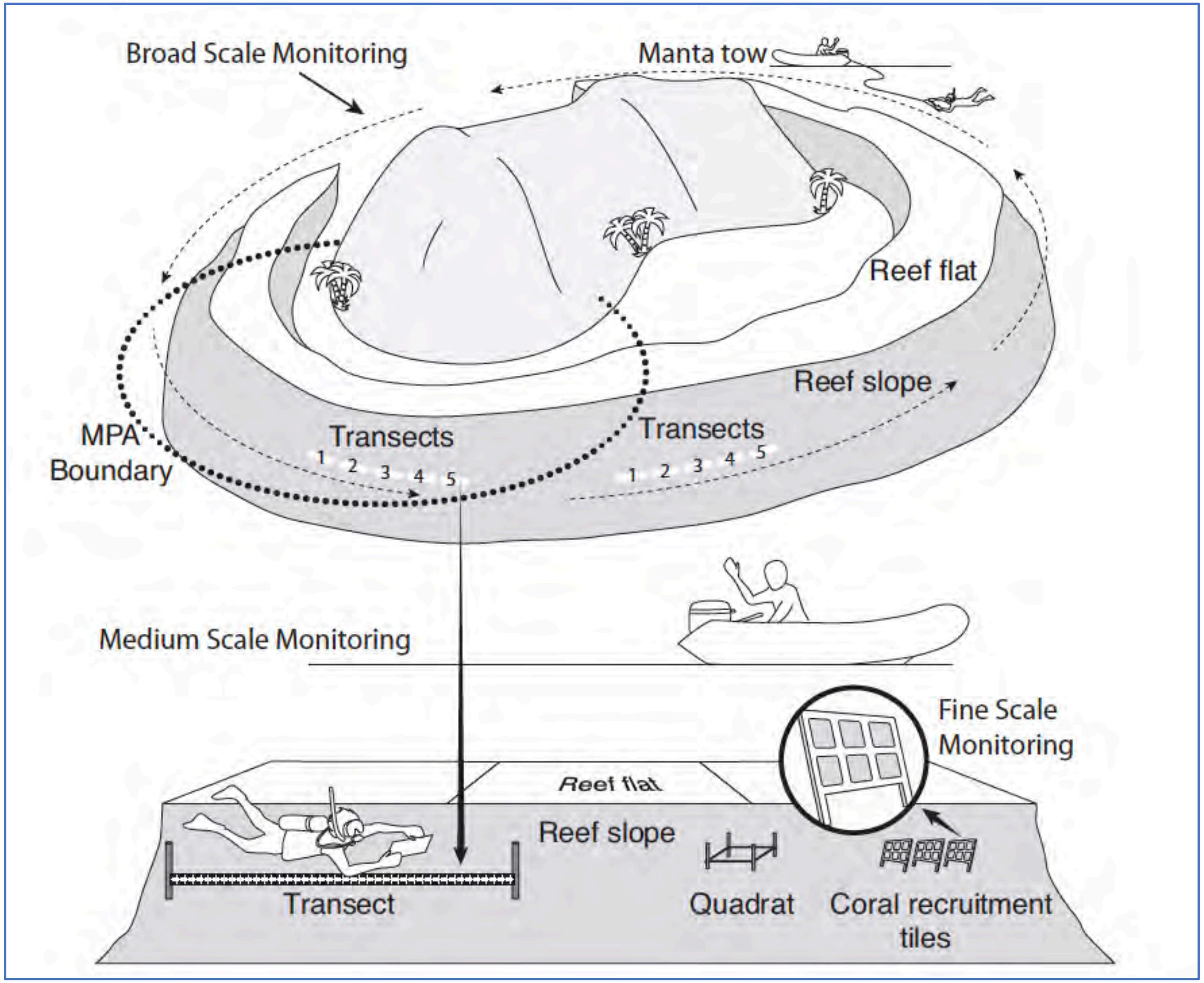


Image: Fig 3 from Hill, J., & Wilkinson, C. (2004). *Methods for ecological monitoring of coral reefs. Version 1*. Townsville, Qld: Copyright Australian Institute of Marine Science, Reproduced with permission.

The AIMS Standard operating procedure for conducting reef surveys is available here:

https://www.aims.gov.au/docs/research/monitoring/reef/sampling-methods.html

Note from AIMS

The link on the survey methods page of our website links to old versions of the SOPs and needs to be updated.

AUSTRALIAN INSTITUTE OF MARINE SCIENCE

Survey methods

The Australian Institute of Marine Science (AIMS) Long-term Monitoring Program (LTMP) is designed to detect changes in reef communities on inshore, mid-shelf and outer shelf reefs across the continental shelf.

Reef surveys involve three approaches:

- manta tow surveys of crown-of-thorns starfish populations and reef-wide coral cover
- photographic surveys of benthic organisms on fixed transects
- visual counts of reef fish, juvenile corals, crown-of-thorns starfish, coral-eating snails and coral disease and bleaching.

AIMS diver using a manta board

Image:Australian Institute of Marine Science
Available: https://www.aims.gov.au/docs/research/monitoring/reef/sampling-methods.html

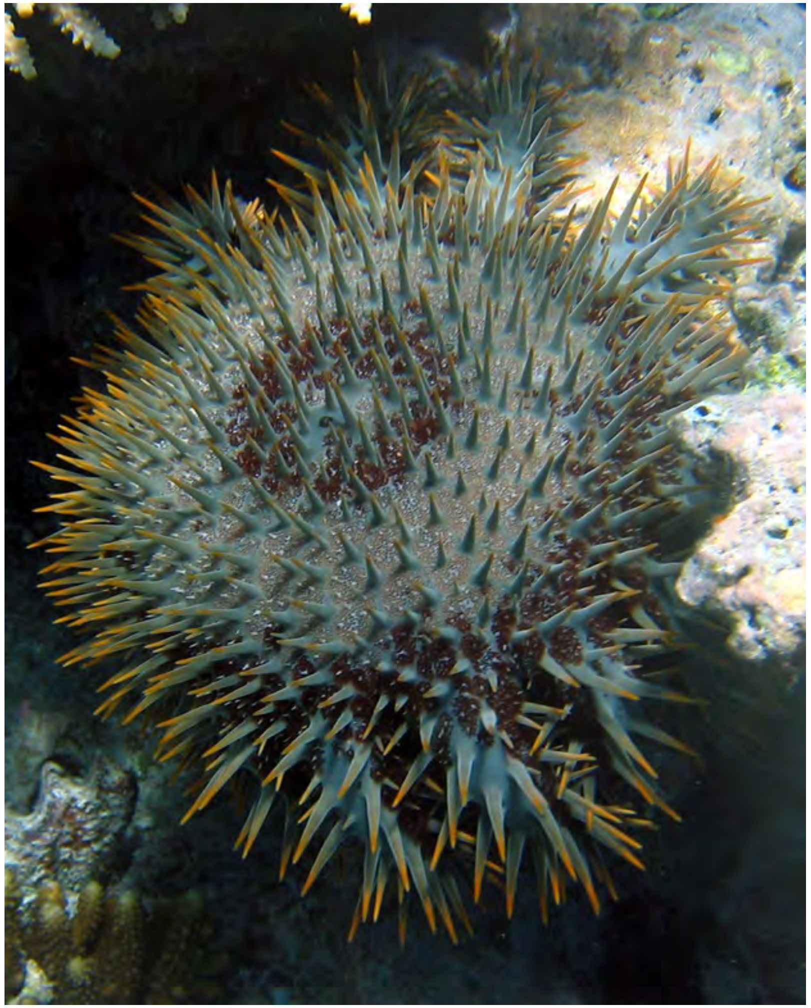
The survey methods used as part of the LTMP can be found here:
https://www.aims.gov.au/docs/research/monitoring/reef/sampling-methods.html

Manta tow and timed swims

These involve either towing a diver behind a boat around a reef or a diver swimming for a set time or distance, are the best methods for obtaining a broad scale, general description of a reef site.

Manta tows are used for monitoring Crown of Thorns Starfish populations and estimating coral cover.

Reference:
Hill, J., & Wilkinson, C. (2004). *Methods for ecological monitoring of coral reefs. Version 1*. Townsville, Qld: Australian Institute of Marine Science.
Available: https://www.cbd.int/doc/case-studies/tttc/tttc-00197-en.pdf



Crown of Thorns Starfish

Line intercept transect

Transects and quadrats were introduced for population dynamics investigations in topic 56. Laying a transect line underwater is significantly more difficult than it is on land

Reef Check survey fish, substrate (benthic cover), invertebrates and human impact using a transect line.

Reef Check Heron Island 2016

YouTube video by Reef Check Australia, available: https://youtu.be/XmutcW5MCEg

This YouTube video shows how to conduct a fish census, benthic survey and belt transect.

How to Conduct a Coral Reef Survey

You Tube video by Khaled bin Sultan Living Oceans Foundation, available: https://youtu.be/L2ifY5ZJe6g

Video transects

The use of video cameras makes the data collection process much faster, and therefore cheaper. A 20m chain transect that would take 4 hours to survey can be video recorded in 5 minutes.

XL Catlin survey 0130020775 of Heron Island Reef

Available:
https://youtu.be/4gsLgnvN3yc

You can make your own video transects on a field trip and analyse the results back at school.
If you can’t get to the reef, you can use online video transects, ask an EEC or a citizen science group, such as Coral Watch if they can share some videos.

Underwater permanent quadrats

This video shows an underwater remotely operated video (ROV) camera pre-assessing a reef site for a longitudinal study with permanent quadrats.

Monitoring the reef

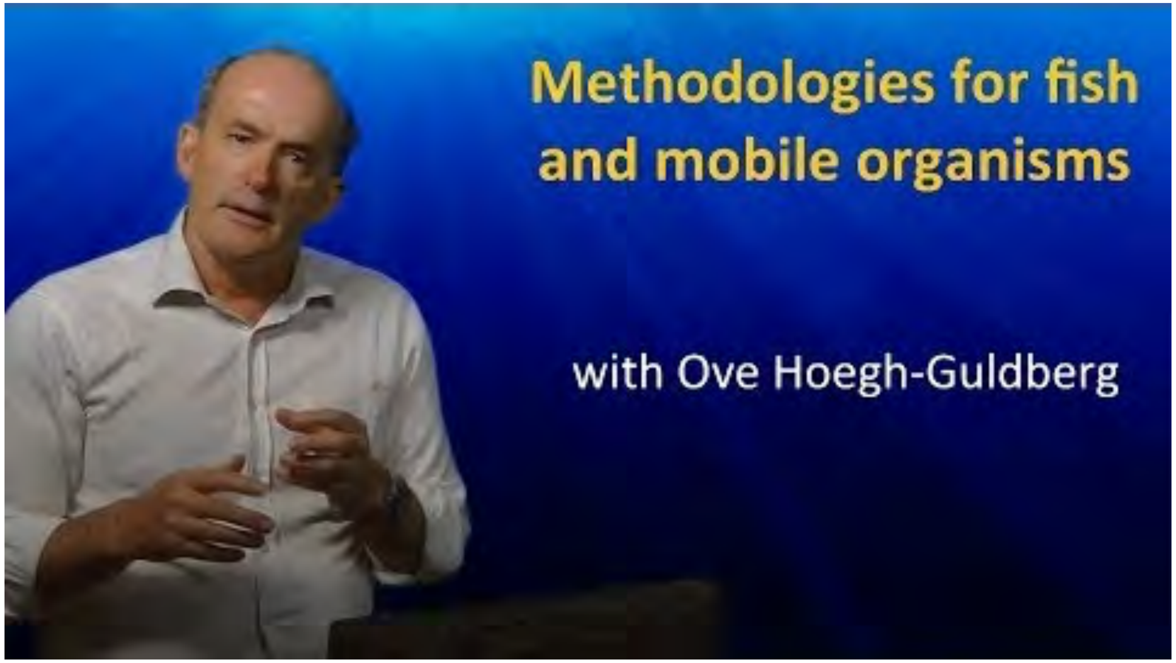
Available:
https://youtu.be/PkYk6b2JLek

Fish counts

This YouTube video addresses how fish can be counted on a reef, using belt transects, video cameras, BRUVs* and the importance of abiotic and satellite data.

BRUV

Baited Remote Underwater Video



Available:
https://youtu.be/c0yh9Pf4PPM

Methodologies for Fish and Mobile Organisms

YouTube video by UQx Tropic101x Tropical Coastal Ecosystems,

Available:
https://youtu.be/c0yh9Pf4PPM

BRUVs, or Baited Remote Underwater Videos are a non-invasive way of determining fish numbers and diversity.

Great Barrier Reef fish survey 7459, Green zone, Barcoo Bank

YouTube video by eAtlas AIMS, Available: https://youtu.be/46XkJIsqSxE

Available:

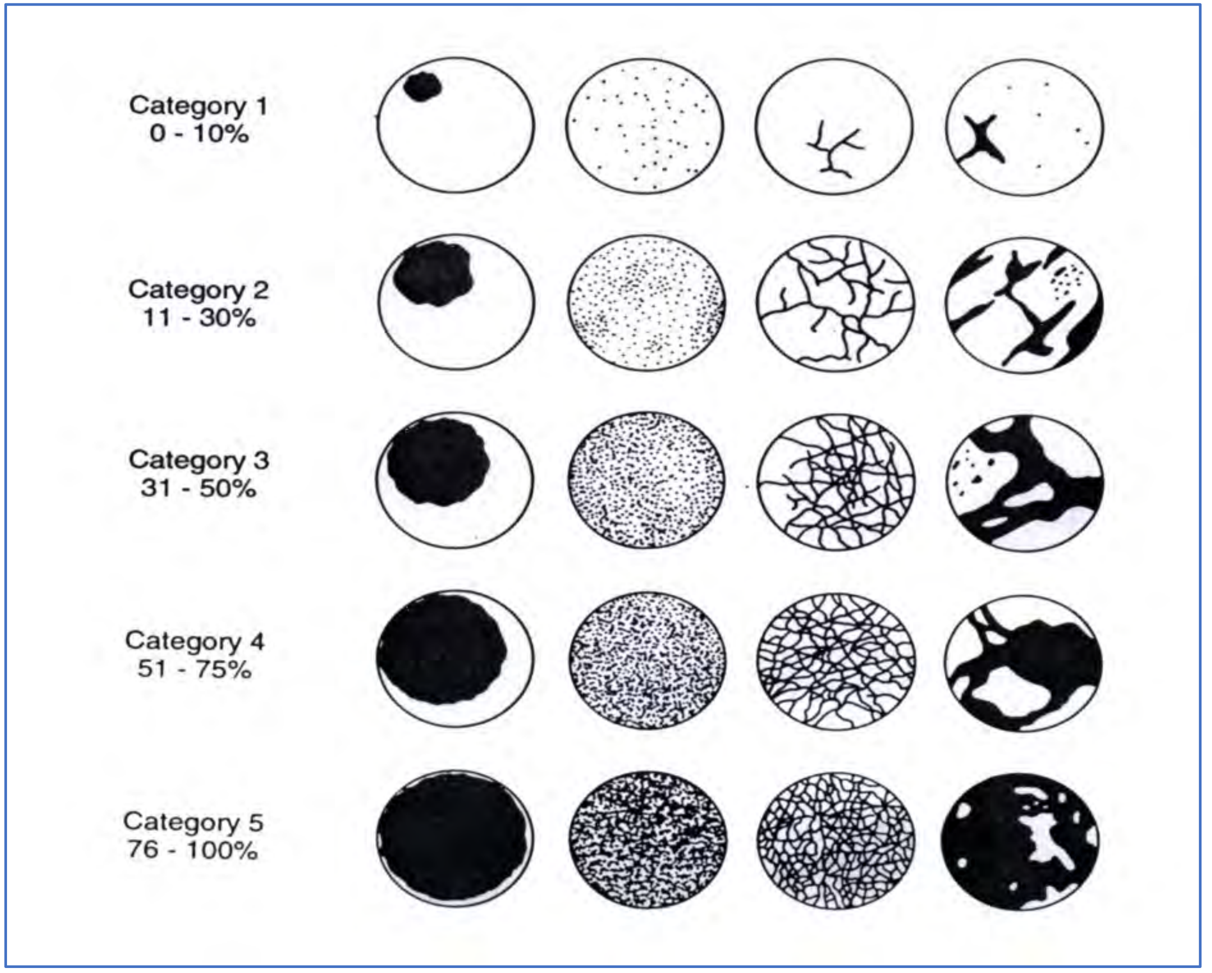
https://youtu.be/46XkJIsqSxE

Search “BRUV” in your search engine, or ask your local Environmental Education Centre for some local footage.

Benthic surveys

Benthic or substrate surveys are used to provide estimates of coral cover.

The categories used by AIMS are Hard coral, soft coral, coralline algae, macroalgae, turf algae, sponge, other and indeterminate.



A visual estimate of coral % cover.

Image- Dahl (1981) in English et al. (1997), in Hill, J., & Wilkinson, C. (2004). *Methods for ecological monitoring of coral reefs. Version 1*. Townsville, Qld: Australian Institute of Marine Science.

Invertebrate counts

This (23 minute long) YouTube video shows some of the incredible diversity of organisms found on just one coral boulder:

UQx TROPIC101x 2.1.4 Coral Reef Organism Diversity

YouTube video by UQx TROPIC101x 2.1.4 Coral Reef Organism Diversity, available: https://youtu.be/mLeHqaWFDj8

Available:

https://youtu.be/mLeHqaWFDj8

Rugosity measurement

Reef rugosity was covered in Topic 87.

It is a measure of how complex the reef topography is.
It can be measured by laying a chain over the reef and calculating the ratio of the chain to the distance covered.

Image: with permission Nyssa Silbiger

Laying out a chain carefully to avoid damaging the coral.

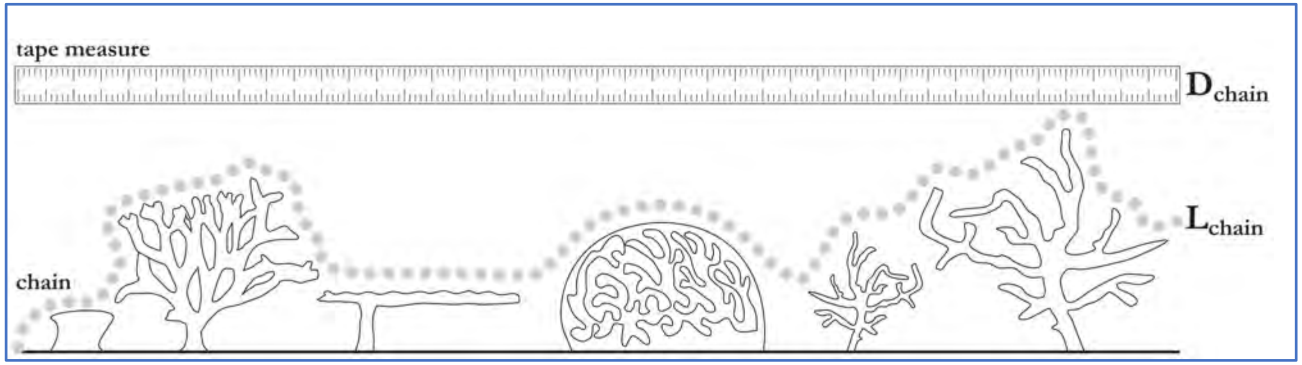
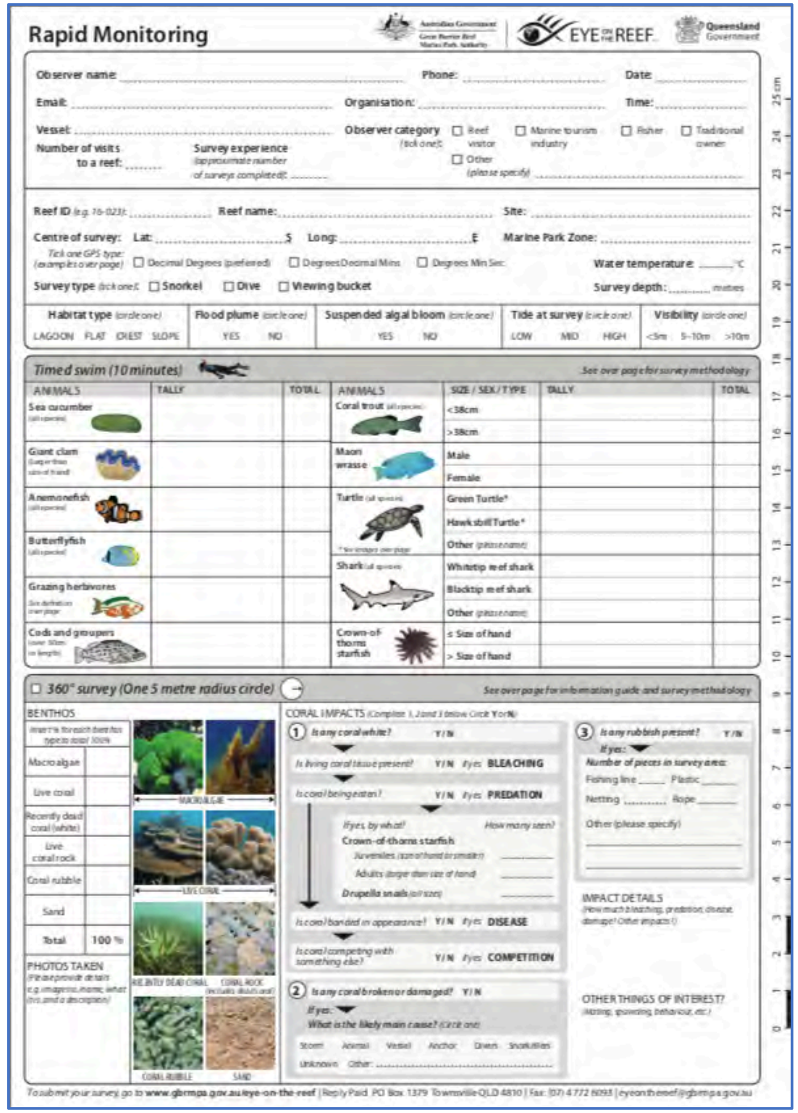


Image: Friedman, A., Pizarro, O., Williams, S., & Johnson-Roberson, M. (2012). Multi-Scale Measures of Rugosity, Slope and Aspect from Benthic Stereo Image Reconstructions. *Plos ONE*, *7*(12), e50440. doi: 10.1371/journal.pone.0050440 adapted from Hill J, Wilkinson C (2004) Methods for ecological monitoring of coral reefs. Technical report. Available: https://doi.org/10.1371/journal.pone.0050440.g002

Eye on the Reef

GBRMPA's Eye on the Reef reef monitoring and assessment program enables you to contribute to its long-term protection by collecting valuable information about reef health, marine animals and incidents.

Rapid monitoring involves a timed swim to tally sighted organisms, and a 360° survey to determine % cover and identify impacts



Rapid Monitoring

Observer name: Phone: Date:
Email: Organisation: Time:
Vessel: Observer category (tick one) ☐ Reef visitor ☐ Marine tourism industry ☐ Fisher ☐ Traditional owner ☐ Other (please specify)
Number of visits to a reef: Survey experience (approximate number of surveys completed):

Reef ID (e.g. 16-023): Reef name: Site:
Centre of survey: Lat: S Long: E Marine Park Zone:
Tick one GPS type (examples over page) ☐ Decimal Degrees (preferred) ☐ Degrees Decimal Mins ☐ Degrees Min Sec Water temperature: °C
Survey type (tick one) ☐ Snorkel ☐ Dive ☐ Viewing bucket Survey depth: metres

Habitat type (circle one)	Flood plume (circle one)	Suspended algal bloom (circle one)	Tide at survey (circle one)	Visibility (circle one)
LAGOON FLAT CREST SLOPE	YES NO	YES NO	LOW MID HIGH	<5m 5-10m >10m

Timed swim (10 minutes) — See over page for survey methodology

ANIMALS	TALLY	TOTAL	ANIMALS	SIZE / SEX / TYPE	TALLY	TOTAL
Sea cucumber			Coral trout	<38cm		
				>38cm		
Giant clam			Maori wrasse	Male		
				Female		
Anemonefish			Turtle	Green Turtle*		
				Hawksbill Turtle*		
Butterflyfish				Other		
			Shark	Whitetip reef shark		
Grazing herbivores				Blacktip reef shark		
				Other		
Cods and groupers			Crown-of-thorns starfish	≤ Size of hand		
				> Size of hand		

☐ 360° survey (One 5 metre radius circle) — See over page for information guide and survey methodology

BENTHOS	%
Macroalgae	
Live coral	
Recently dead coral (white)	
Live coral rock	
Coral rubble	
Sand	
Total	100 %

PHOTOS TAKEN

MACROALGAE / LIVE CORAL / RECENTLY DEAD CORAL / CORAL ROCK / CORAL RUBBLE / SAND

CORAL IMPACTS
1. Is any coral white? Y/N
Is living coral tissue present? Y/N If yes: BLEACHING
Is coral being eaten? Y/N If yes: PREDATION
If yes, by what? How many seen? Crown-of-thorns starfish; Drupella snails
Is coral banded in appearance? Y/N If yes: DISEASE
Is coral competing with something else? Y/N If yes: COMPETITION
2. Is any coral broken or damaged? Y/N If yes: What is the likely main cause? Storm Animal Vessel Anchor Divers Snorkellers Unknown Other
3. Is any rubbish present? Y/N If yes: Number of pieces in survey area: Fishing line Plastic Netting Rope Other (please specify)

IMPACT DETAILS

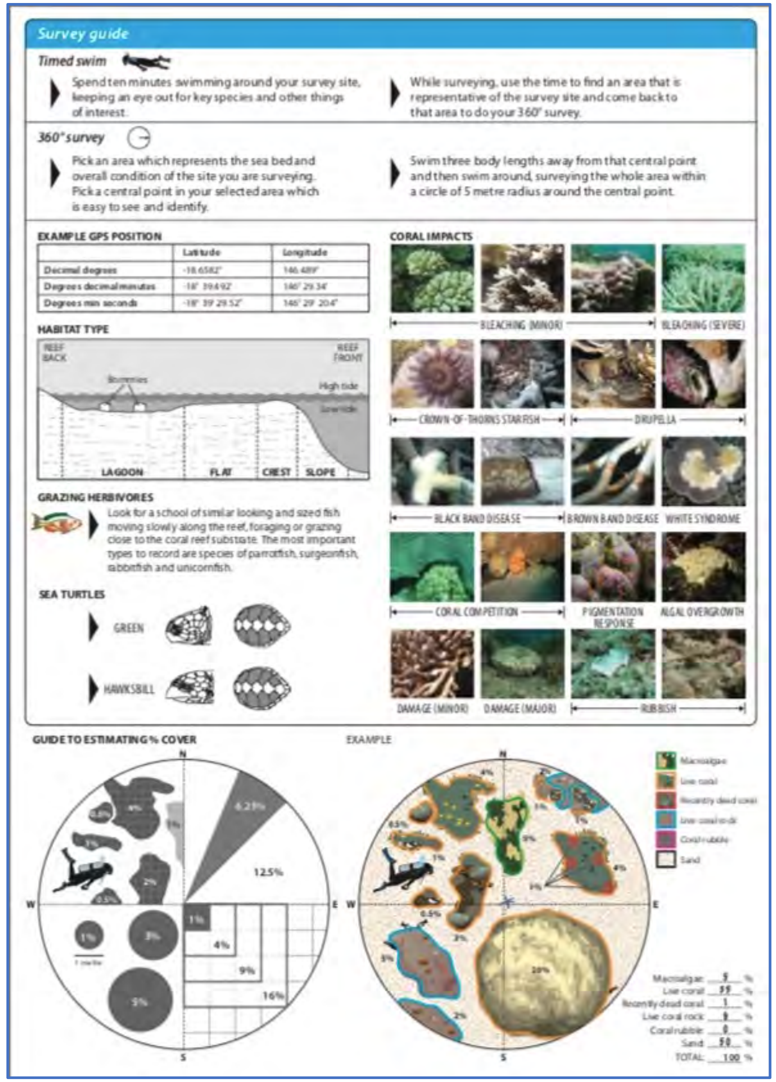
OTHER THINGS OF INTEREST?

Page 1 of the Eye on the Reef Rapid Monitoring form

Available:
http://www.gbrmpa.gov.au/__data/assets/pdf_file/0007/237346/Rapid-Monitoring-Form-V.2.0.pdf

The Rapid Monitoring Survey uses an underwater monitoring slate to record keystone species and reef health. Download the Reef Rapid Monitoring form here:
http://www.gbrmpa.gov.au/__data/assets/pdf_file/0007/237346/Rapid-Monitoring-Form-V.2.0.pdf

You can submit and view the data via the Eye on the Reef database:
http://www.gbrmpa.gov.au/eye-on-the-reef



Copyright GBRMPA:. Reproduced with permission

Page 2 of the Eye on the Reef Rapid Monitoring form

Available:
http://www.gbrmpa.gov.au/__data/assets/pdf_file/0007/237346/Rapid-Monitoring-Form-V.2.0.pdf

This YouTube video explains the Eye on the Reef large-scale monitoring program.

Learn more about this here:

http://www.gbrmpa.gov.au/our-work/our-programs-and-projects/eye-on-the-reef/the-rapid-monitoring-survey

Play the video

https://youtu.be/q9Xe8TIgg30

Keeping an eye on the Great Barrier Reef

YouTube video by Great Barrier Reef Marine Park Authority, available: https://youtu.be/q9Xe8TIgg30

Reef Check

Visit:
https://www.reefcheckaustralia.org

To order some ReefSearch underwater slates or a field kit.

These slates will help you collect data on:

- reef composition (percent cover of what is making up the reef)
- signs of reef stress (abundance and severity of impacts)
- abundance of key invertebrates
- abundance of indicator fish (as feasible)
- information about site use and disturbances

ReefSearch slates
Image: Reef Check, https://www.reefcheckaustralia.org/shop

REEFSearch is an more accessible survey tool than Reef Check and may be more suitable for schools groups. There is online data entry tool that will allow you to share your results.

Cleveland District State High School uses REEFSearch on Lady Elliot Island

YouTube video by Reef Check Australia, available:https://youtu.be/a2zMQkGCWhc

Find more information on how to become a REEFSearcher here: https://www.reefcheckaustralia.org/reefsearch

Available

https://youtu.be/a2zMQkGCWhc

Reef check data available here:
https://www.reefcheckaustralia.org/data

Images: screen shots from https://www.reefcheckaustralia.org/data

You can select one of many reefs.

I have selected Harry's Bommie on Heron reef.

If you or your school registers, you can access the Reef check database, with access to even more data.

Images: screen shots from https://www.reefcheckaustralia.org/data

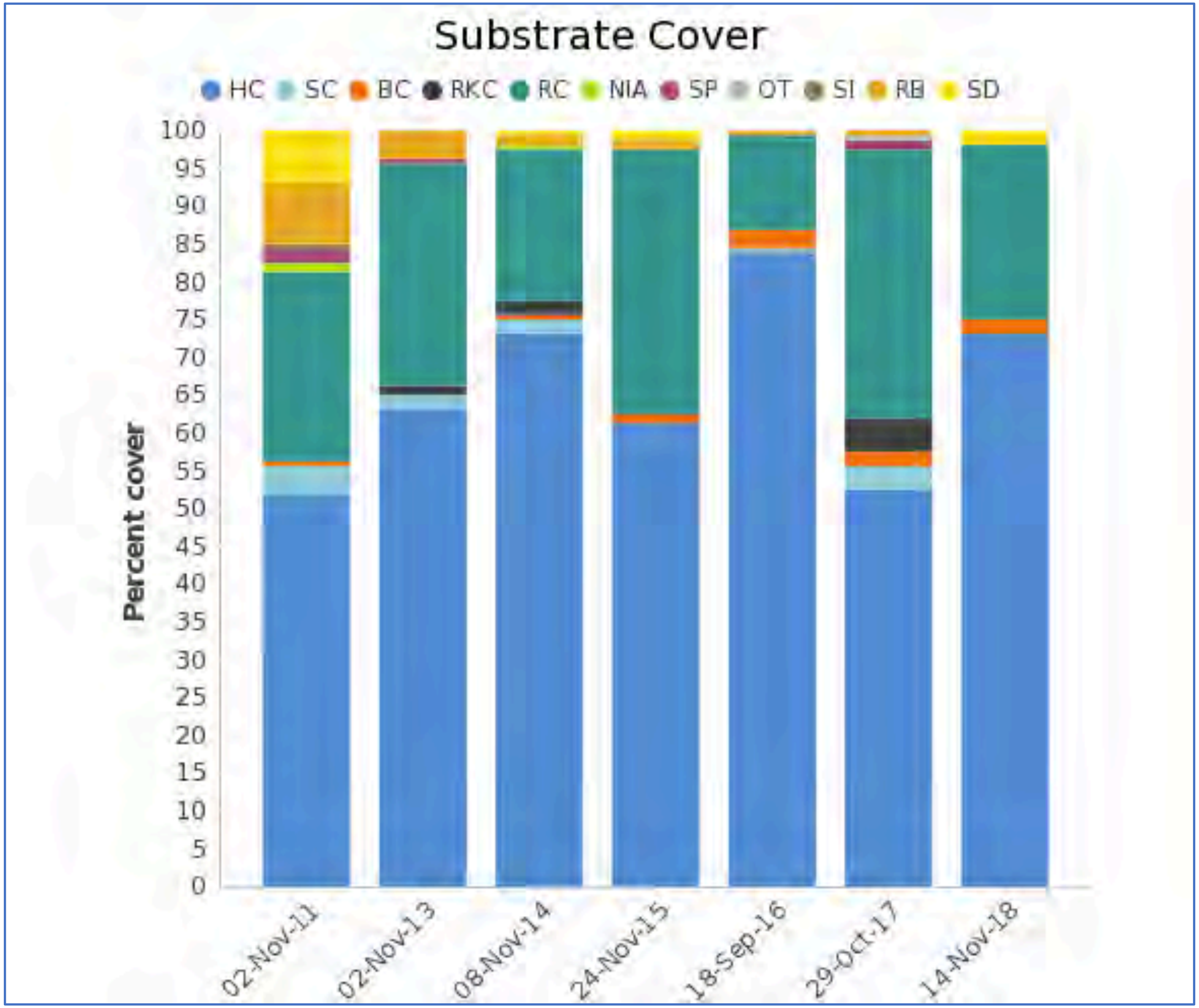
Here is some of the data available for Harry’s bommie:

From https://www.reefcheckaustralia.org/data

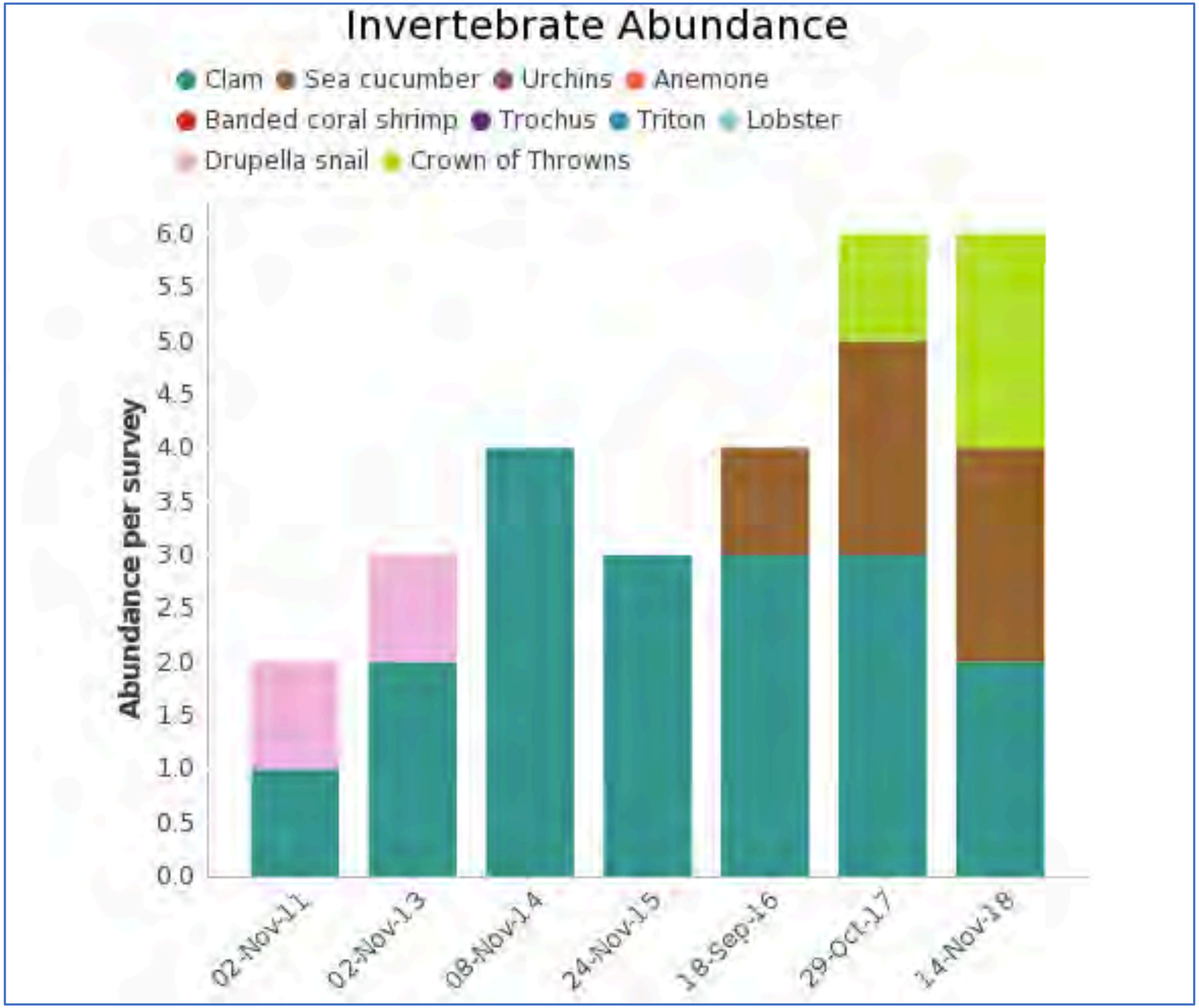
Heron Reef / Harry's Bommie / Site 1

Name	Site 1
Site Id	1
Habitat	Fringing reef seaward
Depth	9 metres
Start	151.929717E -23.460349S
End	151.930370E -23.460965S
Zoom	18
Description	Sloping reef in scientific zone

Images: screen shots from https://www.reefcheckaustralia.org/data

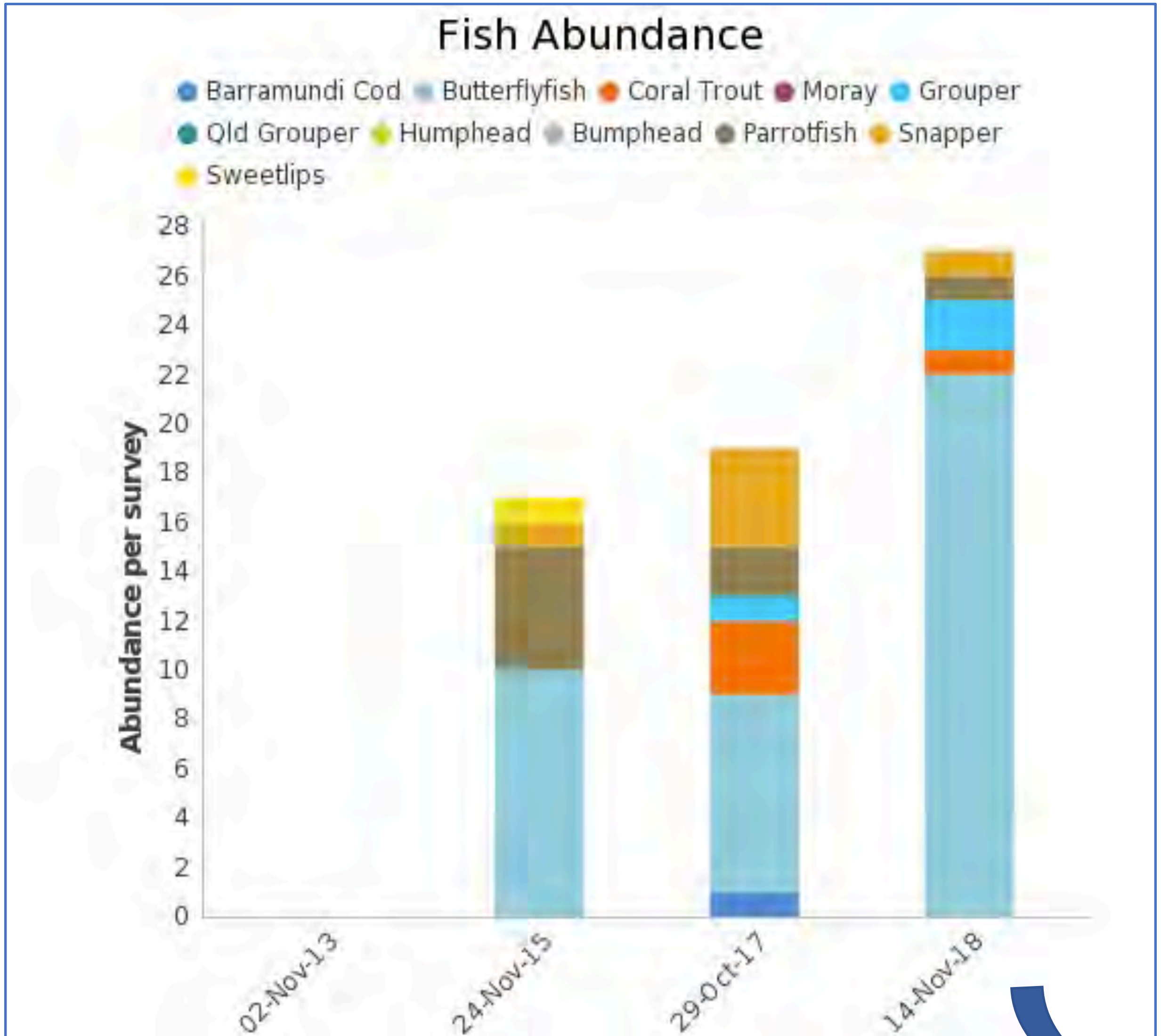


Images: screen shots from https://www.reefcheckaustralia.org/data



Images: screen shots from https://www.reefcheckaustralia.org/data

Here is some of the data available for Harry's bommie:



	2015	2017	2018
Barramundi cod	0	1	0
Butterflyfish	10	7	22
Coral trout	0	3	1
Moray	0	0	0
Grouper	0	1	2
Qld Grouper	0	0	0
Humphead	0	0	0
Bumphead	0	0	0
Parrotfish	5	20	1
Snapper	1	4	1
Sweetlips	1		0

"Raw data" can be extracted from these summary graphs and used for your own analysis.

The XL Catlin Global Reef Record is a free database on coral reefs.
This video shows how the Catlin survey team collect coral reef data.

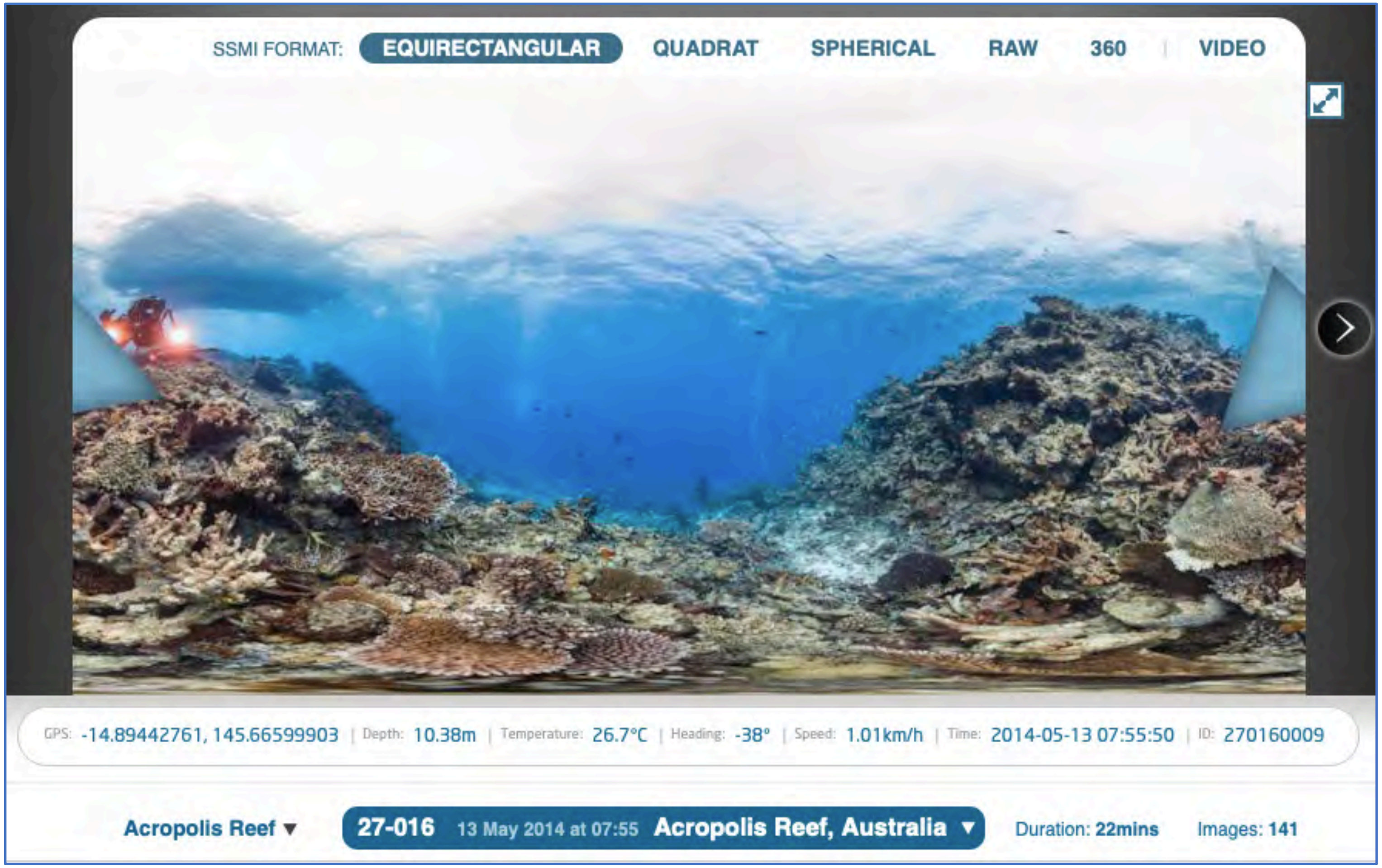
There is a high speed underwater transect at 3:50

And a great revision of quadrats at 5:00

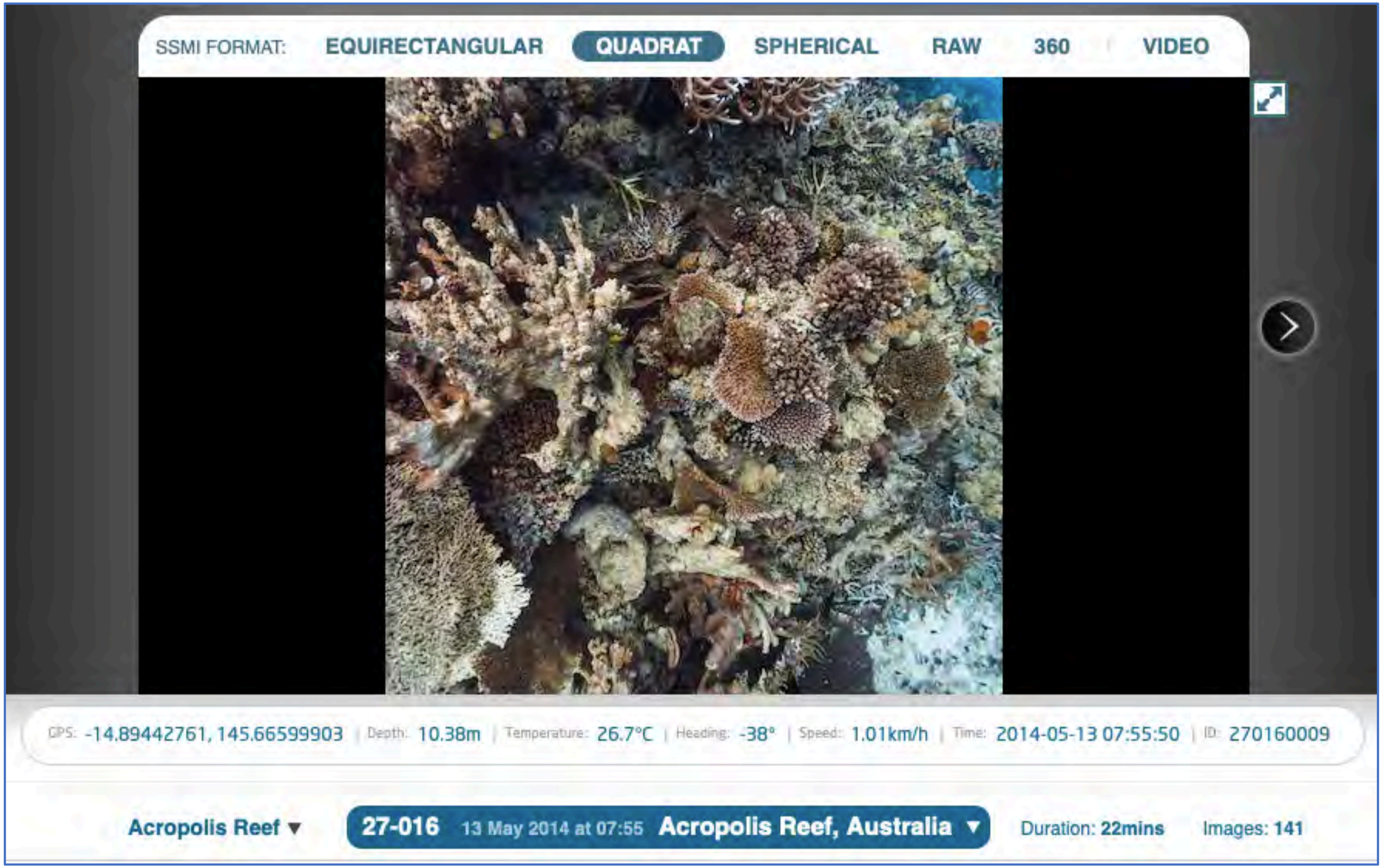
Can you find me? (Streetview on the Great Barrier Reef) - Smarter Every Day 114

YouTube video by SmarterEveryDay, available: https://youtu.be/az1PTIehYKI
Database link: Underwater Earth / XL Catlin Global Reef Record

Visit: http://globalreefrecord.org/data
Select Australia (or somewhere else if you like)
Choose one of the 79 reefs surveyed (I've chosen Acropolis, as it's the first alphabetically)



Here is the quadrat view.
You can scroll through and zoom in on 141 images from this one transect.

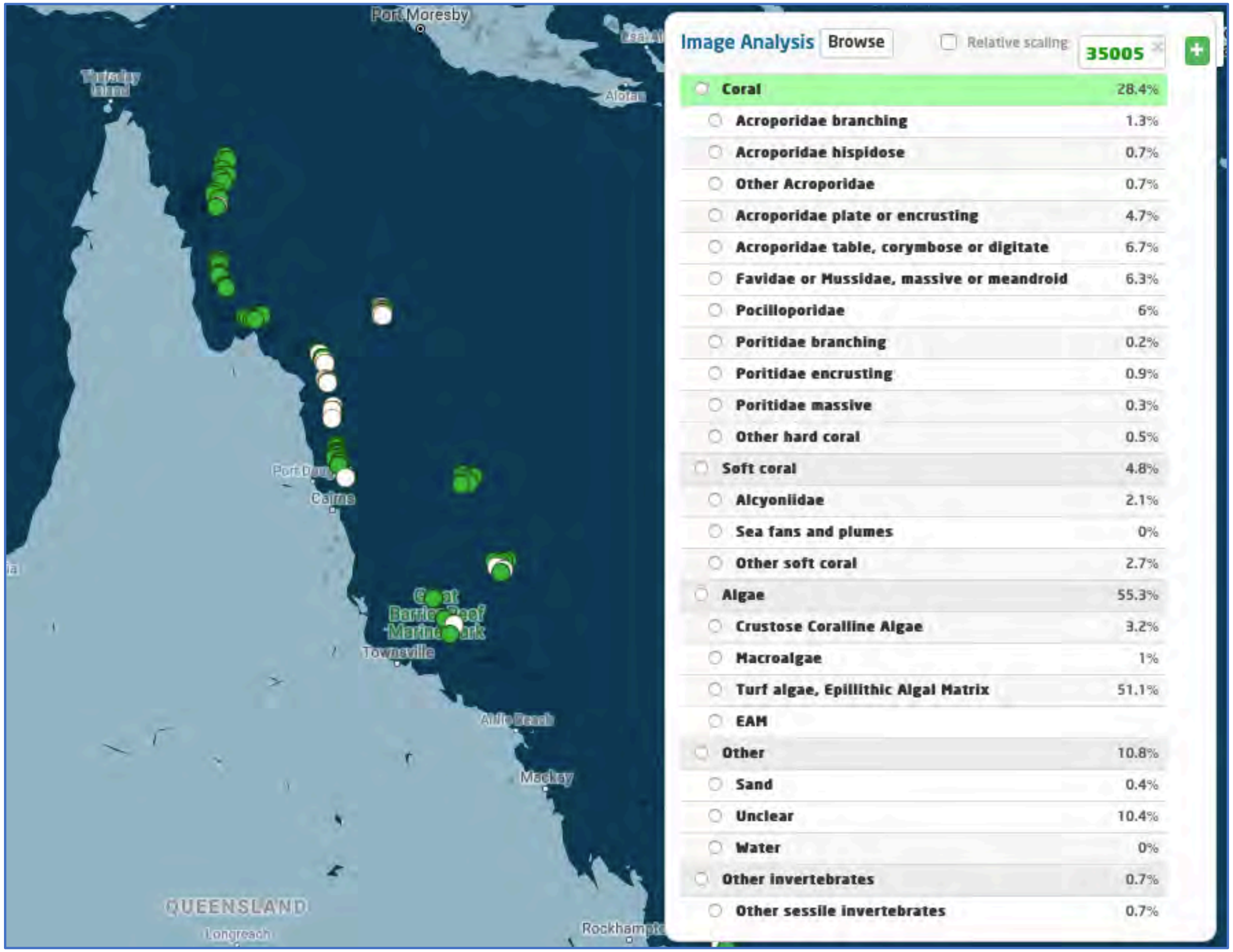


Or you can select the video:

XL Catlin survey 0270160009 of Acropolis reef May 13, 2014

Available: https://youtu.be/tQZrp-BegYc

Many (but not all) of these transects have been analysed.
This transect 35-005 is from Agincourt reef 2a on 26 November 2014



You could compare this data between different reefs: inshore- offshore or between northern, central and southern sectors.

We look at analysing reef diversity data in the next topic

Question

Explain the method that you used to obtain data on coral diversity.

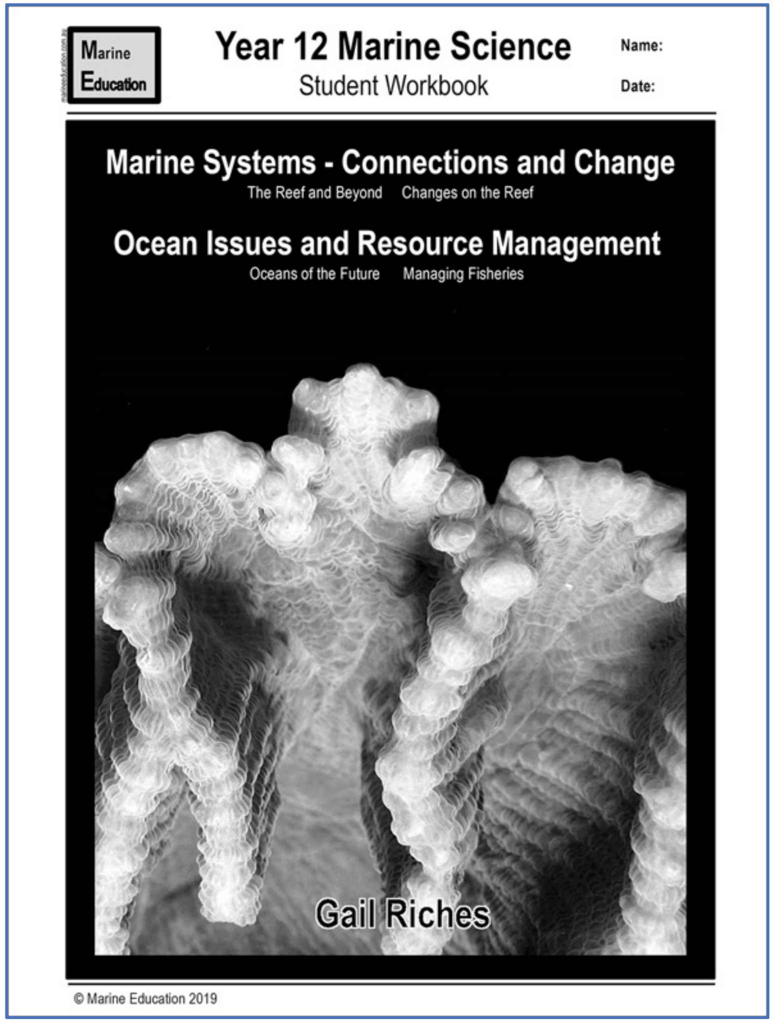
Worksheet

Discovering with Data

by

Gail Riches

www.marineeducation.com.au



T094 Analyse reef diversity

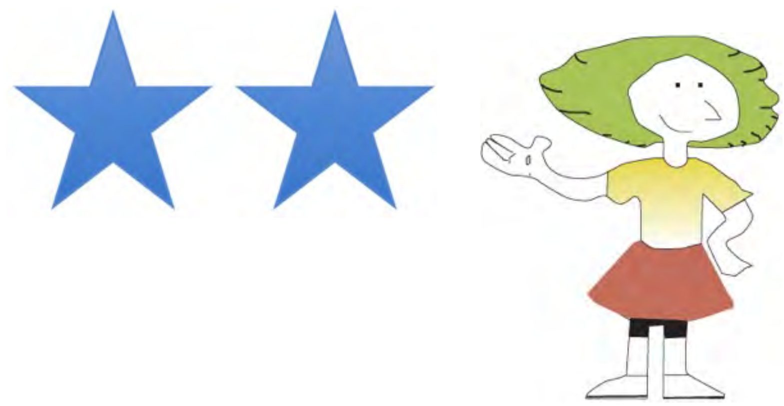
Adam Richmond

Syllabus statement

At the end of this topic you should be able to ...

Analyse

Reef diversity data using an index, to determine rank abundance.



Diversity data

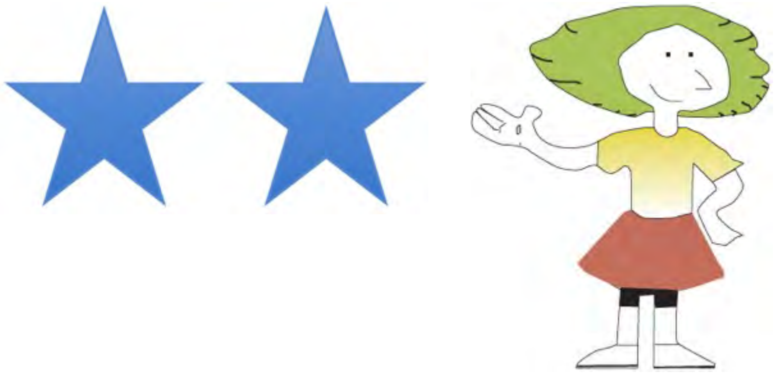
- measurements of an attribute or attributes; data may be quantitative or qualitative and be from primary or secondary sources (ACARA 2015c)

Diversity indices

- used to rank abundance could include
    - Shannon-Wiener,
    - Simpson's,
    - Jaccard and
    - Sorensen's

Analyse

- dissect to ascertain and examine constituent parts and/or their relationships;
- break down or examine in order to identify the essential elements, features, components or structure;
- determine the logic and reasonableness of information;
- examine or consider something in order to explain and interpret it, for the purpose of finding meaning or relationships and identifying patterns, similarities and differences



Objectives

Determine rank abundance using the following diversity indices

- Shannon-Wiener,
- Simpson's,
- Jaccard and
- Sorensen's

Rank abundance

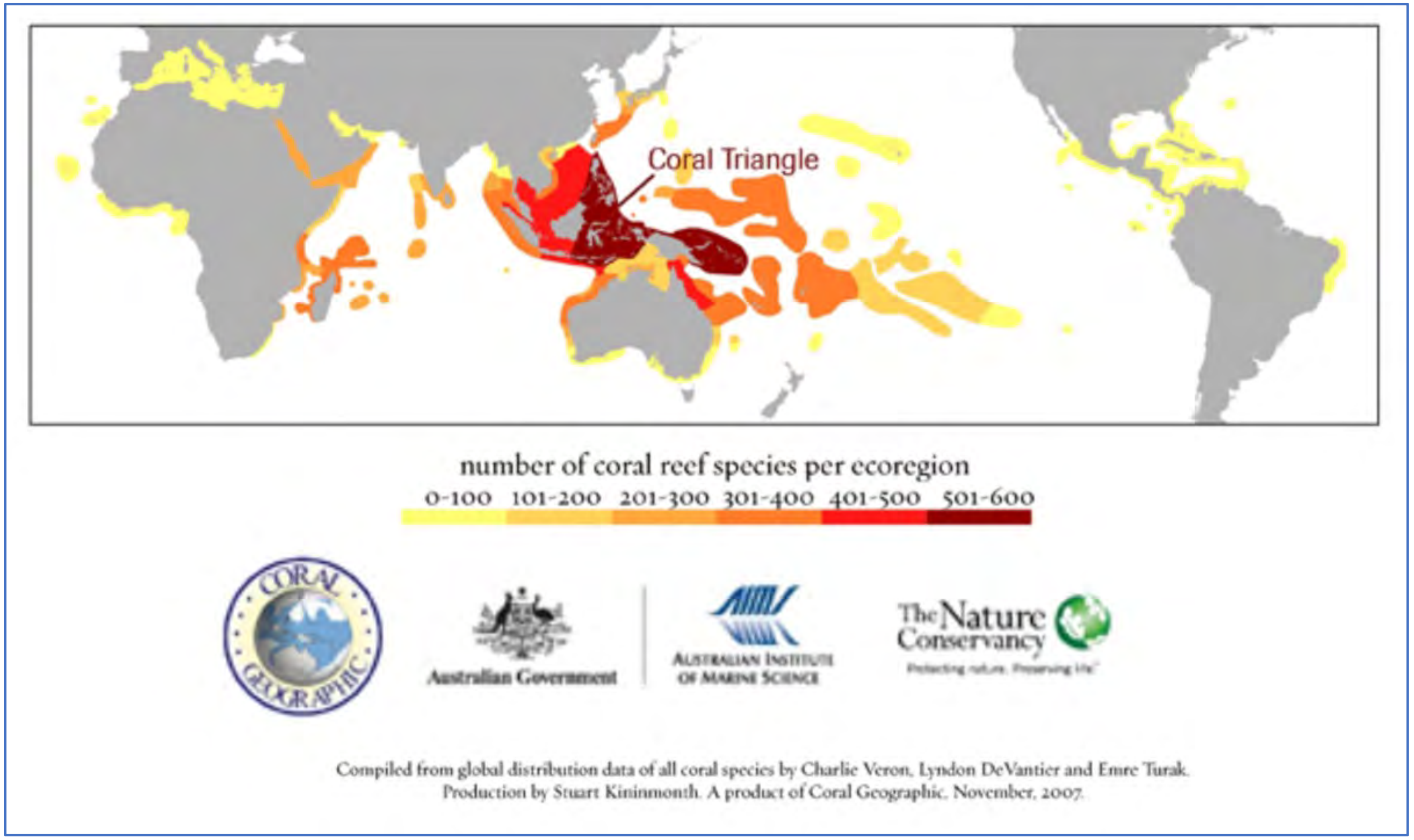
Rank abundance is one way to measure diversity of an ecosystem. When comparing the biodiversity of ecosystems, ecologists consider the number of individuals, the richness and diversity of species, and the relative abundance or evenness of different species.

A healthy ecosystem often has high biodiversity and evenness.

Dominance of one organism is an indicator of poor health.

Some areas naturally have greater diversity than others, such as the coral triangle.

Scientists need to compare locations in order to identify priority areas for conservation, and compare the same areas over time to determine changes in reef health.



Also http://ctatlas.reefbase.org/coraltriangle.aspx

Image: Coral Guardian https://www.coralguardian.org/en/coral-triangle/

For example, Mellin *et al* used analysis based on Sørensen 's and Simpsons indices to compare differences in reef communities through space and time across the Great Barrier Reef.

You can read the article here:

https://royalsocietypublishing.org/doi/pdf/10.1098/rspb.2013.1993

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Research

Cite this article: Mellin C, Bradshaw CJA, Fordham DA, Caley MJ. 2014 Strong but opposing β-diversity–stability relationships in coral reef fish communities. *Proc. R. Soc. B* **281**: 20131993. http://dx.doi.org/10.1098/rspb.2013.1993

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Subject Areas:
ecology, environmental science, theoretical biology

Strong but opposing β-diversity–stability relationships in coral reef fish communities

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The 'diversity–stability hypothesis', in which higher species diversity within biological communities buffers the risk of ecological collapse, is now generally accepted. However, empirical evidence for a relationship between β-diversity (spatial turnover in community structure) and temporal stability in community structure remains equivocal, despite important implications for theoretical ecology and conservation biology. Here, we report strong β-diversity–stability relationships across a broad sample of fish taxa on Australia's Great Barrier Reef. These relationships were robust to random sampling error and spatial and environmental factors, such as latitude, reef size and isolation. While β-diversity was positively associated with temporal stability at the community level, the relationship was negative for some taxa, for example surgeonfishes (Acanthuridae), one of the most abundant reef fish families. This demonstrates that the β-diversity–stability relationship should not be indiscriminately assumed for all taxa, but that a species' risk of extirpation in response to disturbance is likely to be taxon specific and trait based. By combining predictions of spatial and temporal turnover across the study area with observations in marine-protected areas, we conclude that protection alone does not necessarily confer temporal stability and that taxon-specific considerations will improve the outcome of conservation efforts.

Image: https://royalsocietypublishing.org/doi/pdf/10.1098/rspb.2013.1993

Reference: Mellin, C., Bradshaw, C., Fordham, D., & Caley, M. (2014). Strong but opposing -diversity-stability relationships in coral reef fish communities. *Proceedings Of The Royal Society B: Biological Sciences*, *281*(1777), 20131993-20131993. doi: 10.1098/rspb.2013.1993

The following pages of discussion and exercises refer to the following report.

Download the Reef Check Australia Heron Island Reef Health Report 2018 here:

https://d3n8a8pro7vhmx.cloudfront.net/rca/pages/449/attachments/original/1554438573/Heron_Report_2018_FINAL-compressed.pdf?1554438573

Or a report from a different location or year from this webpage:

https://www.reefcheckaustralia.org/publications

Image: Reef Check, Reef Check Australia 2018 Heron Island Reef Health Report

This report should be cited as: J. Salmond, J. Passenger, E. Kovacs, C. Roelfsema and D. Stetner. Reef Check Australia 2018 Heron Island Reef Health Report. Reef Check Foundation Ltd.

The following fish survey data was extracted from Heron Island Reef Health Report 2018

	parrotfish	snapper	butterflyfish	coral trout	grouper	moray eel	humphead wrasse
Canyons	3	9	52	1	1	0	0
Cappuccino Express	9	12	15	0	2	1	0
Coral Cascade	6	1	8	0	5	0	0
Coral Garden	4	8	5	0	0	0	0
Coral Grotto	3	6	9	0	3	0	0
Gorgonian Hole	0	21	22	0	2	0	1
Harry's Bommie	1	1	22	1	0	0	0
Heron Bommie	9	15	26	7	0	0	0
Jetty Flat	3	1	6	0	0	0	0
Last Resort	0	2	4	0	0	1	0
Libby's Lair	5	4	20	5	0	0	0
Research Zone	1	0	15	0	0	0	0
Shark Bay	2	0	12	0	1	0	0
Stevos Carbonara	0	0	0	0	0	0	0
White Wedding	0	12	0	0	0	0	0

We will determine the species richness, species diversity (using Simpsons and Shannon-Wiener indices) and similarity (using Jaccard and Sørensen's coefficients) of this reef data

Reference: J. Salmond, J. Passenger, E. Kovacs, C. Roelfsema and D Stetner. Reef Check Australia 2018 Heron Island Reef Health Report. Reef Check Foundation Ltd.

Species Richness (S)

Species richness is the number of different species represented in an ecological community, (in this case reef). Species richness is simply a count of species, and it does not take into account the abundances of the species or their relative abundance distributions.

	parrotfish	snapper	butterflyfish	coral trout	grouper	moray eel	humphead wrasse	S
Canyons	3	9	52	1	1	0	0	5
Cappuccino Express	9	12	15	0	2	1	0	5
Coral Cascade	6	1	8	0	5	0	0	4
Coral Garden	4	8	5	0	0	0	0	3
Coral Grotto	3	6	9	0	3	0	0	4
Gorgonian Hole	0	21	22	0	2	0	1	4
Harry's Bommie	1	1	22	1	0	0	0	4
Heron Bommie	9	15	26	7	0	0	0	4
Jetty Flat	3	1	6	0	0	0	0	3
Last Resort	0	2	4	0	0	1	0	3
Libby's Lair	5	4	20	5	0	0	0	4
Research Zone	1	0	15	0	0	0	0	2
Shark Bay	2	0	12	0	1	0	0	3
Stevos Carbonara	0	0	0	0	0	0	0	0
White Wedding	0	12	0	0	0	0	0	1

The species richness of Canyons and Cappuccino Express are both 5.

Next we will determine if their diversity is the same.

Species diversity indices take into account both species richness and species evenness.

In Topic 042 Simpson's Diversity Index, you learned how to calculate the biodiversity of a sand dune ecosystem using Simpsons Diversity index (SDI or D).
Simpson's index considers the number of species present and the relative abundance of each species.

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)} \right)$$

In Topic 043 Apply biodiversity data, you used Shannon's diversity index.

$$H = -\sum (n/N) \ln(n/N)$$

If you've forgotten what these are- revisit Topics 42 and 43.
There are lots of useful websites and tutorials online, like this one:
https://entnemdept.ifas.ufl.edu/hodges/protectus/lp_webfolder/9_12_grade/student_handout_1a.pdf

Simpson's Diversity Index (using Heron Island data for Canyons)

SDI canyons	n	n-1	n(n-1)
parrotfish	3	2	6
snapper	9	8	72
butterflyfish	52	51	2652
coral trout	1	0	0
grouper	1	0	0
moray eel	0	-1	0
humphead wrasse	0	-1	0
	N=66		Σn(n-1) = 2730

66 x 65 = 4290

$$D = 1 - \left(\frac{\Sigma n(n-1)}{N(N-1)} \right)$$

$$D = 1 - \left(\frac{2730}{4290} \right)$$

$$= 1 - 0.64$$

$$= 0.36$$

Need help?

Visit: https://www.statisticshowto.datasciencecentral.com/simpsons-diversity-index/

Simpson's Diversity Index (using Heron Island data for Cappuccino)

SDI cappuccino	n	n-1	n(n-1)
parrotfish	9	8	72
snapper	12	11	132
butterflyfish	15	14	210
coral trout	0	-1	0
grouper	2	1	2
moray eel	1	0	0
humphead wrasse	0	-1	0
	N=39		Σn(n-1)= 416

39 x 38 =1482

$$D = 1 - \left(\frac{\Sigma n(n-1)}{N(N-1)} \right)$$

$$D = 1 - \left(\frac{416}{1482} \right)$$

$$= 1 - 0.28$$

$$= 0.72$$

Simpson's Diversity Index (using Heron Island data for Coral Cascade)

SDI coral cascade	n	n-1	n(n-1)
parrotfish	6	5	30
snapper	1	0	0
butterflyfish	8	7	56
coral trout	0	-1	0
grouper	5	4	20
moray eel	0	-1	0
humphead wrasse	0	-1	0
	N=20		$\Sigma n(n-1) = 106$

$$D = 1 - \left(\frac{\Sigma n(n-1)}{N(N-1)} \right)$$

20 x 19 = 380

$$D = 1 - \left(\frac{106}{380} \right)$$

$= 1 - 0.28$

$= 0.72$

Simpson's Diversity Index

	parrotfish	snapper	butterflyfish	coral trout	grouper	moray eel	humphead wrasse	S	N	D
Canyons	3	9	52	1	1	0	0	5	66	0.36
Cappuccino Express	9	12	15	0	2	1	0	5	39	0.72
Coral Cascade	6	1	8	0	5	0	0	4	20	0.72

The Simpson's diversity index (D) at Canyons is 0.36
The Simpson's diversity index (D) at Cappuccino express is 0.72
The Simpson's diversity index (D) at Coral Cascade is 0.72

So what does this mean?

Species richness is the same at Canyons and Cappuccino Express, but the distribution of organisms is much more even at Cappuccino express.
Coral Cascade has less species richness, but more even distribution than Canyons.
Coral Cascade has less species richness, but the same diversity index as Cappuccino express.

Shannon-Wiener Index

In Topic 043 you learned how to calculate Shannon-Wiener diversity index.

This example was done using Excel (and using the same Heron Island data for Canyons reef)

Shannon canyons	number	proportion	natural log of (n/N)	Product of proportion x natural log
species	n	n/N	ln(n/N)	n/N x ln(n/N)
parrotfish	3	0.05	-3.09	-0.14
snapper	9	0.14	-1.99	-0.27
butterflyfish	52	0.79	-0.24	-0.19
coral trout	1	0.02	-4.19	-0.06
grouper	1	0.02	-4.19	-0.06
	N=66			Σ= -0.73
				H= 0.73

$\frac{\text{the number of one species (n)}}{\text{the total number of organisms (N)}}$

The natural log (LN) function of the proportion

$$H = -\sum(n/N)\ \ln(n/N)$$

Shannon cappuccino	number	proportion	natural log of (n/N)	Product of proportion x natural log
species	n	n/N	ln(n/N)	n/N x ln(n/N)
parrotfish	9	0.23	-1.47	-0.34
snapper	12	0.31	-1.18	-0.36
butterflyfish	15	0.38	-0.96	-0.37
grouper	2	0.05	-2.97	-0.15
moray eel	1	0.03	-3.66	-0.09
	N=39			Σ= -1.31
				H= 1.31

Shannon coral cascade	number	proportion	natural log of (n/N)	Product of proportion x natural log
species	n	n/N	ln(n/N)	n/N x ln(n/N)
parrotfish	6	0.30	-1.20	-0.36
snapper	1	0.05	-3.00	-0.15
butterflyfish	8	0.40	-0.92	-0.37
grouper	5	0.25	-1.39	-0.35
	N=20			Σ= -1.22
				H= 1.22

This is the same process for the data from Coral Cascade and Cappuccino express

Shannon-Wiener index

	parrotfish	snapper	butterflyfish	coral trout	grouper	moray eel	humphead wrasse	S	N	D	H
Canyons	3	9	52	1	1	0	0	5	66	0.36	0.73
Cappuccino Express	9	12	15	0	2	1	0	5	39	0.72	1.31
Coral cascade	6	1	8	0	5	0	0	4	20	0.72	1.22

So what does this mean?

The Shannon Wiener indices followed a similar pattern, but is more sensitive than the Simpson’s diversity index.
Cappuccino Express is slightly more diverse than Coral Cascade, which are both more diverse than Canyons.

These Shannon-Wiener index values are low, literature suggests that Shannon Wiener values are typically between 1.3 (low) and 4.5 (high).

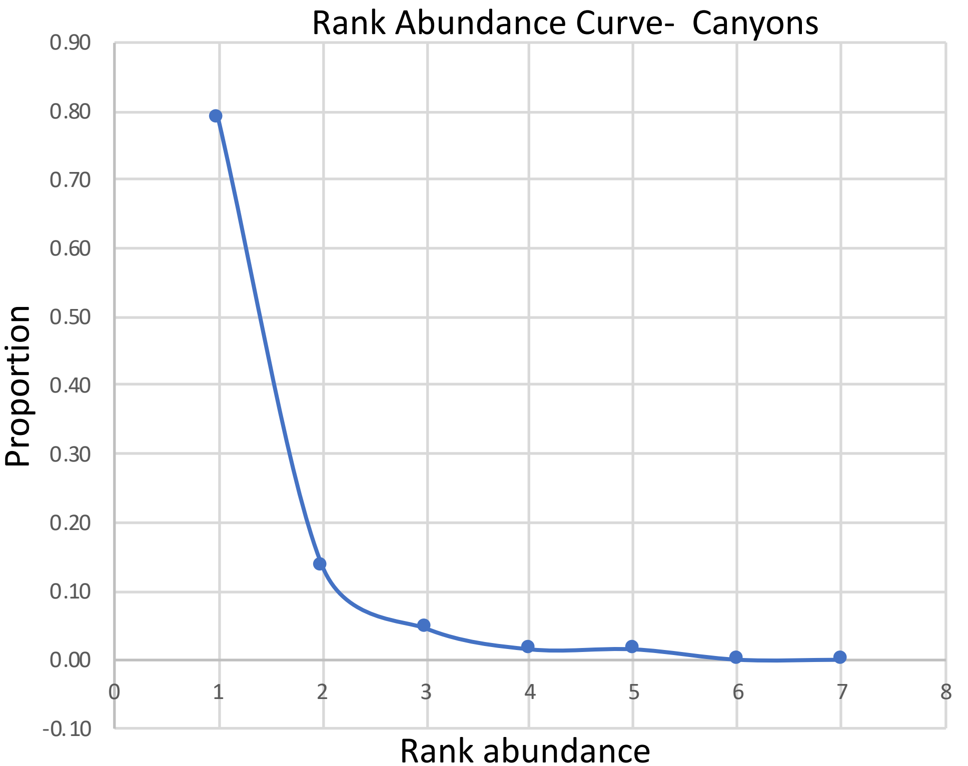
Rank Abundance Curves (also known as Whittaker curves)

Rank abundance curves show the relative abundance of each species on the Y axis against its abundance rank on the X axis.
They provide a visual representation of species richness and species evenness

The organisms need to be sorted from most abundant to least abundant.

The proportions are the same as calculated for the Shannon Wiener index.

Rank abundance Canyons	n	Rank	proportion
butterflyfish	52	1	0.79
snapper	9	2	0.14
parrotfish	3	3	0.05
coral trout	1	4	0.02
grouper	1	5	0.02
moray eel	0	6	0.00
humphead wrasse	0	7	0.00
	N=66		



There is a very simple tutorial here:
https://www.youtube.com/watch?v=3oTD1iONMnQ

Similarity Indices help determine the similarity (or lack of similarity) between different samples, quadrats, or communities.

Numerous similarity indices have been proposed to measure the degree to which species composition of data sets is alike.

How similar are quadrats 100130210 and 100130220 from Flinders reef?

Jaccard similarity index

The Jaccard coefficient is the simplest index, and is widely used to assess similarity of quadrats. Uses presence/absence data (ignores info about abundance)

$$S_J = a/(a + b + c)$$

Where:
S_J = Jaccard similarity coefficient,
a = number of species common to (shared by) both quadrats,
b = number of species unique to the first quadrat, and
c = number of species unique to the second quadrat

S_J usually is multiplied by 100% (i.e., S_J = 67%), and may be represented in terms of dissimilarity (i.e., $D_J = 1.0 - S_J$)

Need help?
Visit: https://www.statisticshowto.datasciencecentral.com/jaccard-index/

Jaccard similarity index

	parrotfish	snapper	butterflyfish	coral trout	grouper	moray eel	humphead wrasse
Canyons	3	9	52	1 b	1	0	0
Cappuccino Express	9	12	15	0	2	1 c	0
	a	a	a		a		

a = number of species common to (shared by) both quadrats = 4
b = number of species unique to the first quadrat = 1
c = number of species unique to the second quadrat = 1

$$S_J = a/(a + b + c)$$

$S_J = 4/(4 + 1 + 1)$
$= 4/6$
$= 0.67$

0.67 x 100 = 67%
These two fish communities are 67% similar

1 – 0.67 = 0.34

Alternatively, these communities are 33% dissimilar

Jaccard similarity index

	parrotfish	snapper	butterflyfish	coral trout	grouper	moray eel	humphead wrasse
Harry's Bommie	1	1	22	1	0	0	0
Heron Bommie	9	15	26	7	0	0	0
	a	a	a		a		

a = number of species common to (shared by) both quadrats = 4

b = number of species unique to the first quadrat = 0

c = number of species unique to the second quadrat = 0

$$S_J = a/(a + b + c)$$

$S_J = 4/(4 + 0 + 0)$

$= 4/4$

$= 1.00$

1.00 x 100 = 100%

These two fish communities are 100% similar.

Sørensen's similarity index

The Sørensen coefficient is a simple index, that gives greater "weight" to species common to the quadrats than to those found in only one quadrat.
Like the Jaccard index, Sørensen's index uses presence/absence data.

$$S_S = 2a/(2a + b + c)$$

> The Sørensen index is sometimes called a Bray-Curtis index, Steinhaus index or Czekanowski index

Where:
S_S = Sørensen similarity coefficient,
a = number of species common to (shared by) both quadrats,
b = number of species unique to the first quadrat, and
c = number of species unique to the second quadrat

S_S usually is multiplied by 100% (i.e., S_S = 67%), and may be represented in terms of dissimilarity (i.e., $D_S = 1.0 - S_S$)

Sørensen's similarity index

	parrotfish	snapper	butterflyfish	coral trout	grouper	moray eel	humphead wrasse
Canyons	3	9	52	1	1	0	0
Cappuccino Express	9	12	15	0	2	1	0

a = number of species common to (shared by) both quadrats = 4
b = number of species unique to the first quadrat = 1
c = number of species unique to the second quadrat = 1

$S_S = 2a/(2a + b + c)$

$S_J = 2x\ 4/(2x\ 4 + 1 + 1)$
$= 8 / (8 + 2)$
$= 8/10$
$= 0.80$

0.800 x 100 = 80%
These two fish communities are 80% similar

1 – 0.80 = 0.34

Alternatively, these communities are 20% dissimilar.

Question

The following invertebrate survey data is from Heron Island Reef Health Report 2018. Analyse this data using the indices in this presentation.

	edible sea cucumbers	giant clam	triton	trochus	drupella	anemone
Canyons	0	6	0	0	0	1
Cappuccino Express	17	3	0	0	0	1
Coral Cascade	1	3	0	0	0	1
Coral Garden	0	0	0	1	0	0
Coral Grotto	2	5	0	0	4	2
Gorgonian Hole	2	0	0	0	4	3
Harry's Bommie	2	2	0	0	0	0
Heron Bommie	1	12	0	0	1	0
Jetty Flat	4	0	0	0	0	0
Last Resort	30	7	0	0	0	0
Libby's Lair	2	0	0	0	1	1
Research Zone	1	2	0	0	0	0
Shark Bay	38	7	0	0	0	0
Stevos Carbonara	2	1	0	0	0	0
White Wedding	2	12	0	0	0	0

Reference: J. Salmond, J. Passenger, E. Kovacs, C. Roelfsema and D Stetner. Reef Check Australia 2018 Heron Island Reef Health Report. Reef Check Foundation Ltd.

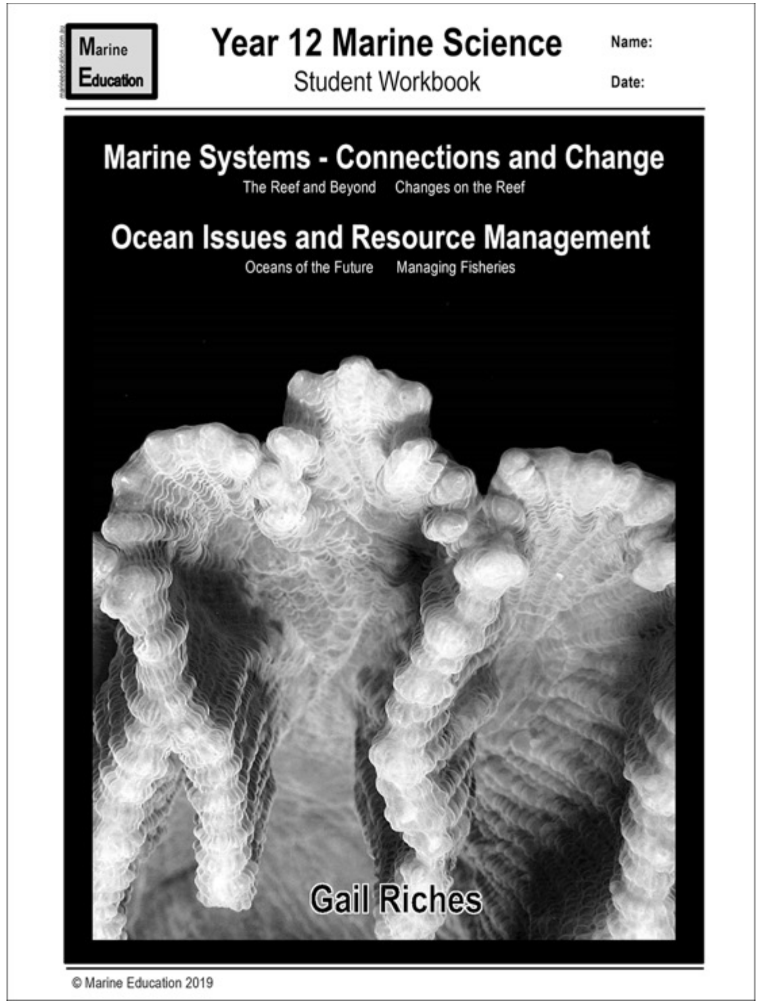
Further activity

Worksheet –

Life in one number

by
Gail Riches

www.marineeducation.com.au



T095 Interpret reef changes

Adam Richmond

Syllabus statement

At the end of this topic you should be able to ...

Interpret

with reference to regional trends, how coral cover has changed on a reef over time

When interpreting coral cover change, recognise that reefs can and do recover from pulse events but this may take decades.

Interpret

- use knowledge and understanding to ***recognise*** trends and draw conclusions from given information; make clear or explicit; elucidate or understand in a particular way;
- bring out the meaning of, e.g. a dramatic or musical work, by performance or execution; bring out the meaning of an artwork by artistic representation or performance; give one's own interpretation of;
- identify or draw meaning from, or give meaning to, information presented in various forms, such as words, symbols, pictures or graphs

Recognise

Identify or recall particular features of information from knowledge; identify that an item, characteristic or quality exists; perceive as existing or true; be aware of or acknowledge

Objectives

1. Recognise and describe trends in coral cover graphs

2. Demonstrate understanding of factors that affect coral cover

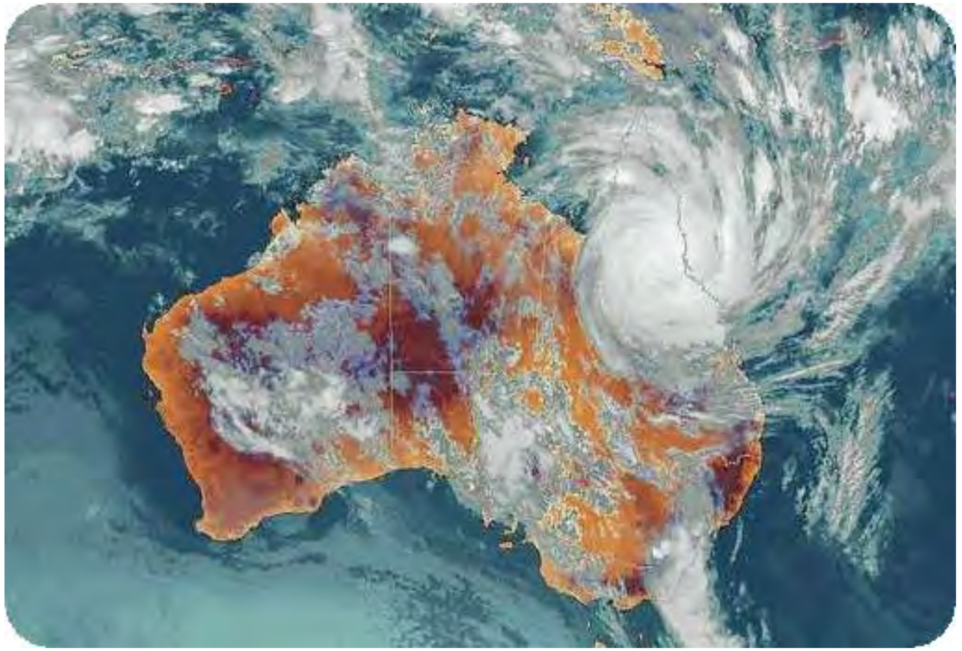
3. Interpret a coral cover graph in your own words

4. Recall
    - what pulse events are;
    - how they affect coral cover;
    - that corals can recover but that recovery can take decades

Pulse events

Pulse events, or acute disturbances, cause temporary loss of coral cover and degradation of reef systems. This coral loss can be extreme and widespread.

Examples include: severe tropical storms, mass coral bleaching due to heat stress, and outbreaks of coral predators or coral disease



Australia Infrared Satellite Image Cyclone Yasi

Image: @gletham GIS, flickr. CC BY2.0

Threats to the reef

A short search of the literature revealed the following threats to coral reefs.
Which of these are pulse (acute, short term) events?

- Anchoring: direct crushing and chain damage
- Chemical and oil pollution
- Cyclones
- Disease events: such as white band disease
- Fishing: commercial, line, trawl, traditional
- Landfill/reclamation and dredging
- Nutrient enrichment from runoff/sewage
- Sedimentation due to floods
- Storm damage/waves
- Temperature rise global warming
- Temperature spikes: anomalies and El Niño
- Tourism pressure
- Tsunamis

Coral bleaching is considered a pulse event

Image: Wikipedia
https://upload.wikimedia.org/wikipedia/en/9/90/Keppelbleaching.jpg

Coral cover

Coral cover is the percentage of substrate that is occupied by scleractinian (hard) corals.

% Coral cover is commonly used as a measure of coral reef ecosystem health because changes in coral cover are readily apparent and easy to measure"[1]

Coral cover for the AIMS long term monitoring program, referred to during this topic, was estimated using the manta tow technique.

Reference:

1. Pratchett, M., & Hoogenboom, M. (2019). Disturbances and pressures to coral reefs. In P. Hutchings, M. Kingsford & O. Hoegh-Guldberg, *The Great Barrier Reef: Biology, Environment and Management* (2nd ed., pp. 131-141). Clayton South: CSIRO.

Manta tow is used for coral cover and COTS counts

Cyclone Debbie destroyed coral and caused heavy sedimentation

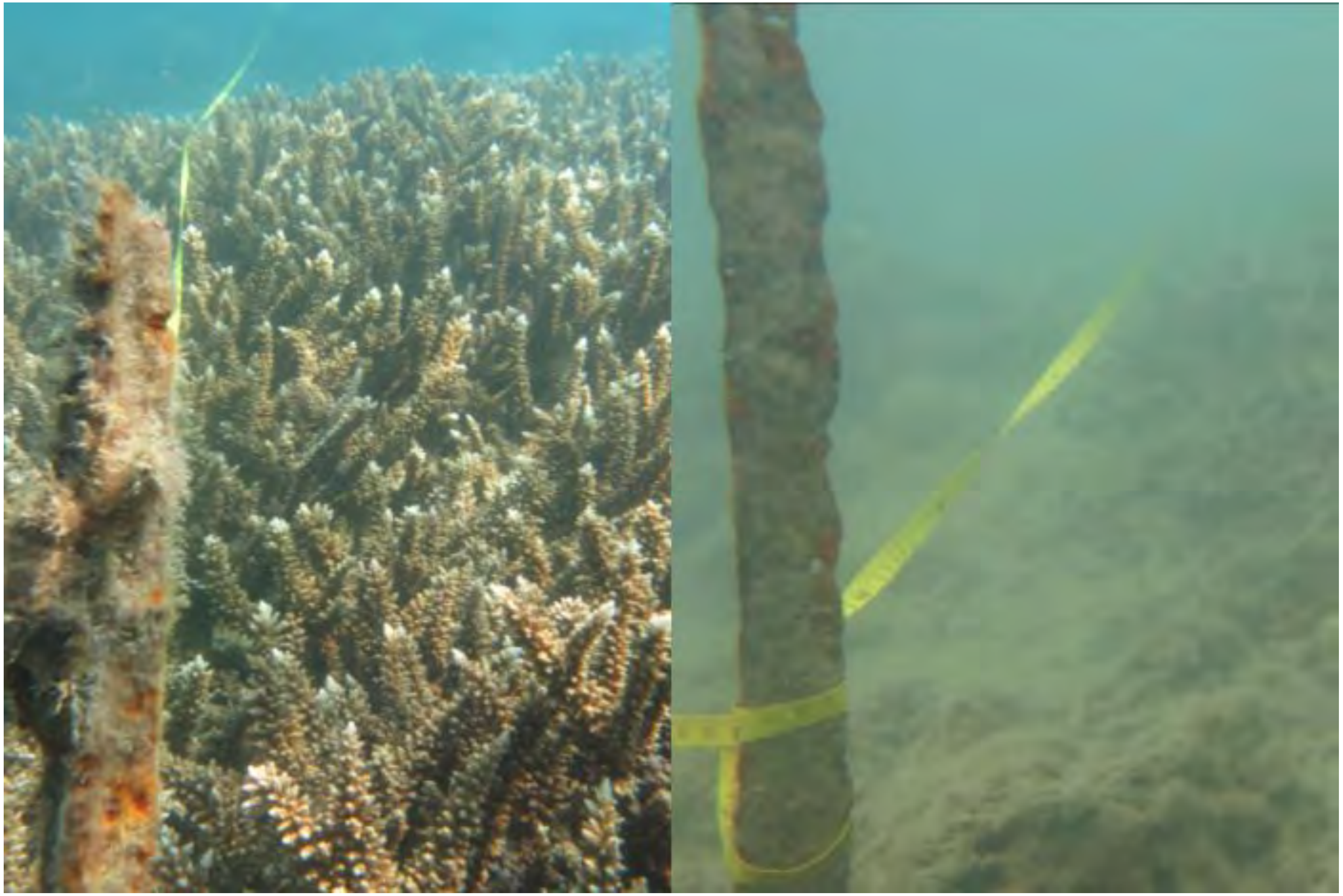


Image: A. Thompson, Copyright Australian Institute of Marine Science. Reproduced with permission.

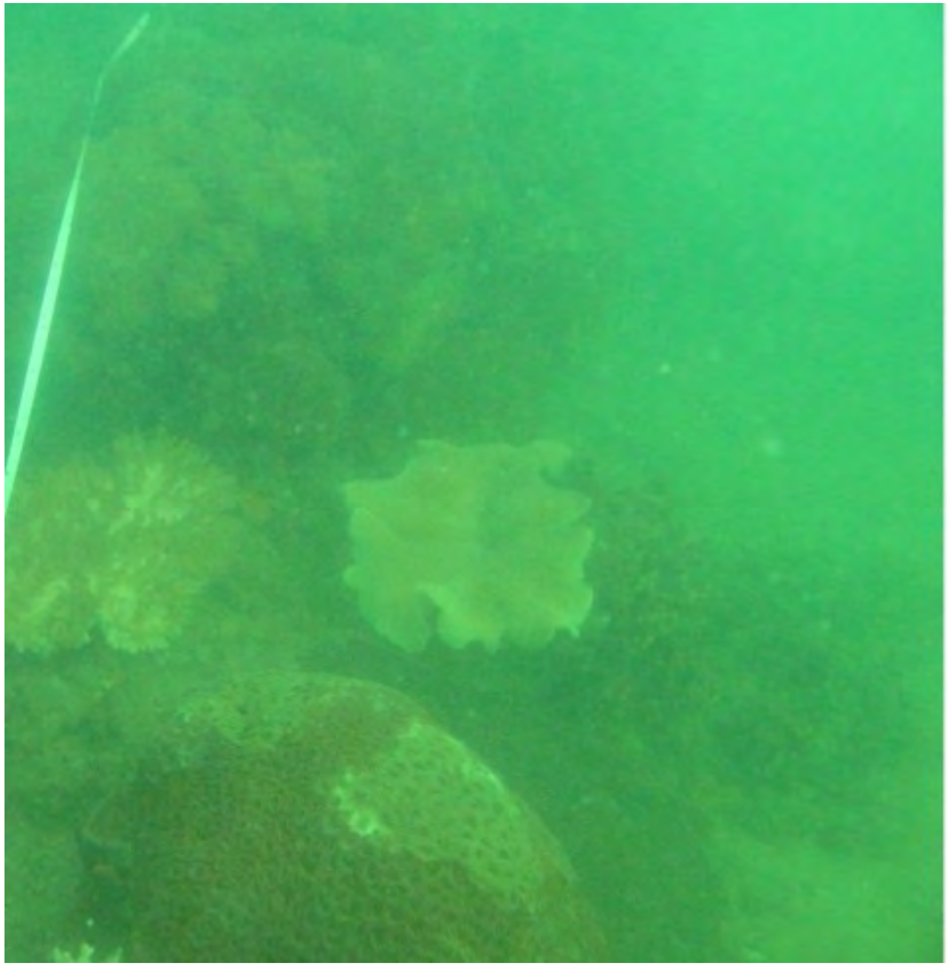
Chronic pressures

Chronic pressures are persistent changes in conditions that cause continuous, long-term pressure on reef systems and species.

These pressures may not directly cause significant coral mortality, but impact on growth, reproduction, recruitment and reduce the capacity of the reef system to recover effectively.

Examples include:

- Declining water quality due to sediments, nutrients and pollutants;
- Global climate change - sea surface temperature, ocean acidification.



Corals at Pelican Island have low water clarity due to runoff from the land

Pulse events kill and destroy some established reef organisms.

However, this makes space available for new coral recruits, which contributes to habitat heterogeneity and biodiversity.

Juvenile and teenage corals are increasing coral cover at North Reef

If pulse events are too frequent or too severe, ecosystems cannot recover completely between successive disturbances, leading to a progressive loss of species and degradation of reef ecosystems.

The graphs to the right show the different impacts of 3 pulse events on the % cover of hard and soft corals at Lizard Island. *Acropora hyacinthus quickly* becomes the dominant coral between disturbances.

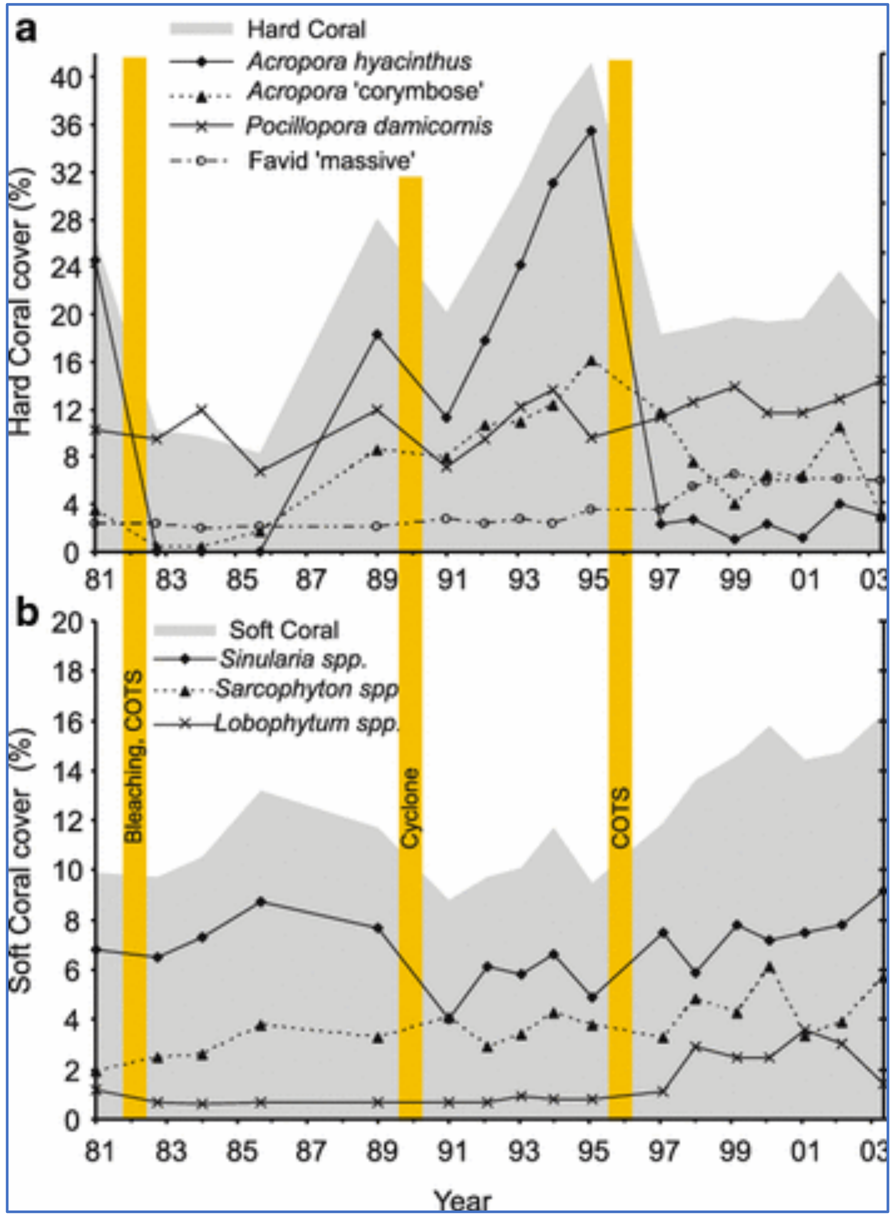
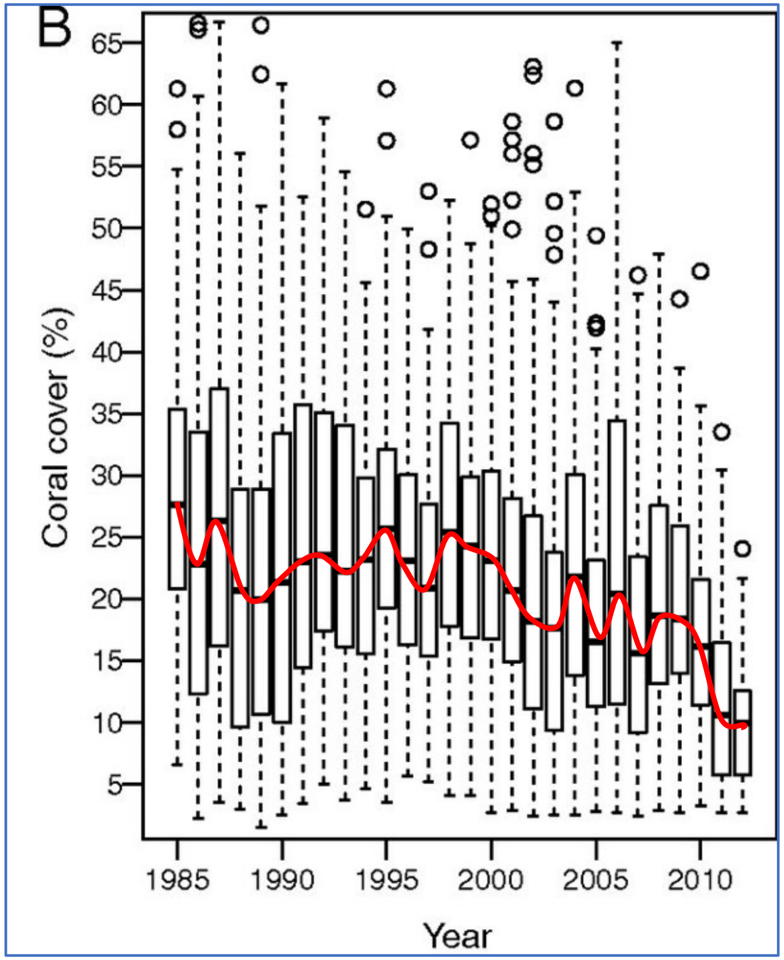


Image and reference: Wakeford, M., Done, T., & Johnson, C. (2007). Decadal trends in a coral community and evidence of changed disturbance regime. *Coral Reefs*, *27*(1), 1-13. doi: 10.1007/s00338-007-0284-0. Open access. CC 4.0 BY

De'ath *et al* investigated coral cover in the Great Barrier from 1985-2012.



Reference and Image : De'ath, G., Fabricius, K. E., Sweatman, H. & Puotinen, M. (2012). The 27-year decline of coral cover on the Great Barrier Reef and its causes. Proceedings of the National Academy of Sciences of USA, 109 (44), 17995-17999. *(red line added to image for clarity) NonCommercial No Derivatives 4.0 International (CC BY-NC-ND 4.0)*

This graph shows the coral cover over the 214 reefs surveyed across the entire Great Barrier Reef.

Box plots indicate the percentiles (25%, 50%, and 75%) of the coral cover distributions within each year. % Cover on individual reefs ranged from 1.5%-80%

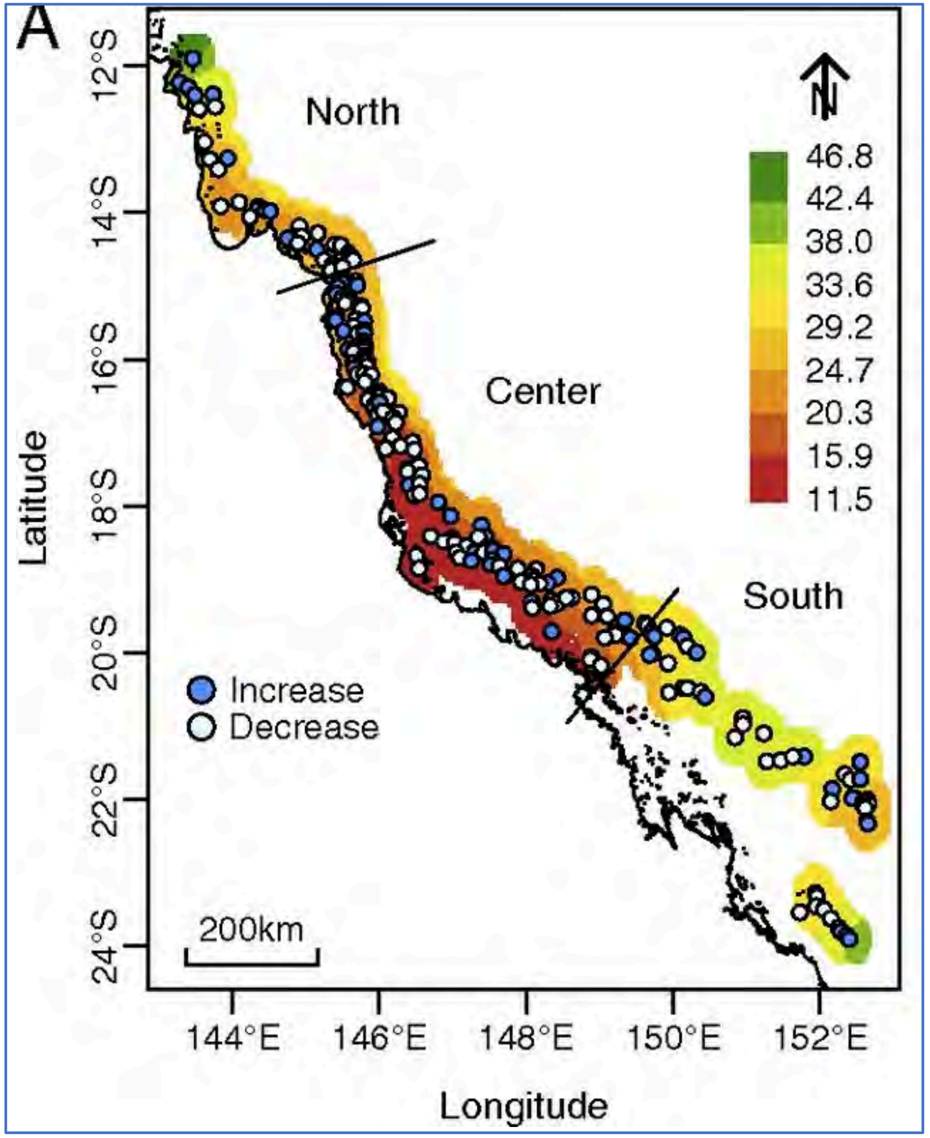
The mean coral cover show a substantial decline from 28.0% to 13.8%- a 50.7% loss in coral cover over the 27 years.

Download the open access article here:
https://www.pnas.org/content/109/44/17995

This map of the GBR shows the location of the 214 surveyed reefs in the northern, central, and southern regions.

The colour shading (green- red) indicates mean coral cover averaged over the period 1985-2012.

The colour of the circles (blue/white) indicates the direction of change in cover over time: 68% of reefs declined, while 32% experienced an increase n coral cover.



Reference: De'ath, G., Fabricius, K. E., Sweatman, H. & Puotinen, M. (2012). The 27-year decline of coral cover on the Great Barrier Reef and its causes. Proceedings of the National Academy of Sciences of USA, 109 (44), 17995-17999 NonCommercial No Derivatives 4.0 International (CC BY-NC-ND 4.0).

Changes in % coral cover vary regionally

"Interestingly, the pattern of decline (in coral cover) varies among regions.

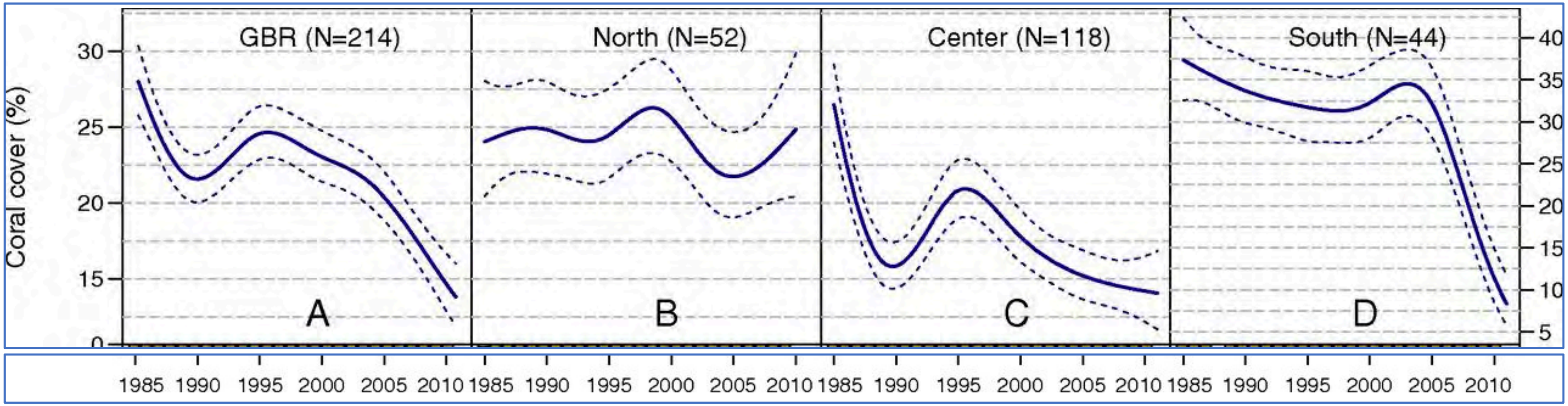
In the northern Great Barrier Reef coral cover has remained relatively stable, whereas in the southern regions we see the most dramatic loss of coral, particularly over the last decade when storms have devastated many reefs."[1]

Dr Peter Doherty, Research Fellow at AIMS.

1. Verbatim from Australian Institute of Marine Science. (https://www.aims.gov.au/docs/media/media.html)
October 2012 - The Great Barrier Reef has lost half of its coral in the last 27 years

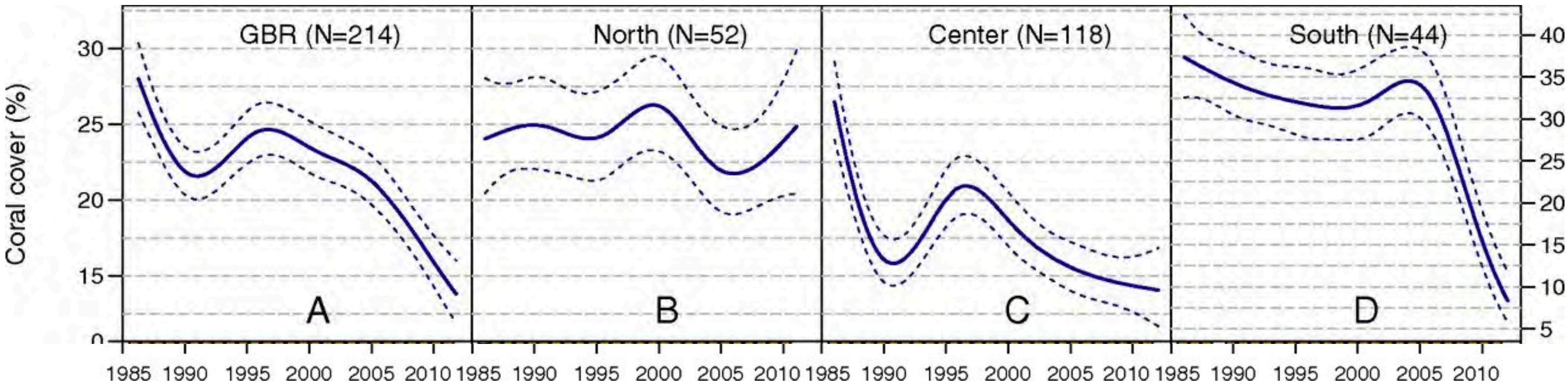
These graphs shows the trend in coral cover for the whole GBR and the northern, central, and southern regions over the period 1985–2012.

Can you interpret the trends? (shown by the blue line)



This graphs shows the trends in coral cover for the whole GBR and the northern, central, and southern regions over the period 1985–2012.

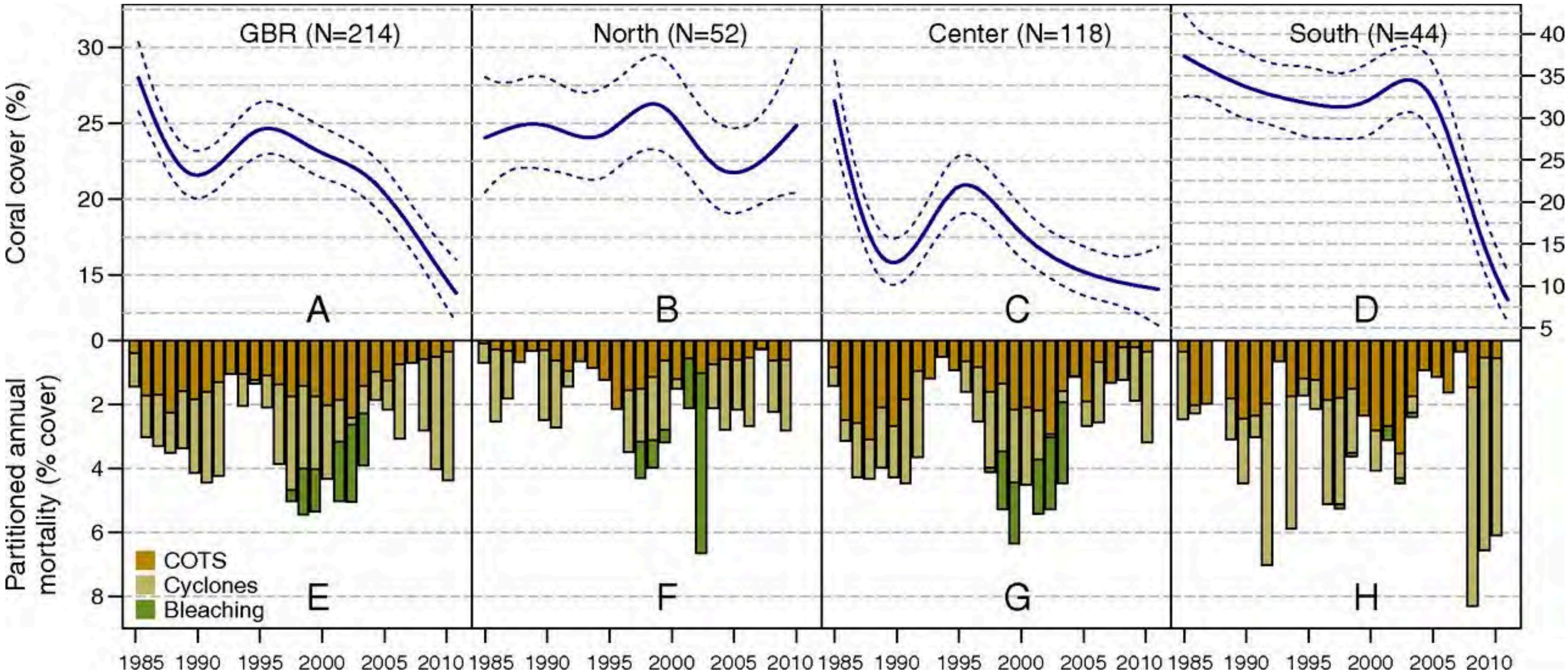
The blue lines indicate mean coral cover (±2 SEs) of each trend. (N is the number of reefs).



28 % to 13.8% 50.7% decline Rate of decline increasing	24% to 24% 0% decline Consistent coral % cover	24.4 % to 14.1% 42.2% decline Rate of decline increasing	37.4 % to 8.2% 78% decline Rate of decline increasing

Reference: De'ath, G., Fabricius, K. E., Sweatman, H. & Puotinen, M. (2012). The 27-year decline of coral cover on the Great Barrier Reef and its causes. Proceedings of the National Academy of Sciences of USA, 109 (44), 17995-17999.

This is the same graph, but includes the proportions of annual mortality due to COTS, cyclones, and bleaching. Composite bars indicate the estimated mean coral mortality for each year, and the sub-bars indicate the relative mortality due to COTS, cyclones, and bleaching.

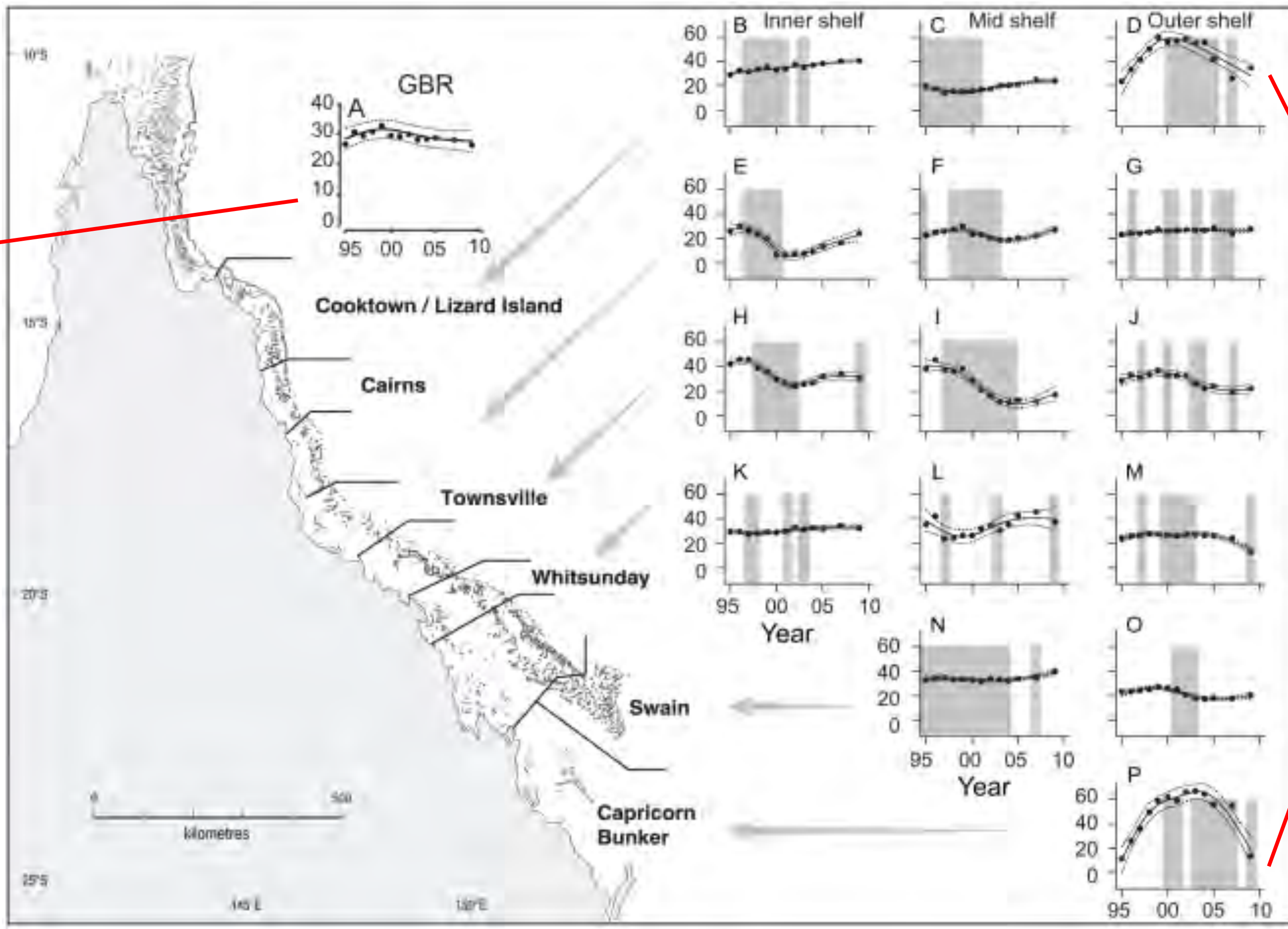


Of the total decline in coral cover over the study period, tropical cyclones caused 48%; Crown of Thorns starfish caused 42%; and coral bleaching only 10%.

Reference: De'ath, G., Fabricius, K. E., Sweatman, H. & Puotinen, M. (2012). The 27-year decline of coral cover on the Great Barrier Reef and its causes. Proceedings of the National Academy of Sciences of USA, 109 (44), 17995-17999. NonCommercial No Derivatives 4.0 International (CC BY-NC-ND 4.0)

Osborne et al studied coral cover between 1995 and 2009, a period when there was "no net decline" in coral cover when averaged across the Great Barrier Reef.
They found contrasting and uncorrelated temporal trends in coral cover at <u>subregional</u> scales (10–100 km) as a result of localised disturbance events, mainly Crown of Thorns predation and cyclones.

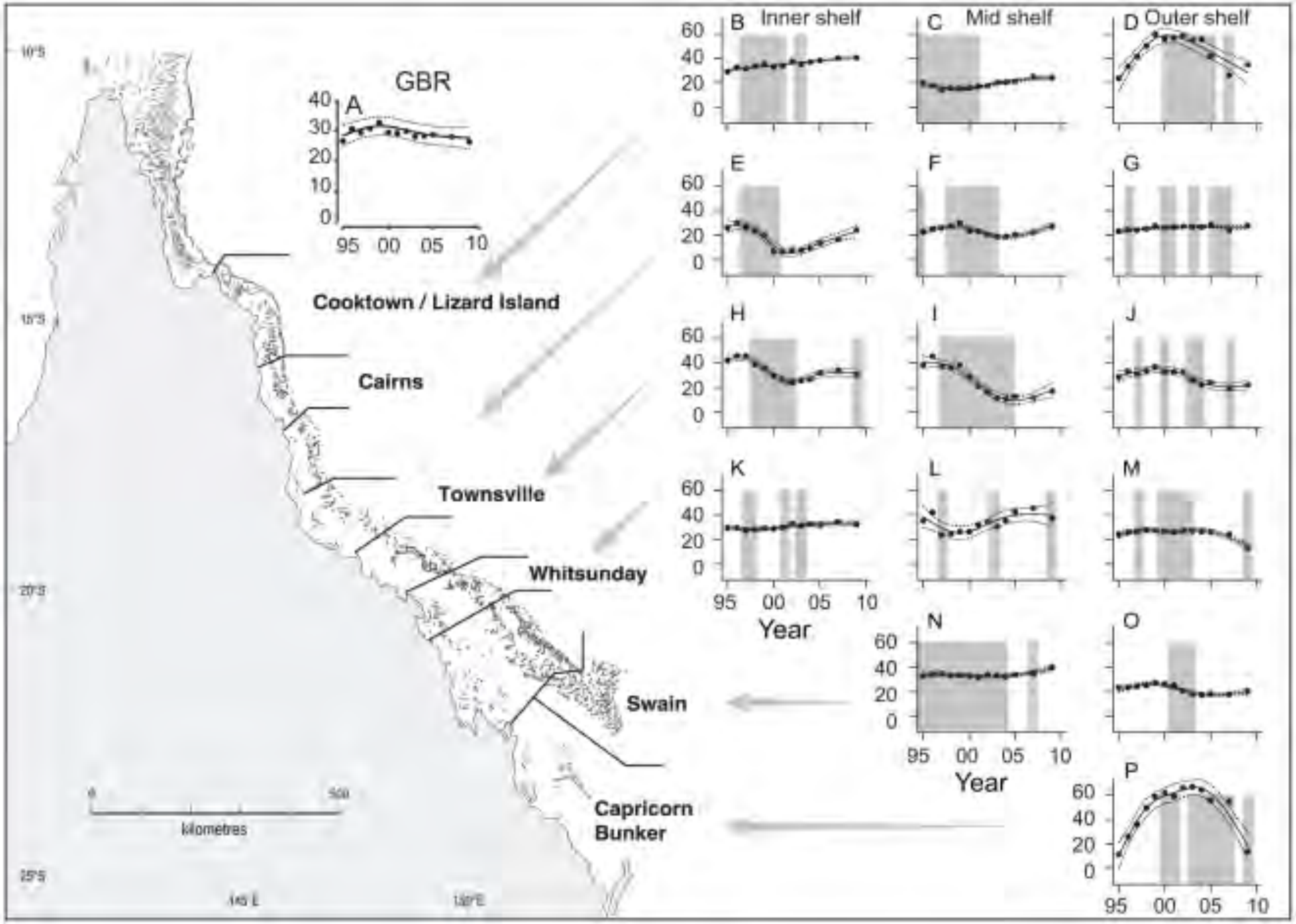
No net decline across the GBR



Huge changes in these two subregions

Reference and image: Osborne, K., Dolman, A., Burgess, S., & Johns, K. (2011). Disturbance and the Dynamics of Coral Cover on the Great Barrier Reef (1995–2009). *Plos ONE*, *6*(3), e17516. doi: 10.1371/journal.pone.0017516. CC 4.0 (CC BY

For clarity

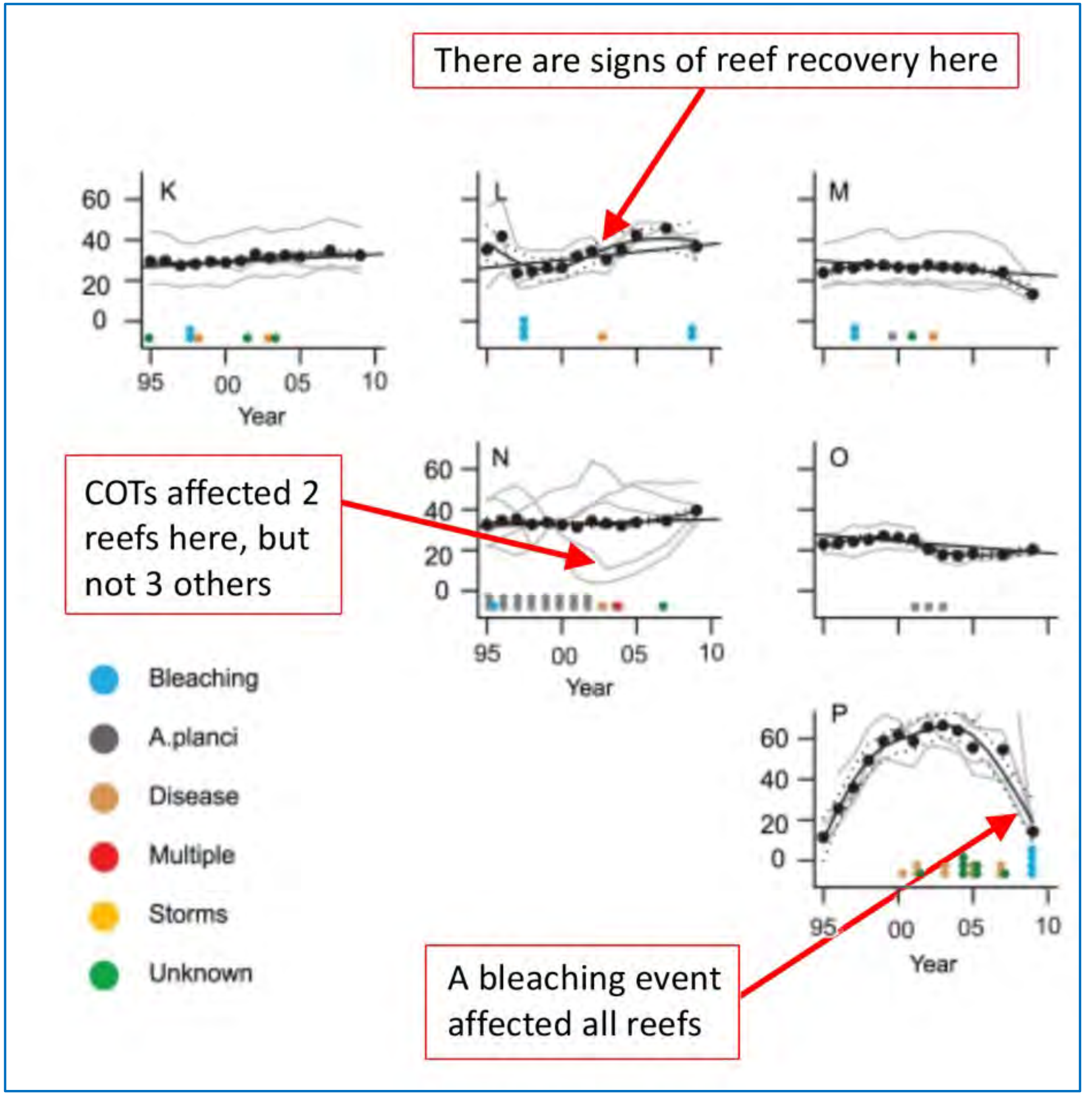


Reference and image: Osborne, K., Dolman, A., Burgess, S., & Johns, K. (2011). Disturbance and the Dynamics of Coral Cover on the Great Barrier Reef (1995–2009). *Plos ONE*, *6*(3), e17516. doi: 10.1371/journal.pone.0017516. CC 4.0 (CC BY

This figure, from the same study, shows disturbances associated with coral decline are represented by a dot for each reef where that type of disturbance occurred.

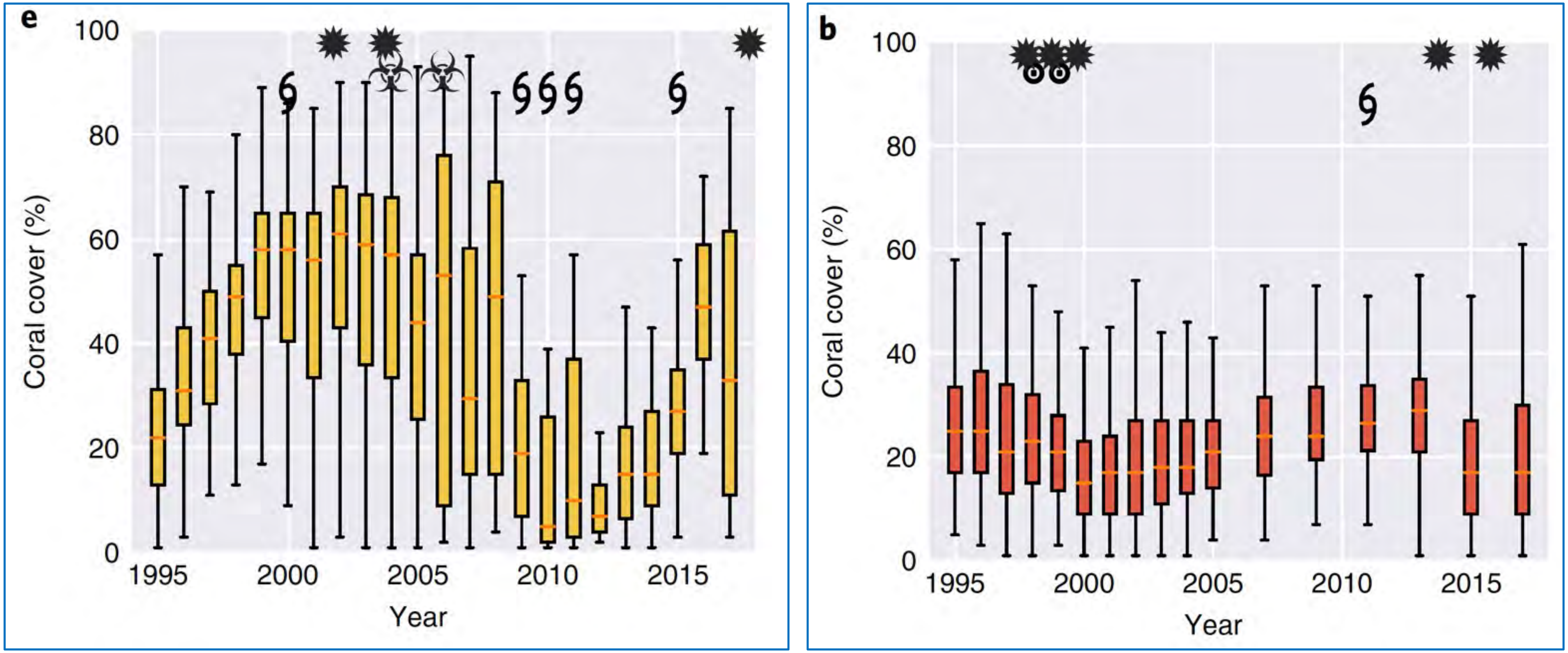
Download the article here: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3053361/

During this study, a disturbance occurred on average every 4 years, with moderate disturbances every 6 years and large disturbances every 11 years



Reference and image: Osborne, K., Dolman, A., Burgess, S., & Johns, K. (2011). Disturbance and the Dynamics of Coral Cover on the Great Barrier Reef (1995–2009). *Plos ONE*, *6*(3), e17516. doi: 10.1371/journal.pone.0017516

Pulse events have a greater impact on the coral cover of reef communities dominated by fast growing corals than slower growing species.



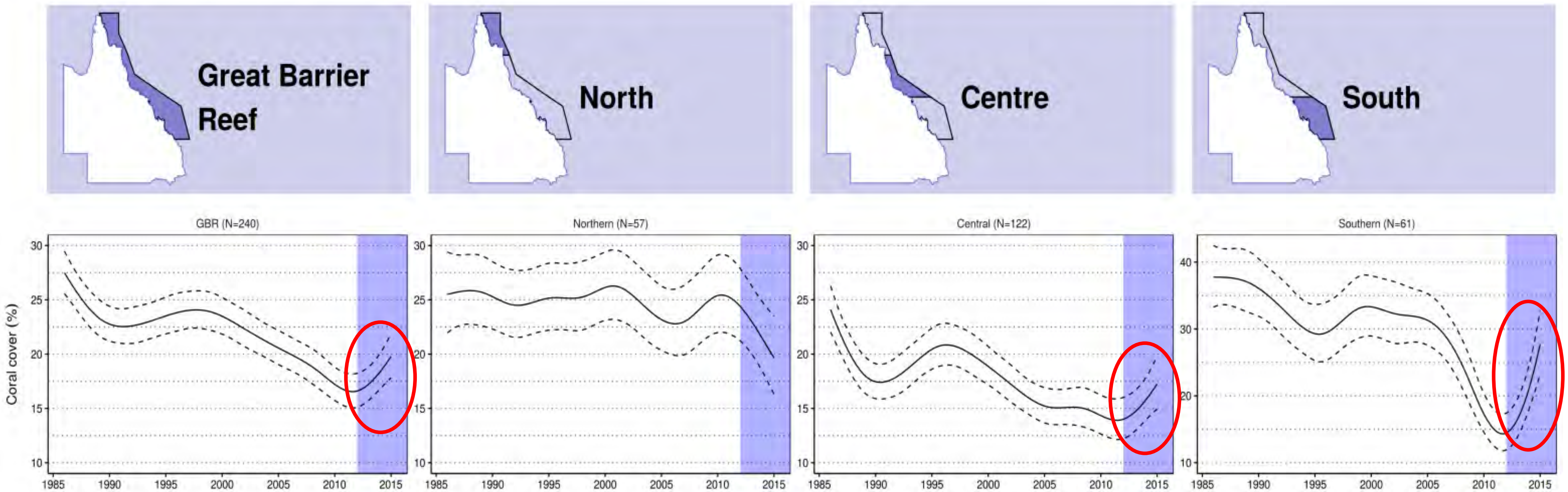
Trends in hard coral on Acropora (left) and Porites/Alcyoniidae (right) dominated reefs

Image: Reprinted by permission from Springer Nature: *Nature Ecology & Evolution,* Water quality mediates resilience on the Great Barrier Reef, M. Aaron MacNeil et al., *Nature Ecology & Evolution*, *3*(4), 620-627. doi: 10.1038/s41559-019-0832-3 ©2019

Reefs can recover

The specific requirements for reef recovery will be covered in T106 Bleaching recovery conditions.

Data collected by the AIMS Long Term Monitoring Program from 2012 – 2015 shows that hard coral cover in the central and southern sections of the reef **increased**.



In contrast, the northern section shows a decline in coral cover between 2012-2015 because of an intense cyclone and a crown-of-thorns starfish outbreak in the region.

Image and reference: Australian Institute of Marine Science, https://www.aims.gov.au/-/05-april-condition-of-great-barrier-reef-corals-before-the-mass-bleaching-event-in-2016

These images show

- (c) algae blooms following TC Yasi in 2011,
- (d) the transition from recently dead coral to live coral rock, and
- (e) coral recruitment and recovery by 2013 at Helix Reef.
- In this study recovery of % coral cover was approximately 2% per year. [1]

Estimates show that coral cover has the potential to increase by almost three per cent per year when cyclones, crown-of- thorns starfish and bleaching are removed as drivers of change.[2]

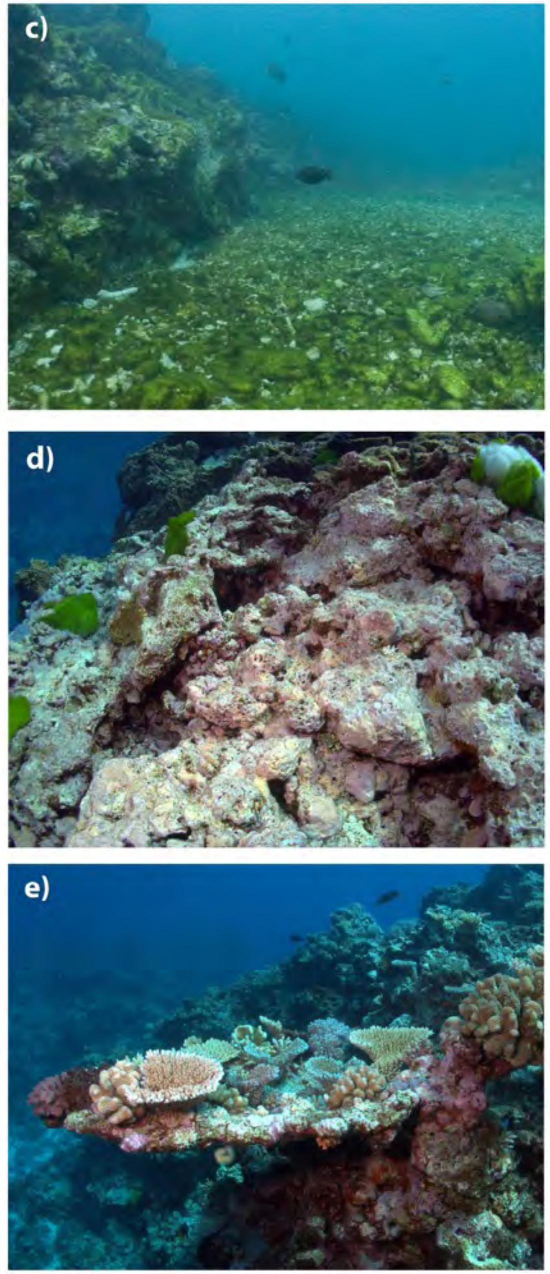
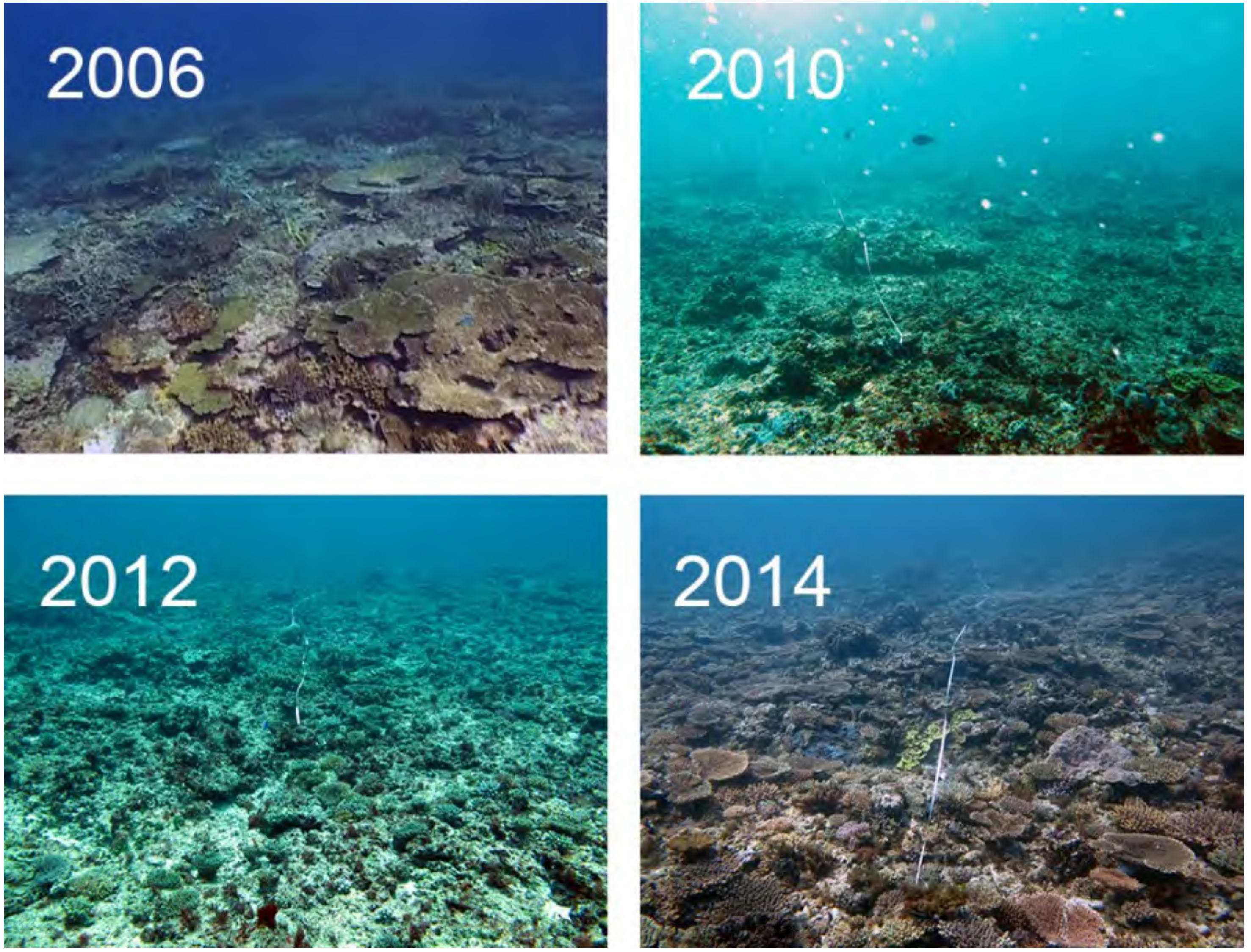


Image and Reference 1. Beeden R, Maynard J, Puotinen M, Marshall P, Dryden J, Goldberg J, et al. (2015) Impacts and Recovery from Severe Tropical Cyclone Yasi on the Great Barrier Reef. PLoS ONE 10(4): e0121272. https://doi.org/10.1371/journal.pone.0121272 open access Creative Commons 4.0 (CC BY)

The first survey on North Reef in Capricorn-Bunkers on the Great Barrier Reef was in 2006.

In 2008 and 2009 storms caused coral cover to decline to very low levels.

Coral recovery was rapid - in 2014, coral cover exceeded pre-disturbance levels.



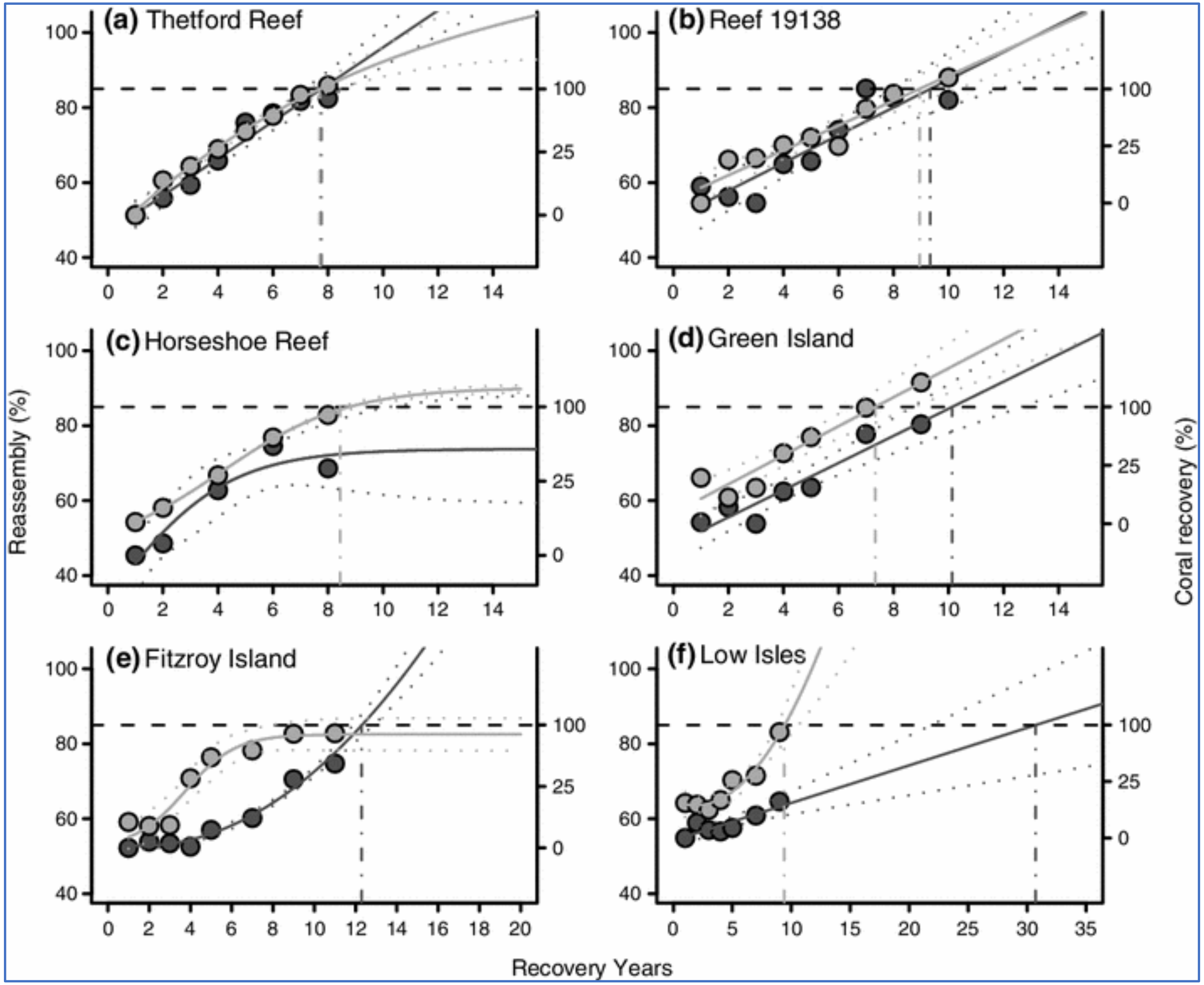
Time series of coral reef disturbance and recovery at North Reef.

Johns *et al* (2014)studied six reefs where coral cover had returned to pre-disturbance levels.

Most of them regained coral cover (grey circles) within 7-10 years (except e).

It took 8-13 years for the community assemblage (black circles) to be restored (except c and f).

Offshore reefs with fast growing *Acropora* corals showed the best recovery; inshore reefs with Porites and soft corals were unlikely to recover.



Reference and Image: Johns, K., Osborne, K., & Logan, M. (2014). Contrasting rates of coral recovery and reassembly in coral communities on the Great Barrier Reef. *Coral Reefs*, *33*(3), 553-563. doi: 10.1007/s00338-014-1148-z. 4.0 (CC BY)

"Our data show that the reefs can regain their coral cover after such disturbances, but recovery takes 10-20 years. At present, the intervals between the disturbances are generally too short for full recovery and that's causing the long-term losses."[1]

Dr Hugh Sweatman
Senior Research Scientist
Leader of AIMS Long-term Monitoring Program

The scale and severity of coral bleaching events has increased- and the frequency of severe bleaching has increased from once every 25-30 years to once every 5.9 years.
The percentage of reefs experiencing bleaching events is increasing (right)

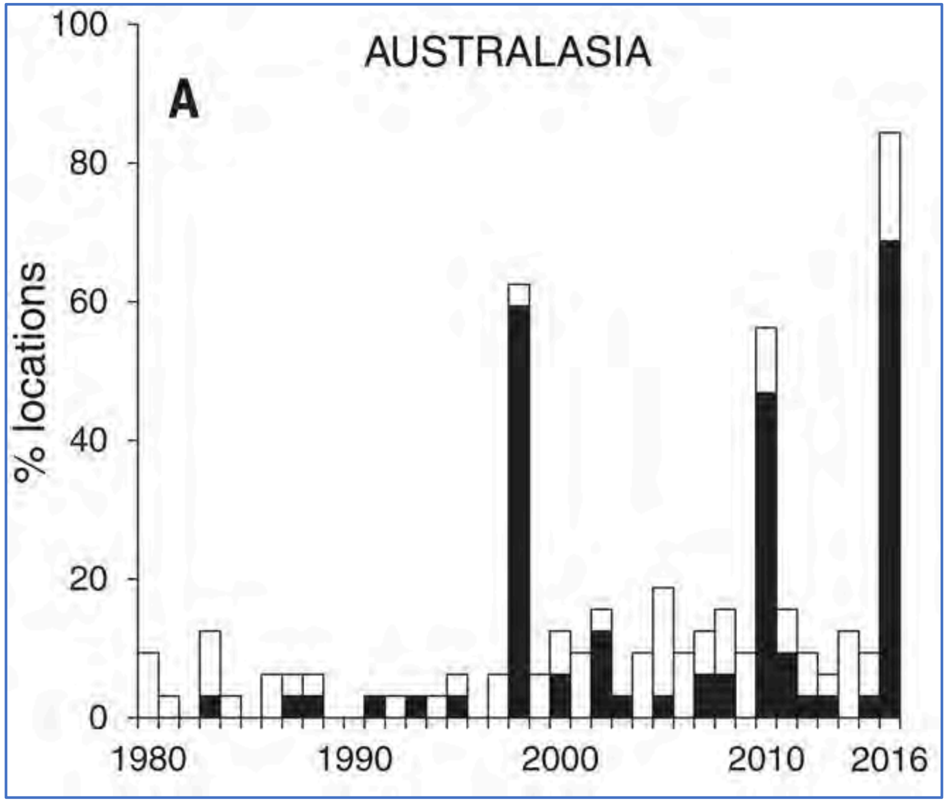


Image: From Hughes, T., Anderson, K., Connolly, S., Heron, S., Kerry, J., & Lough, J. et al. (2018). Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science*, *359*(6371), 80-83. doi: 10.1126/science.aan8048. Reprinted with permission from AIMS.

1. Verbatim from Australian Institute of Marine Science. October 2012 - The Great Barrier Reef has lost half of its coral in the last 27 years. Ref: https://www.aims.gov.au/docs/media/media.html

The latest reports

The 2017/18 Annual summary report on coral reef conditions show that coral cover declined due to the cumulative impacts of multiple, severe disturbances from coral bleaching, cyclones and crown of thorns starfish outbreaks.

Reefs in all regions were affected at different times- but some reefs were affected more than others- shown by the size of the circles (left)

The trends in mean coral cover show a steep decline- which has not been observed in the historical record.

You can download the latest report here:
https://www.aims.gov.au/reef-monitoring/gbr-condition-summary-2017-2018

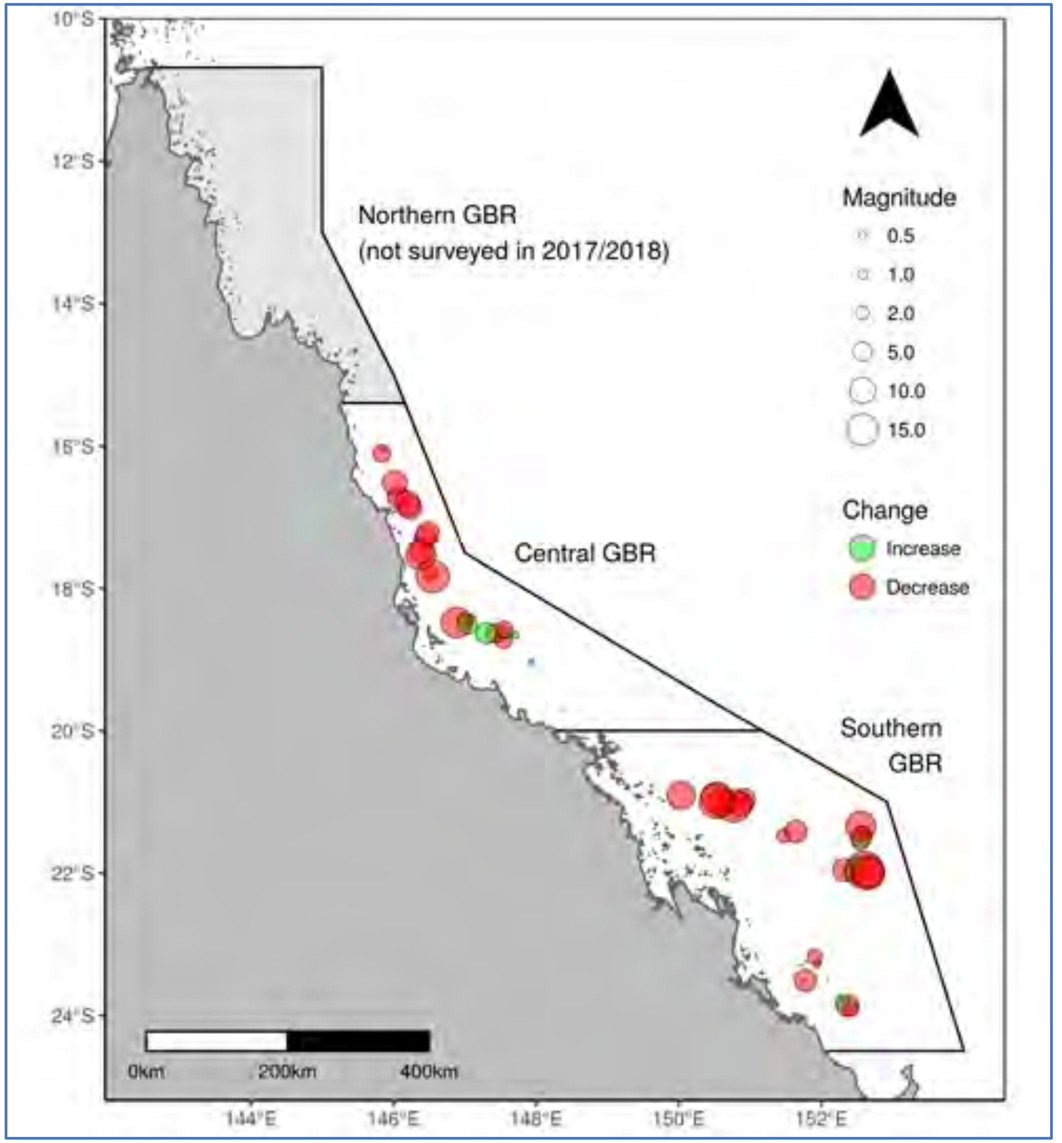
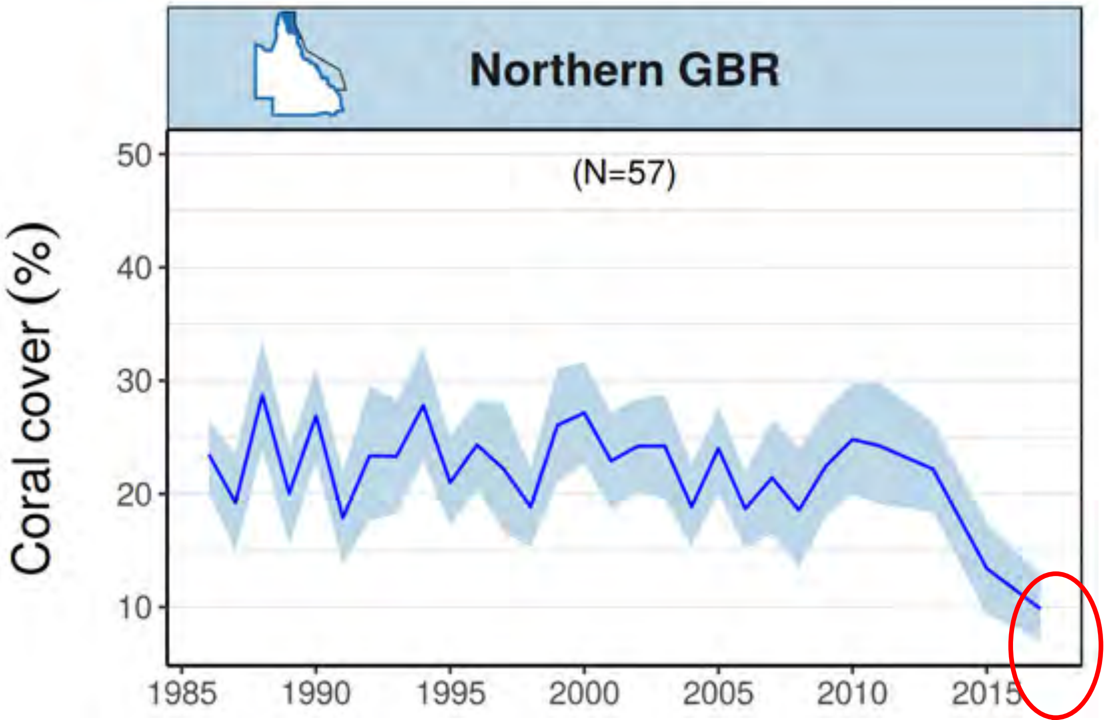


Image: Australian Institute of Marine Science, Long-term Reef Monitoring Program - Annual Summary Report on coral reef condition for 2017/18



Reefs in the Northern region were not surveyed in 2017, which means that the impacts of Tropical Cyclone Debbie and coral bleaching are not yet fully represented in the results

Image: Australian Institute of Marine Science, Long-term Reef Monitoring Program - Annual Summary Report on coral reef condition for 2017/18

Coral cover on the Northern GBR was less than half of what it was in 2013, due to two severe cyclones, an ongoing crown-of-thorns starfish outbreak and back-to-back severe coral bleaching events in 2016 and 2017.

Mean coral cover on survey reefs in the Northern GBR was very low in 2017 (about 10%). It is uncertain how long it will take for these Northern reefs to recover, if not further disturbed, as this is the first time that coral cover this low has been observed in history of the the 30+ year survey.

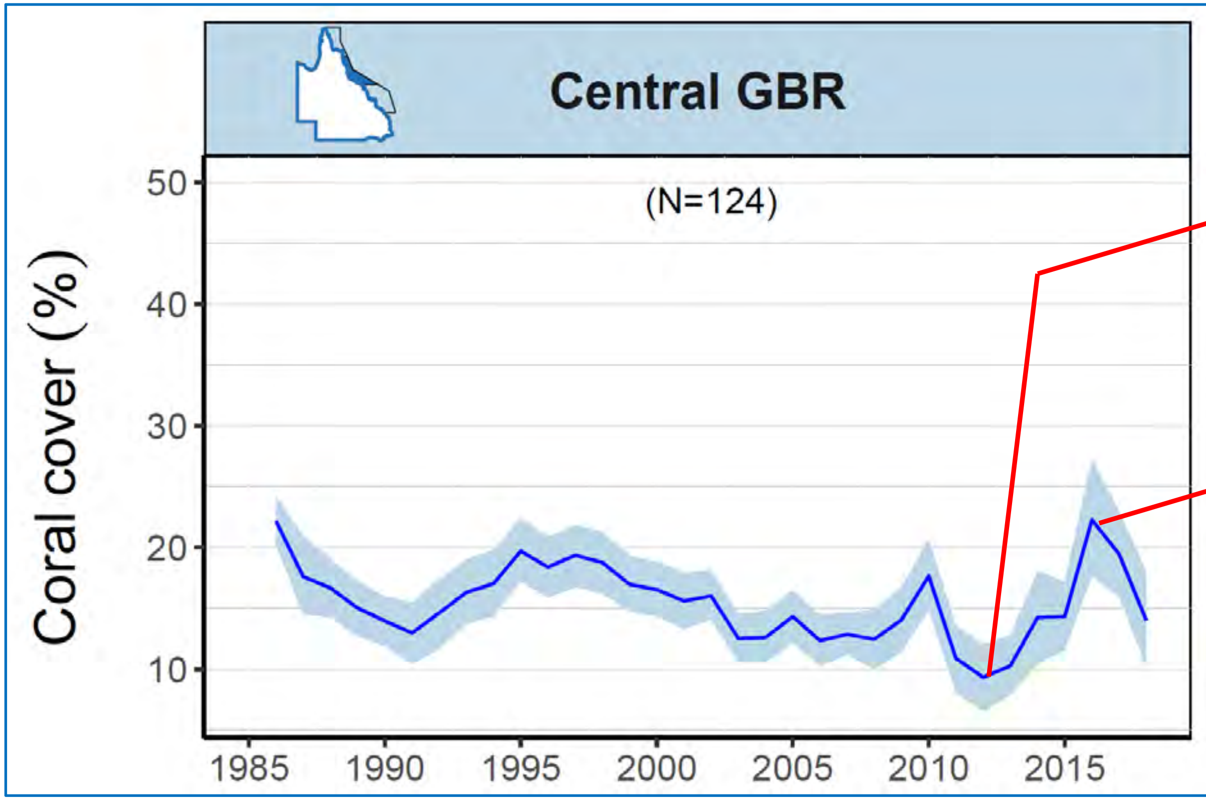


Image: Australian Institute of Marine Science, Long-term Reef Monitoring Program - Annual Summary Report on coral reef condition for 2017/18

Coral cover on reefs in the Central GBR has been generally lower than in the other two regions.

Cover decreased to the lowest level on record in 2012, following the impact of Tropical Cyclone Yasi in 2011.

Coral on these reefs recovered rapidly up until 2016.

Surveys in 2018 found coral cover had declined to 14% due to coral bleaching in 2016 and again in 2017 and increasing activity of crown-of-thorns starfish.

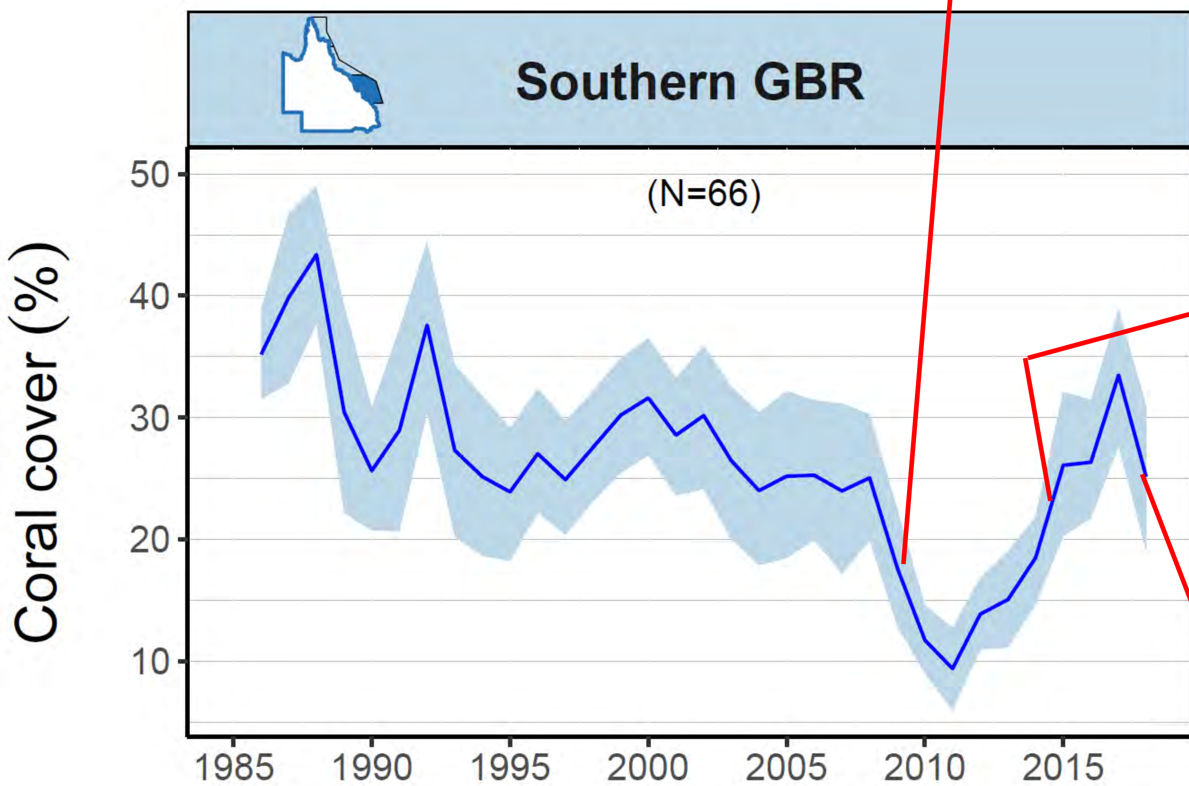


Image: Australian Institute of Marine Science, Long-term Reef Monitoring Program - Annual Summary Report on coral reef condition for 2017/18

Severe Tropical Cyclone Hamish swept across much of the Southern GBR in 2009 causing extensive damage. Mean coral cover in the southern region dropped sharply as a result.

From 2009-2016 there were no severe cyclones and few recorded outbreaks of crown-of-thorns starfish in the Swains or Capricorn-Bunker Sectors, enabling the coral cover on reefs in those sectors to increase.

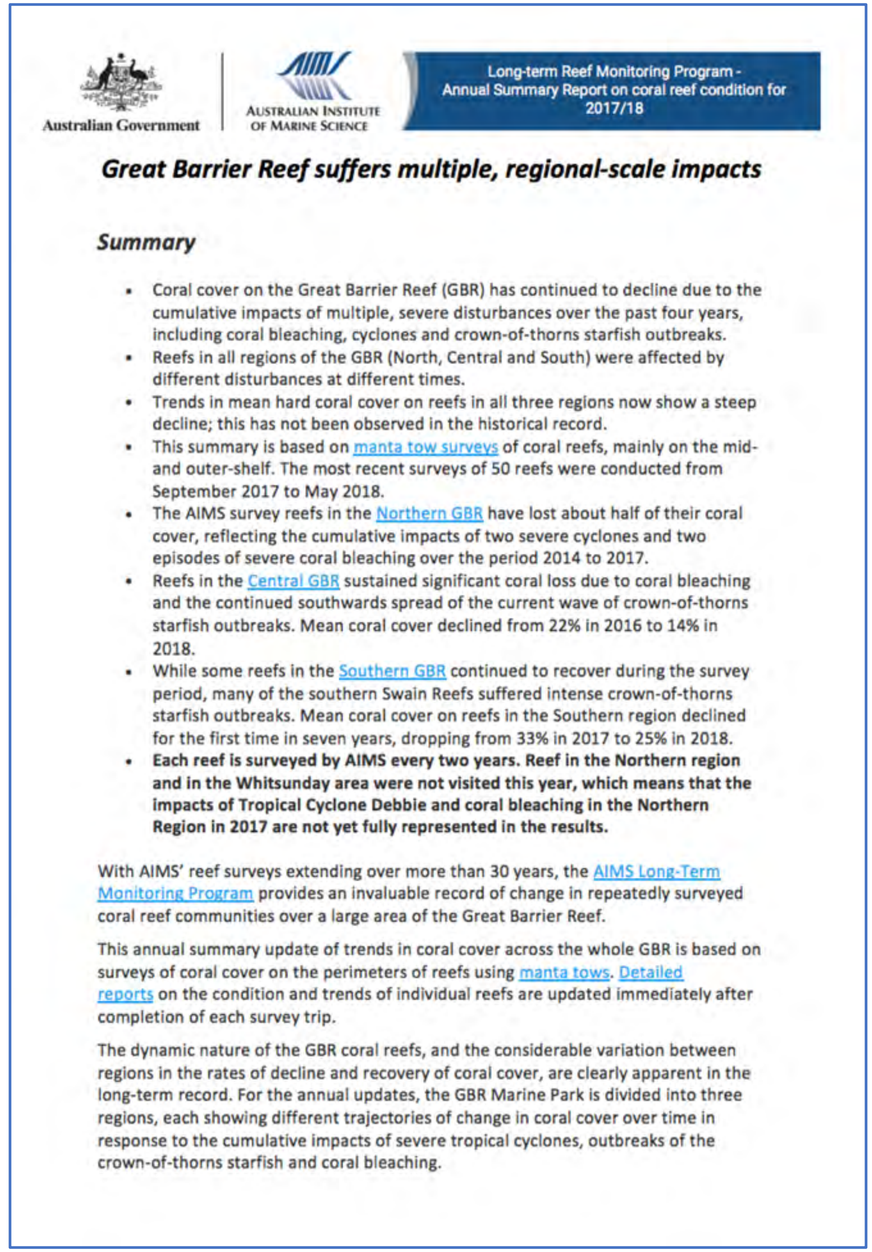
In 2017 an outbreak of crown-of-thorns starfish resulted in an overall decline in mean coral cover in the region from 33% in 2017 to 25% in 2018

AIMS produce an Annual Summary Report on coral reef condition.

The next two slides reproduce the 2017/18 assessment of the health of the Great Barrier Reef.

Download the full report here:

https://www.aims.gov.au/reef-monitoring/gbr-condition-summary-2017-2018



Australian Government | Australian Institute of Marine Science

Long-term Reef Monitoring Program - Annual Summary Report on coral reef condition for 2017/18

Great Barrier Reef suffers multiple, regional-scale impacts

Summary

- Coral cover on the Great Barrier Reef (GBR) has continued to decline due to the cumulative impacts of multiple, severe disturbances over the past four years, including coral bleaching, cyclones and crown-of-thorns starfish outbreaks.
- Reefs in all regions of the GBR (North, Central and South) were affected by different disturbances at different times.
- Trends in mean hard coral cover on reefs in all three regions now show a steep decline; this has not been observed in the historical record.
- This summary is based on manta tow surveys of coral reefs, mainly on the mid- and outer-shelf. The most recent surveys of 50 reefs were conducted from September 2017 to May 2018.
- The AIMS survey reefs in the Northern GBR have lost about half of their coral cover, reflecting the cumulative impacts of two severe cyclones and two episodes of severe coral bleaching over the period 2014 to 2017.
- Reefs in the Central GBR sustained significant coral loss due to coral bleaching and the continued southwards spread of the current wave of crown-of-thorns starfish outbreaks. Mean coral cover declined from 22% in 2016 to 14% in 2018.
- While some reefs in the Southern GBR continued to recover during the survey period, many of the southern Swain Reefs suffered intense crown-of-thorns starfish outbreaks. Mean coral cover on reefs in the Southern region declined for the first time in seven years, dropping from 33% in 2017 to 25% in 2018.
- **Each reef is surveyed by AIMS every two years. Reef in the Northern region and in the Whitsunday area were not visited this year, which means that the impacts of Tropical Cyclone Debbie and coral bleaching in the Northern Region in 2017 are not yet fully represented in the results.**

With AIMS' reef surveys extending over more than 30 years, the AIMS Long-Term Monitoring Program provides an invaluable record of change in repeatedly surveyed coral reef communities over a large area of the Great Barrier Reef.

This annual summary update of trends in coral cover across the whole GBR is based on surveys of coral cover on the perimeters of reefs using manta tows. Detailed reports on the condition and trends of individual reefs are updated immediately after completion of each survey trip.

The dynamic nature of the GBR coral reefs, and the considerable variation between regions in the rates of decline and recovery of coral cover, are clearly apparent in the long-term record. For the annual updates, the GBR Marine Park is divided into three regions, each showing different trajectories of change in coral cover over time in response to the cumulative impacts of severe tropical cyclones, outbreaks of the crown-of-thorns starfish and coral bleaching.

“Major bleaching events in successive years have not been seen on the GBR before 2016 and 2017.

Over the 30+ years of monitoring by AIMS, GBR reefs have shown their ability to recover after disturbances, but such ‘resilience’ clearly has limits.

The predicted consequences of climate change include more powerful storms and more frequent and more intense bleaching events.

More intense disturbances mean greater damage to reefs, so recovery must take longer if the growth rate remains the same.

At the same time, the intervals between acute disturbance events are decreasing and chronic stresses such as high turbidity and high ocean temperatures can slow rates of recovery. ”

Coral community killed by bleaching,
Sir Charles Hardy Reef, Northern GBR region

Text verbatim and image from: Australian Institute of Marine Science, Long-term Reef Monitoring Program - Annual Summary Report on coral reef condition for 2017/18

“The geographic scale of recent bleaching means that breeding populations of corals have been decimated over large areas, reducing the potential sources of larvae to recolonise reefs over the next years.

It is unprecedented in the 30+ year time series that all three regions of the GBR have declined and that many reefs have now very low coral cover.

The reefs in the Southern GBR still have relatively high coral cover but have limited genetic connection to reefs further north and may not be a source of significant broodstock to support reef recovery elsewhere.

The prognosis of more frequent disturbances, each causing greater damage to reefs, combined with slower rates of recovery will inevitably lead to less living coral on reefs of the GBR.

Measuring and understanding the process of coral reef recovery will be a major focus of AIMS’ research and monitoring over the next years.”

Text verbatim and image from: Australian Institute of Marine Science, Long-term Reef Monitoring Program - Annual Summary Report on coral reef condition for 2017/18

Jenkins reef, before and after COTS outbreak

A link to the next topic:

“We can't stop the storms, and ocean warming (the primary cause of coral bleaching) is one of the critical impacts of the global climate change.”

"However, we can act to reduce the impact of crown of thorns…. in the absence of crown of thorns, coral cover would increase at 0.89% per year, so even with losses due to cyclones and bleaching there should be slow recovery.”

"We at AIMS will be redoubling our efforts to understand the life cycle of crown of thorns so we can better predict and reduce the periodic population explosions of crown of thorns. It's already clear that one important factor is water quality, and we plan to explore options for more direct intervention on this native pest.”

Media (https://www.aims.gov.au/docs/media/media.html) 2 October 2012 - The Great Barrier Reef has lost half of its coral in the last 27 years

Crown of thorns starfish
Image: AIMS LTMP

Questions

This graph shows Coral cover on Tiahura fore reef, French Polynesia over the past 40 years.

Key: COT= Crown of thorns; B= Bleaching event; Reva/Wasa/Oli= Cyclones

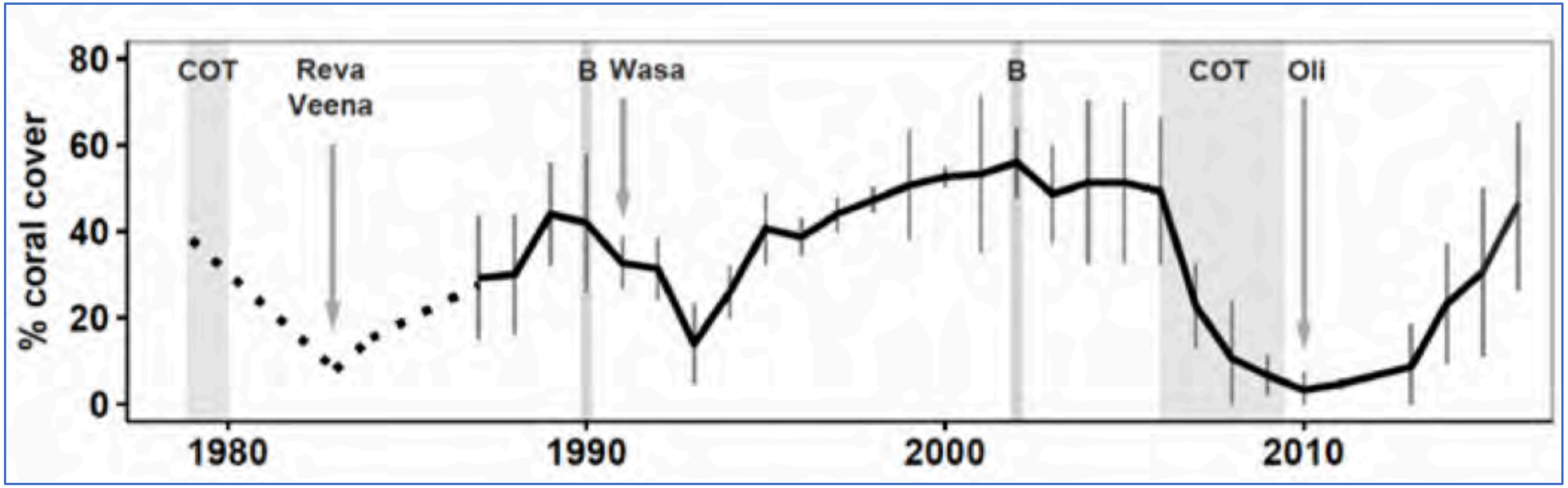


Image: Moritz C, Vii J, Lee Long W, Tamelander J, Thomassin A, Planes S (editors). (2018) Status and Trends of Coral Reefs of the Pacific. Global Coral Reef Monitoring Network.

1. Interpret how coral cover on Tiahura reef has changed over 40 years.

2. Identify the pulse events, and when any reef recovery occurred.

Further activities

See

https://coralwatch.org/index.php/education-2/curriculum-materials/marine-science/

by

CORALWATCH

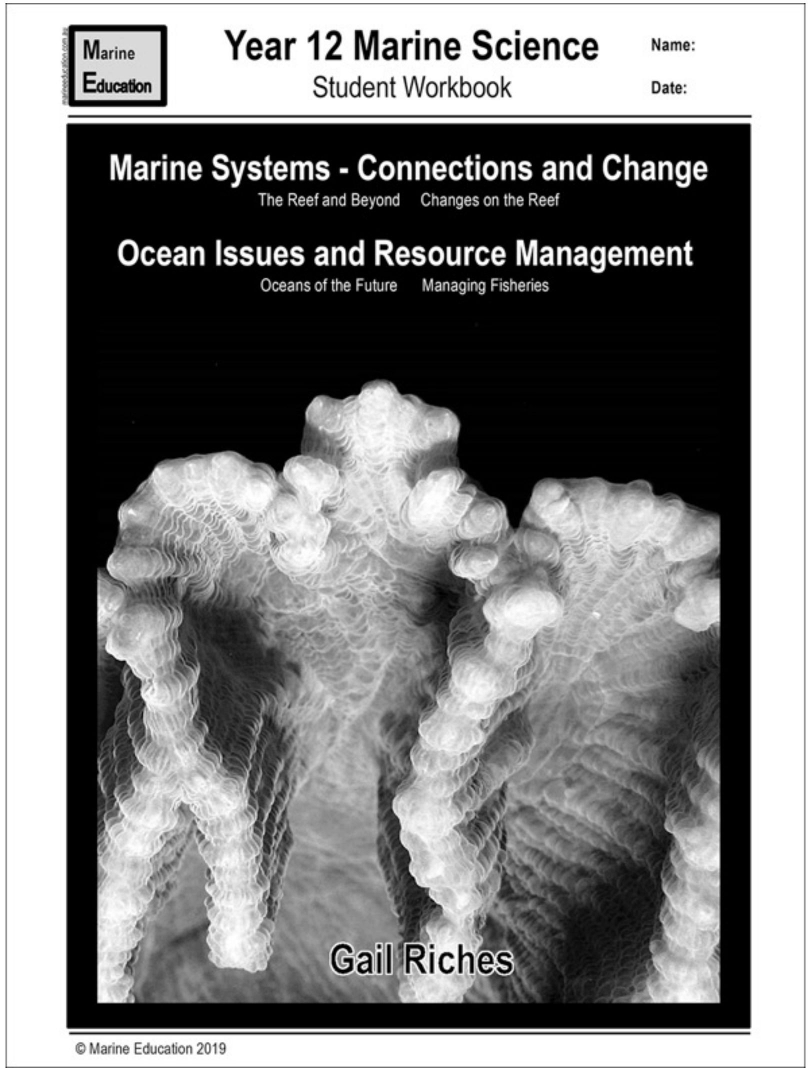
Worksheet

Reef reports

by

Gail Riches

www.marineeducation.com.au



T096 Water quality on reefs

Adam Richmond

Syllabus statement

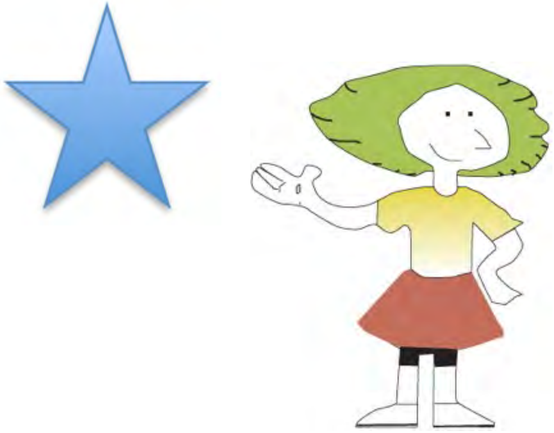
At the end of this topic you should be able to ...

Recognise

that some of the factors that reduce coral cover (e.g. crown-of-thorns) are directly linked to water quality.

Recognise

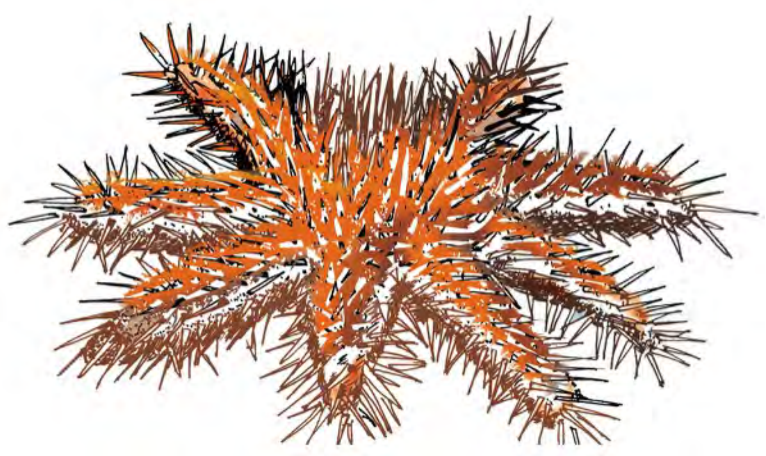
- identify or recall particular features of information from knowledge;
- identify that an item, characteristic or quality exists; perceive as existing or true;
- be aware of or acknowledge



Objective

To see if there is research evidence to links between COTS* outbreaks and water quality.

* COTS – Crown of thorns starfish



In 2012 the following article appeared in Proceedings of the National Academy of Sciences indicating a direct link between water quality and COTS outbreaks.

This Article | Info for Authors | Subscribe | About

PNAS

Proceedings of the National Academy of Sciences of the United States of America

Proc Natl Acad Sci U S A. 2012 Oct 30; 109(44): 17995–17999. PMCID: PMC3497744

Published online 2012 Oct 1. doi: 10.1073/pnas.1208909109 PMID: 23027961

From the Cover

Environmental Sciences

The 27–year decline of coral cover on the Great Barrier Reef and its causes

Glenn De'ath,[a,1] Katharina E. Fabricius,[a] Hugh Sweatman,[a] and Marji Puotinen[b]

• Author information • Copyright and License information Disclaimer

See commentary "Iconic coral reef degraded despite substantial protection" on page 17734.

This article has been cited by other articles in PMC.

ABSTRACT

Go to:

The world's coral reefs are being degraded, and the need to reduce local pressures to offset the effects of increasing global pressures is now widely recognized. This study investigates the spatial and temporal dynamics of coral cover, identifies the main drivers of coral mortality, and quantifies the rates of potential recovery of the Great Barrier Reef. Based on the world's most extensive time series data on reef condition (2,258 surveys of 214 reefs over 1985–2012), we show a major decline in coral cover from 28.0% to 13.8% (0.53% y^{-1}), a loss of 50.7% of initial coral cover. Tropical cyclones, coral predation by crown-of-thorns starfish (COTS), and coral bleaching accounted for 48%, 42%, and 10% of the respective estimated losses, amounting to 3.38% y^{-1} mortality rate. Importantly, the relatively pristine northern region showed no overall decline. The estimated rate of increase in coral cover in the absence of cyclones, COTS, and bleaching was 2.85% y^{-1}, demonstrating substantial capacity for recovery of reefs. In the absence of COTS, coral cover would increase at 0.89% y^{-1}, despite ongoing losses due to cyclones and bleaching. Thus, reducing COTS populations, by improving water quality and developing alternative control measures, could prevent further coral decline and improve the outlook for the Great Barrier Reef. Such strategies can, however, only be successful if climatic conditions are stabilized, as losses due to bleaching and cyclones will otherwise increase.

Tropical cyclones, coral predation by crown-of-thorns starfish (COTS), and coral bleaching accounted for 48%, 42%, and 10% of the respective estimated losses, amounting to 3.38% y−1 mortality rate.

Thus, reducing COTS populations, by improving water quality and developing alternative control measures, could prevent further coral decline and improve the outlook for the Great Barrier Reef.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3497744/

Water quality affects the reef

Declining water quality is recognised as one of the most significant threats to the long-term health and resilience of the Great Barrier Reef.

The main water quality issues facing the Great Barrier Reef are:
Runoff
Pollution
Climate change and ocean acidification

Learn more about water quality and the reef here:

https://www.aims.gov.au/docs/research/water-quality/water-quality.html

Testing for turbidity

AIMS monitors water quality on the Great Barrier Reef and in catchment aquaculture farms by using a series of water quality probes.

Reef Water Quality

YouTube video by Australian Institute of Marine Science
available: https://youtu.be/Ml7A0QVASPA

You can see how Scientists do this at

https://youtu.be/Ml7A0QVASPA

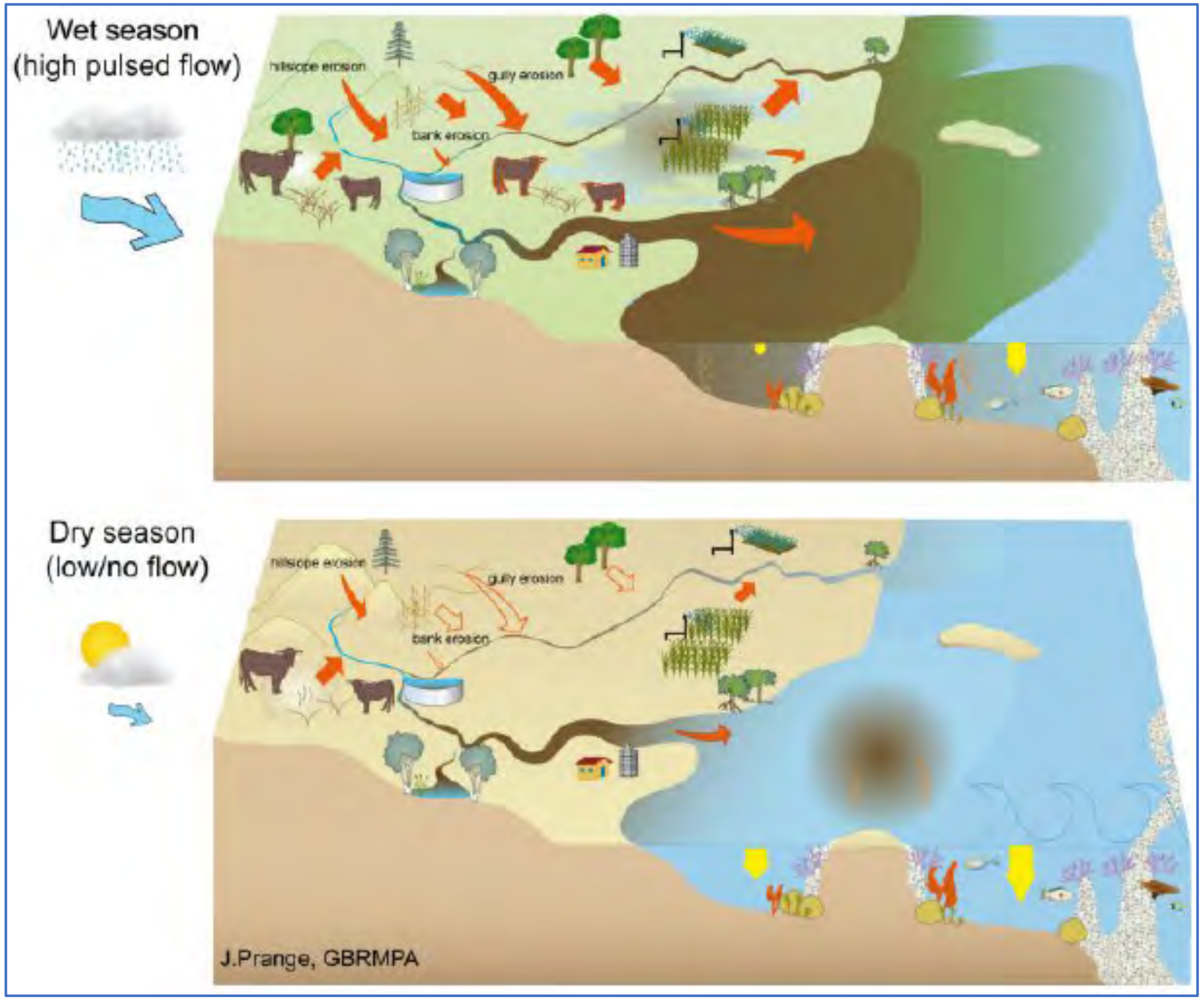
Runoff

Increased sediment and nutrient loads in runoff:

- smothers coral reef organisms due to the settling of suspended sediment
- reduces light availability for coral and seagrass photosynthesis due to increased turbidity
- favours the growth of macroalgae instead of corals due to high nutrient availability.

Contaminants such as agricultural pesticides and herbicides can weaken the health and resilience of corals, making them more susceptible to disease outbreaks or climate impacts.

Reference: Backgrounder: Water quality threats: safeguarding a national asset, AIMS, https://www.aims.gov.au/docs/research/water-quality/position-paper.html



Agricultural runoff conceptual models

Image: J Prange, GBRMPA, reproduced http://www.waterquality.gov.au/anz-guidelines/resources/case-study/great-barrier-reef#examine-current-understanding

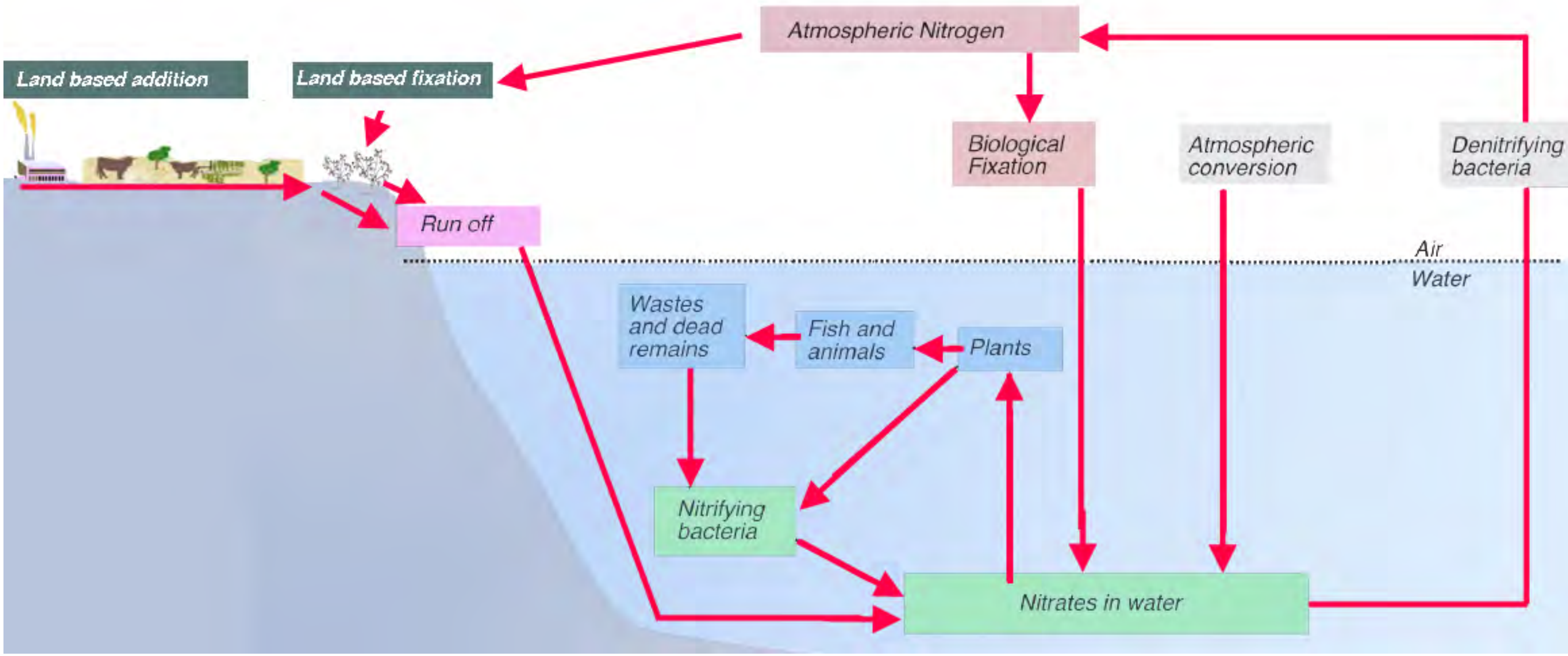
Nutrients

Annual inputs of nitrogen from the land have nearly doubled from 23 000 to 43 000 tonnes over the past 150 years, while phosphorus inputs have tripled from 2400 tonnes to 7100 tonnes.

Reference: Backgrounder: Water quality threats: safeguarding a national asset, AIMS, https://www.aims.gov.au/docs/research/water-quality/position-paper.html

The processes that control the fate of nutrients:

- how long they remain in the Great Barrier reef lagoon,
- what organisms exploit them and
- where they go- are still poorly understood.



Turbidity

Light is an important factor for the growth and survival of coral reefs.
Measurements suggest that coastal waters in some parts of the Great Barrier Reef are becoming more turbid due to increased loads of fine sediment and organic particles, continually resuspended by waves and currents.

Suspended sediment causes poor visibility for divers sampling during a flood plume

Image Source: Australian Institute of Marine Science

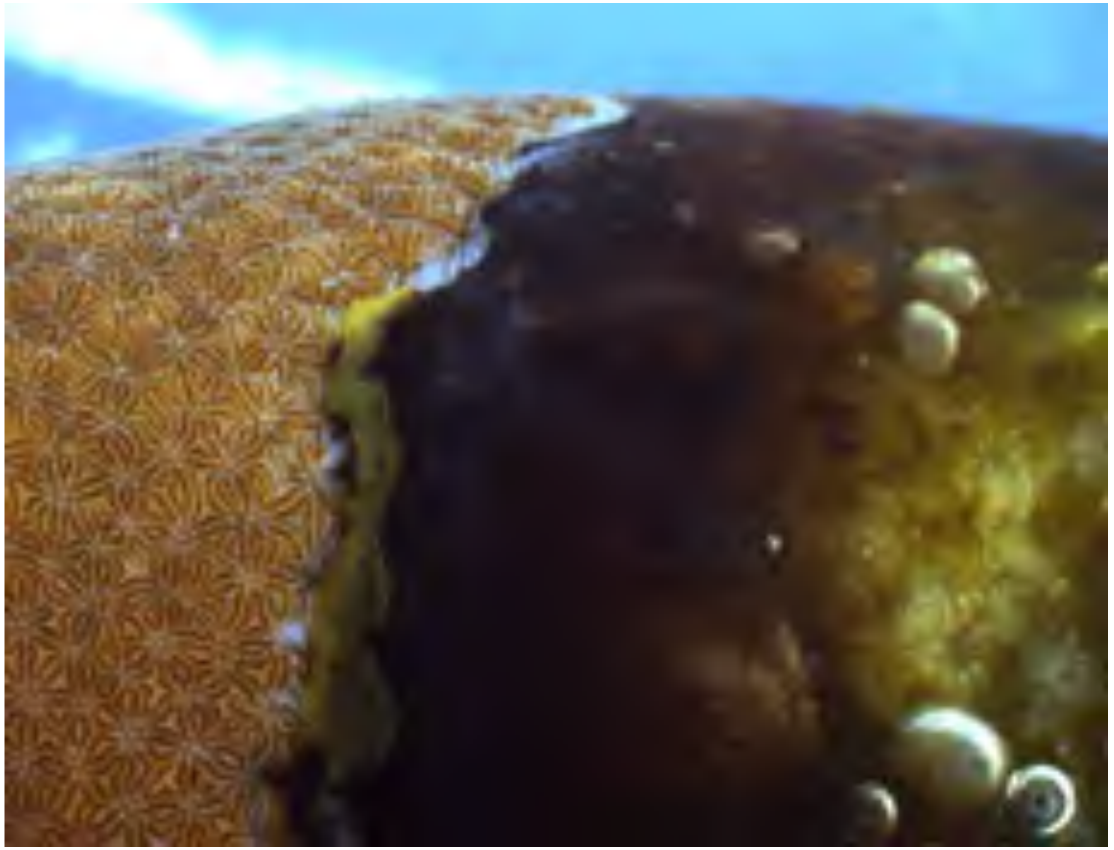
Reference: Backgrounder: Water quality threats: safeguarding a national asset, AIMS, https://www.aims.gov.au/docs/research/water-quality/position-paper.html, and
AIMS, Water quality and the great Barrier reef, https://www.aims.gov.au/documents/30301/2107350/Water+quality.pdf

Disease

Coral disease outbreaks have emerged as a major cause of coral mortality and reef decline globally.

They are often linked to declining water quality, overfishing and heat stress and are now on the rise in areas of the Great Barrier Reef.

Research continues to determine whether microbes cause the disease, or are symptom or cause of stress.



Black band disease is one of the most common diseases affecting corals on the GBR

Reference: Backgrounder: Water quality threats: safeguarding a national asset, AIMS, https://www.aims.gov.au/docs/research/water-quality/position-paper.html

Contaminants

A variety of chemicals used in agricultural, industrial and urban environments have toxic effects on corals.
These chemicals can affect photosynthesis in the coral's symbiotic algae, disrupt coral reproduction and inhibit the successful settlement of coral larvae.

Flood water runoff from this cane field can enter the Herbert River catchment.

Reference: Backgrounder: Water quality threats: safeguarding a national asset, AIMS, https://www.aims.gov.au/docs/research/water-quality/position-paper.html and
AIMS, Water quality and the great Barrier reef, https://www.aims.gov.au/documents/30301/2107350/Water+quality.pdf

Chemicals that can influence corals include herbicides and pesticides, industrial wastes, oils, solvents, industrial chemicals that mimic natural hormones, and nutrients at high levels.

These contaminants weaken the ecosystem, reducing its resilience against disease, physical disturbance and climate change.

This coral branch was exposed to the fungicide MEMC at 1 µg/L, killing coral tissue and exposing the white skeleton underneath.

Image: Andrew Negri, AIMS.

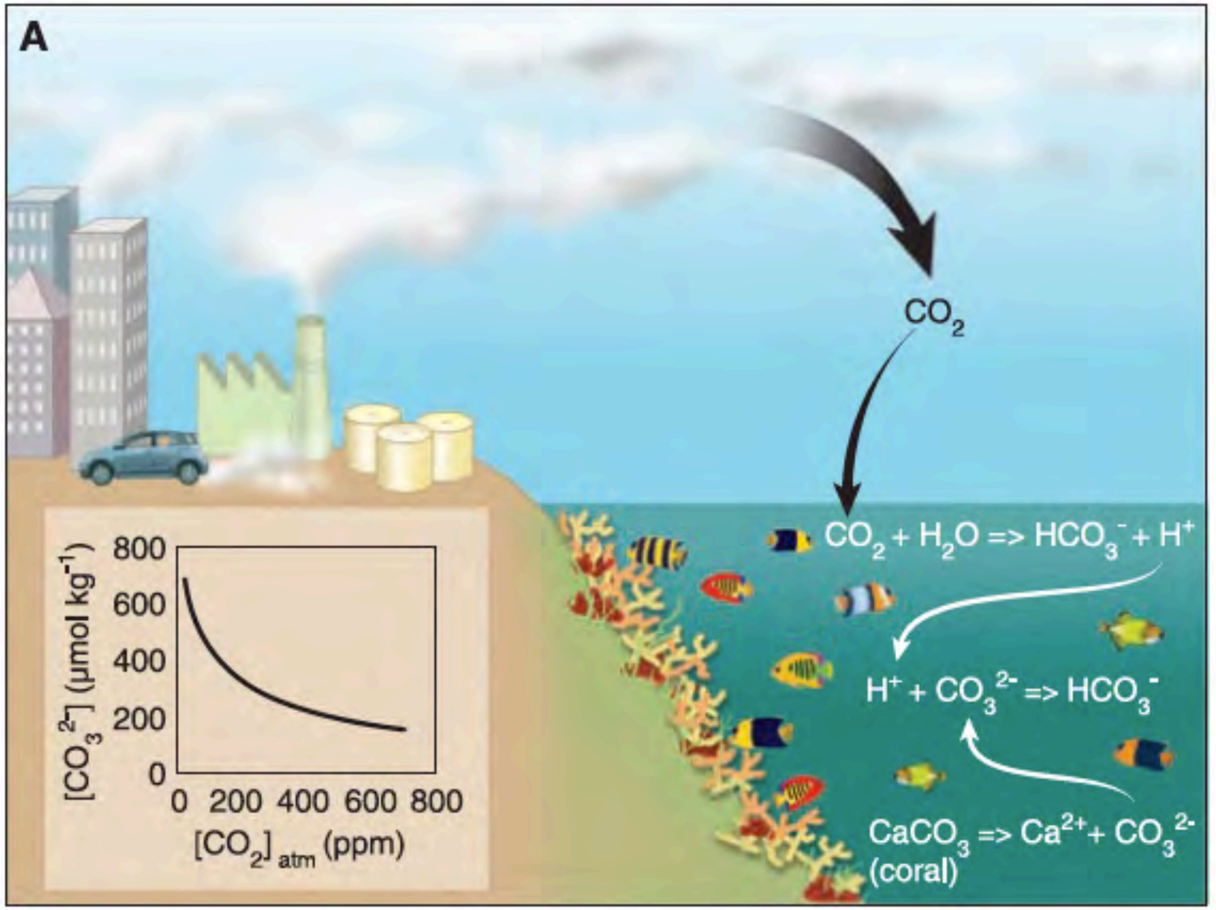
Reference: Backgrounder: Water quality threats: safeguarding a national asset, AIMS, https://www.aims.gov.au/docs/research/water-quality/position-paper.html and
AIMS, Water quality and the great Barrier reef, https://www.aims.gov.au/documents/30301/2107350/Water+quality.pdf

Ocean acidification

Ocean acidification causes significant water quality stress on coral reef ecosystems.
Much of the additional carbon dioxide added to the atmosphere by fossil fuel burning, land use and industrial activities eventually dissolves in the ocean.
This causes a gradual acidification that reduces the ability of corals and other calcifying organisms to produce their calcium carbonate skeletons.

More on this in topic 113

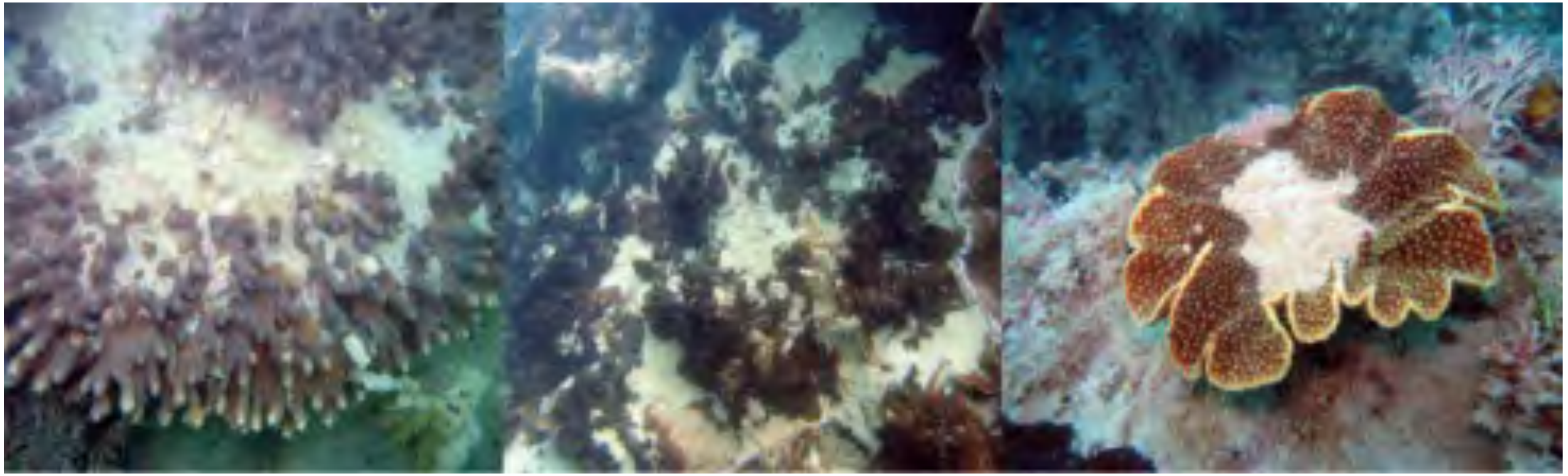
Reference: Backgrounder: Water quality threats: safeguarding a national asset, AIMS, https://www.aims.gov.au/docs/research/water-quality/position-paper.html



Atmospheric CO2 and Ocean Acidification

Image: Hoegh-Guldberg, O., Poloczanska, E., Skirving, W., & Dove, S. (2017). Coral Reef Ecosystems under Climate Change and Ocean Acidification. *Frontiers In Marine Science*, *4*. doi: 10.3389/fmars.2017.00158 open access CC 4.0 BY

Increased sedimentation and nutrients can cause higher algal growth, build-up of pollutants in sediments and marine species, and reduced light and smothered corals.



Corals can be completely covered by sediment

Image: Tony Ayling in Erftemeijer, P., Riegl, B., Hoeksema, B., & Todd, P. (2012). Environmental impacts of dredging and other sediment disturbances on corals: A review. *Marine Pollution Bulletin*, *64*(9), 1737-1765. doi: 10.1016/j.marpolbul.2012.05.008. open access CC 4.0 BY

Reference: Poor water quality from land-based run-off, Great Barrier reef Foiundation, https://www.barrierreef.org/the-reef/the-threats/poor-water-quality

Coral reefs in turbid waters have less structural complexity, and provide habitat for fewer large herbivorous fish.

The lower abundance of herbivores further contributes to a higher level of macroalgal cover.

This is a “Catch-22”

Reference: K.E. Fabricius *et al.* Vulnerability of coral reefs of the Great Barrier Reef to climate change IN
J.E. Johnson, P.A. Marshall (Eds.), Climate Change and the Great Barrier Reef: A Vulnerability Assessment, Great Barrier Reef Marine Park Authority, Townsville, Australia (2007), pp. 515-554, available: http://www.gbrmpa.gov.au/__data/assets/pdf_file/0014/5432/chpt-17-fabricius-et-al-2007.pdf

Havannah Island Reef is now a macro-algae dominated benthic community.

Image: AIMS LTMP, https://eatlas.org.au/media/1024 CC 4.0 BY

High levels of nutrients and sediments lead to high macroalgal cover, low coral biodiversity and low rates of coral reproduction and recruitment on inshore reefs, slowing rates of coral recovery after disturbances, and increasing frequency of outbreaks of crown-of-thorns starfish.

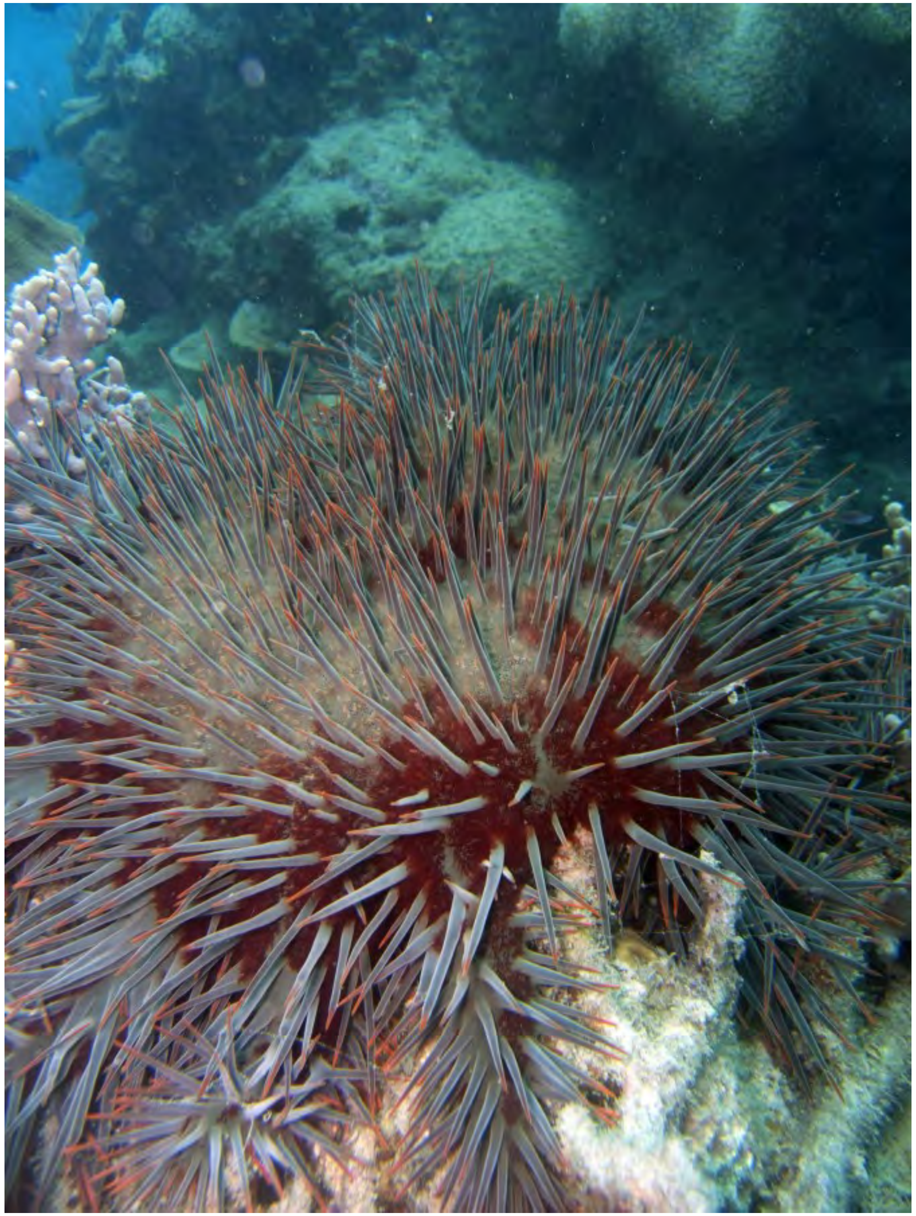


Image: David Williamson, JCU, https://eatlas.org.au/media/669. CC 4.0 BY

Reference: Declining coral growth on the Great Barrier Reef, AIMS, available: https://www.aims.gov.au/docs/research/climate-change/declining-coral-growth.html

Crown of Thorns Starfish

Crown of Thorns starfish (CoTS) outbreaks are one of the most significant disturbances and major causes of coral loss across the Indo-Pacific. CoTs can have a devastating effect on coral cover over a wide geographic area.

A reef before a COTS outbreak (left) and after (right).
Image: AIMS LTMP, https://eatlas.org.au/media/1004

Reference: K.E. Fabricius, O. Hoegh-Guldberg, J. Johnson, *et al.*Vulnerability of coral reefs of the Great Barrier Reef to climate change IN J.E. Johnson, P.A. Marshall (Eds.), Climate Change and the Great Barrier Reef: A Vulnerability Assessment, Great Barrier Reef Marine Park Authority, Townsville, Australia (2007), pp. 515-554, available: http://www.gbrmpa.gov.au/__data/assets/pdf_file/0014/5432/chpt-17-fabricius-et-al-2007.pdf

Nutrient-rich runoff is associated with the initiation of primary outbreaks of CoTS on inshore reefs.

This is thought to be because the planktonic CoTS larvae depend on high abundances of large phytoplankton for their development, and this phytoplankton is most abundant in nutrient-rich conditions.

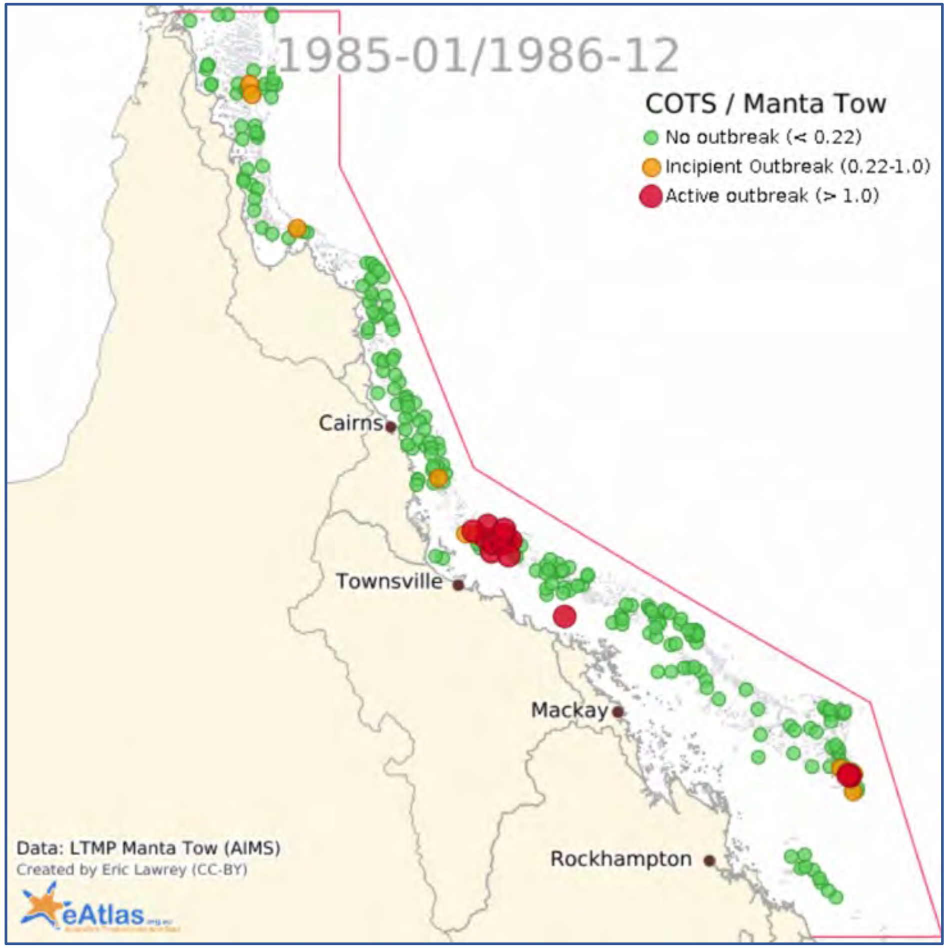
CoTS fertilized eggs and larval stages

Image: AIMS, https://eatlas.org.au/nerp-te/cots-larvae

Reference: K.E. Fabricius, O. Hoegh-Guldberg, J. Johnson, *et al.*Vulnerability of coral reefs of the Great Barrier Reef to climate change IN J.E. Johnson, P.A. Marshall (Eds.), Climate Change and the Great Barrier Reef: A Vulnerability Assessment, Great Barrier Reef Marine Park Authority, Townsville, Australia (2007), pp. 515-554, available: http://www.gbrmpa.gov.au/__data/assets/pdf_file/0014/5432/chpt-17-fabricius-et-al-2007.pdf

Once a CoTS outbreak has begun, outbreaks can spread to reefs far away from terrestrial runoff.
So, terrestrial runoff affects not only some inshore reefs but can also have severe effects on remote offshore reefs.

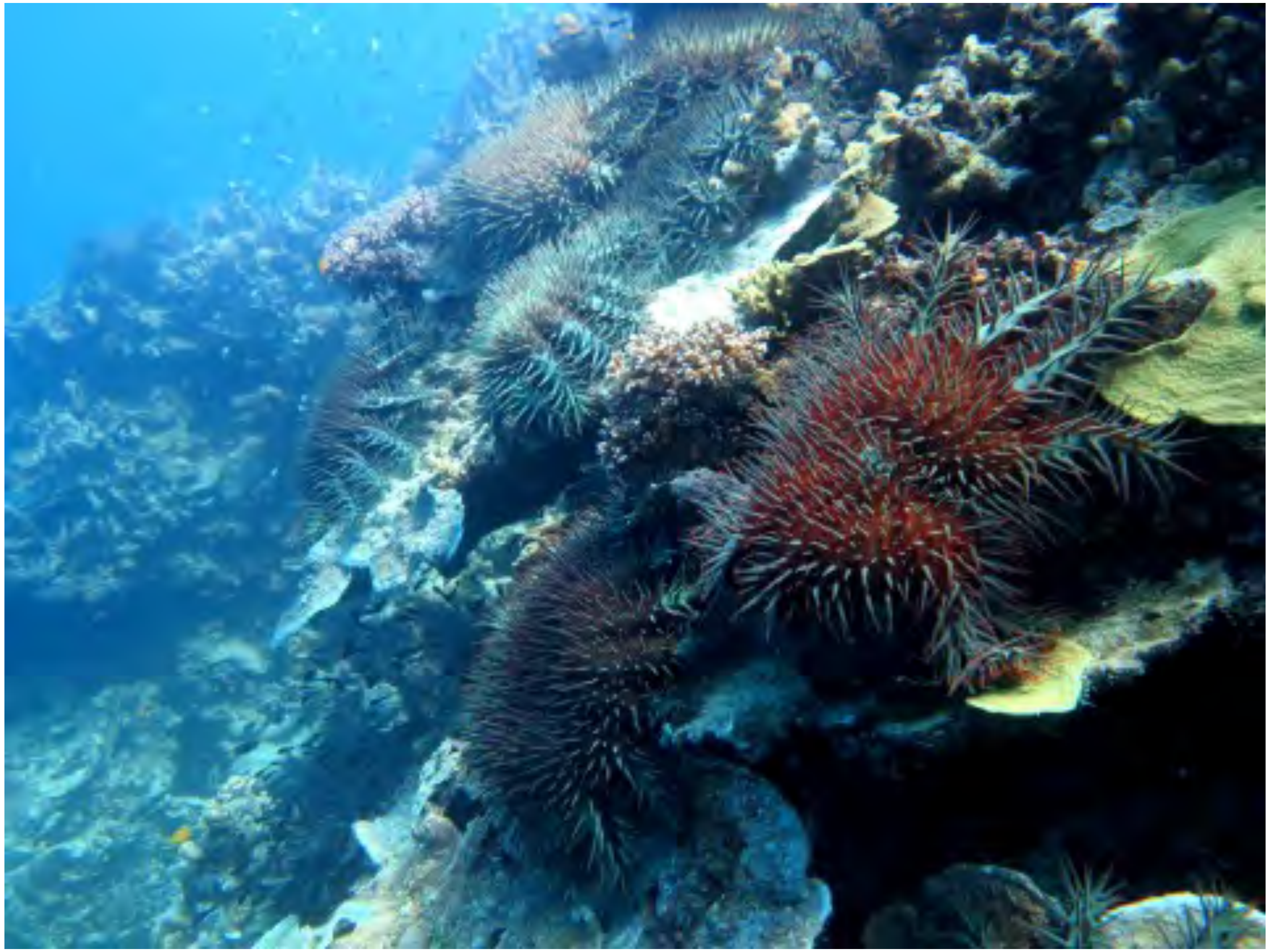
The southwards movement of outbreaks can be seen by following the link below to an animation of CoTS outbreaks over the past 30 years. http://eatlas.org.au/auto-files/gbr-aims-ltmp-manta-animation_COTS-3-cat-2yr-span/GBR_AIMS_LTMP-manta_COTS-3-cat-2yr-span.mp4



Distribution of CoTS outbreaks
Image: AIMS LTMP

Reference: K.E. Fabricius, O. Hoegh-Guldberg, J. Johnson, *et al.*Vulnerability of coral reefs of the Great Barrier Reef to climate change IN J.E. Johnson, P.A. Marshall (Eds.), Climate Change and the Great Barrier Reef: A Vulnerability Assessment, Great Barrier Reef Marine Park Authority, Townsville, Australia (2007), pp. 515-554, available: http://www.gbrmpa.gov.au/__data/assets/pdf_file/0014/5432/chpt-17-fabricius-et-al-2007.pdf

Marine scientists have not reached consensus on whether terrestrial runoff promotes primary outbreaks on the GBR or plays an important role in fuelling subsequent secondary outbreaks.



Crown-of-thorns seastars can form a feeding front that progresses up the reef slope, eating the live coral they encounter.

Image: AIMS, LTMP, CCBY3.0

Reference:
Morgan S. Pratchett, Ciemon F. Caballes, et al, Thirty Years of Research on Crown-of-Thorns Starfish (1986–2016): Scientific Advances and Emerging Opportunities
Reprinted from: *Diversity* **2017**, *9*(4), 41; doi: 10.3390/d9040041

Reefs frequently exposed to terrestrial runoff have lower levels of resilience compared to reefs not exposed to frequent runoff.

This has important implications for reefs exposed to more frequent disturbance from climate-related changes such as coral bleaching and more intense storms.

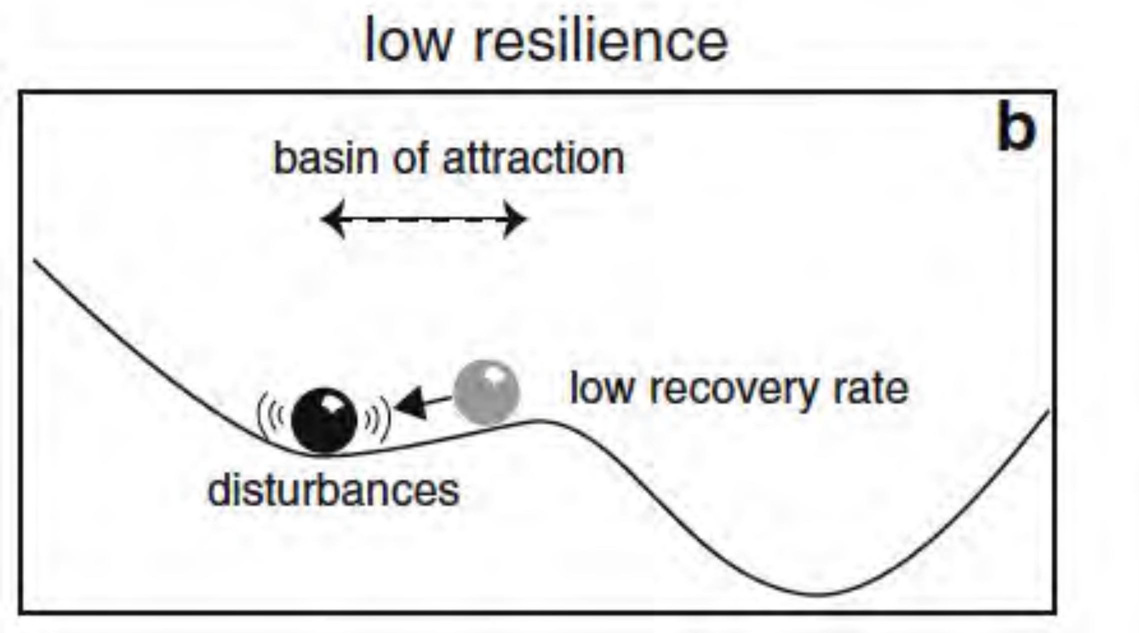


Image: Dakos, V., van Nes, E., Donangelo, R., Fort, H., & Scheffer, M. (2009). Spatial correlation as leading indicator of catastrophic shifts. *Theoretical Ecology*, *3*(3), 163-174. doi: 10.1007/s12080-009-0060-6 open access.

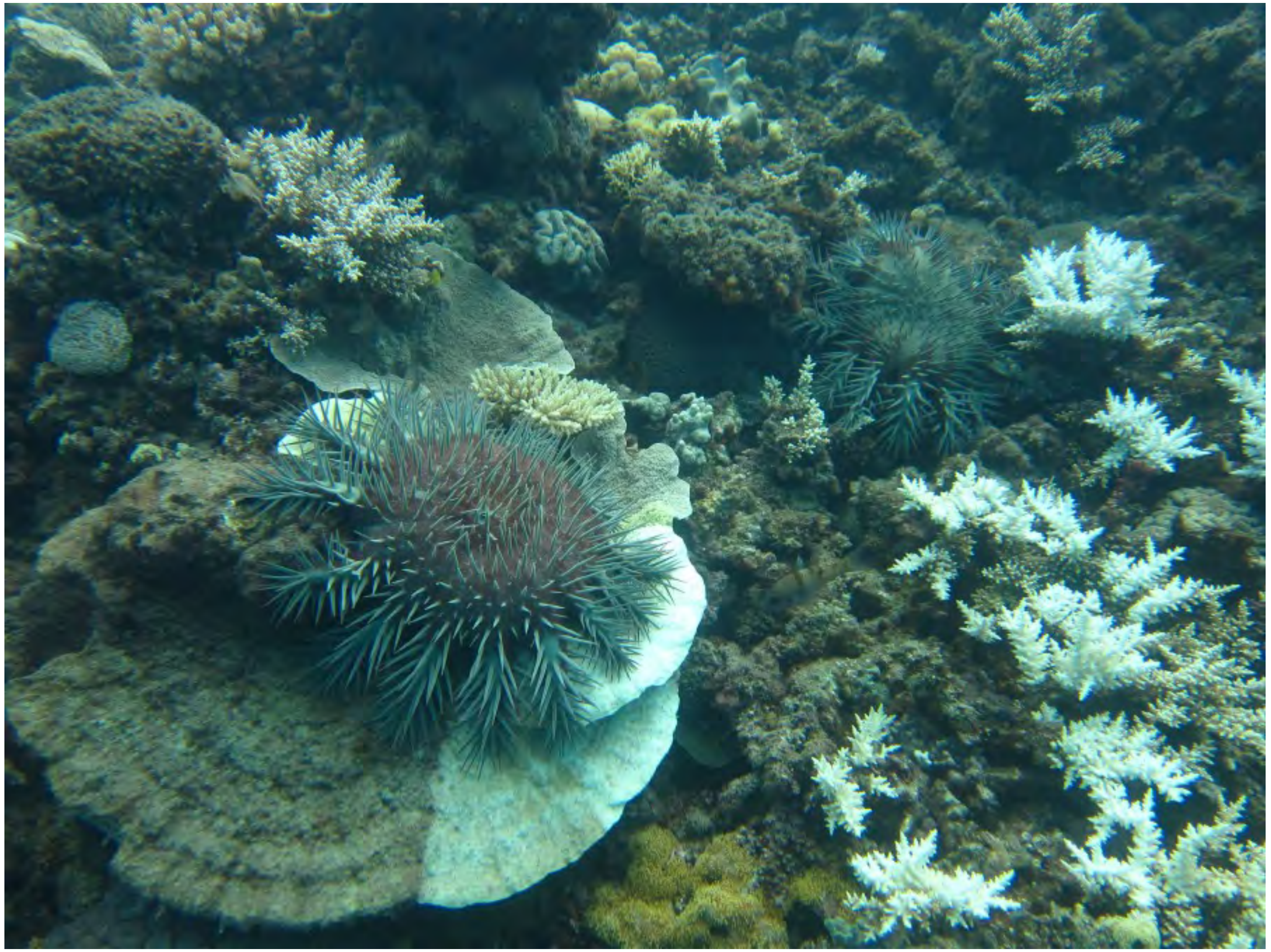
A disturbance such as coral bleaching has a greater impact on a reef with low resilience

Reef resilience was explained in T092: Reef Hysteresis

Reference: K.E. Fabricius *et al* Vulnerability of coral reefs of the Great Barrier Reef to climate change IN J.E. Johnson, P.A. Marshall (Eds.), Climate Change and the Great Barrier Reef: A Vulnerability Assessment, Great Barrier Reef Marine Park Authority, Townsville, Australia (2007), pp. 515-554, available: http://www.gbrmpa.gov.au/__data/assets/pdf_file/0014/5432/chpt-17-fabricius-et-al-2007.pdf

A study into the long term decline of coral cover on the Great Barrier reef concluded that coral cover would increase in the absence of CoTS.

CoTS populations can be reduced by improving water quality and alternative control measures.



Crown-of-thorns starfish feeding. The white coral is recently dead and evidence of starfish feeding activity.

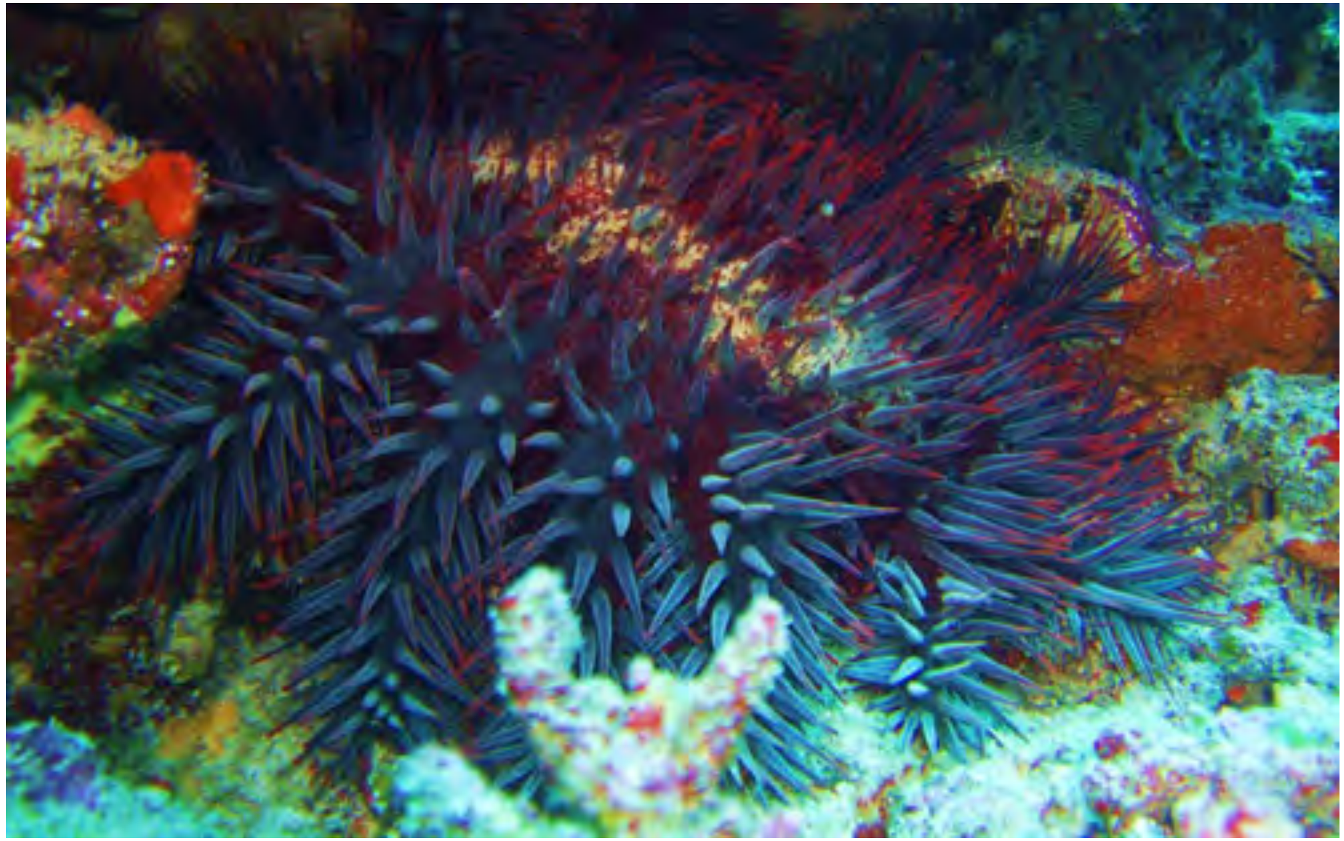
Image: AIMS, LTMP, https://eatlas.org.au/media/566 CC 4.0 BY

De'ath, G., Fabricius, K., Sweatman, H., & Puotinen, M. (2012). The 27-year decline of coral cover on the Great Barrier Reef and its causes. *Proceedings Of The National Academy Of Sciences*, *109*(44), 17995-17999. doi: 10.1073/pnas.1208909109

The Australian Government's crown-of-thorns starfish control programme has two teams of 10 to 12 divers, rotating 10 days on and four days off, out in the water culling and removing the crown-of-thorns starfish.

A toxin, developed at James Cook. University, is injected into the starfish, causing it to break apart and die within 24 hours.

17 million CoTS have so far been killed and/or removed from reefs across the Indo-Pacific[1].



CoTS near Lady Musgrave Island on the Great Barrier Reef
Image: Reef HQ Aquarium, © Commonwealth of Australia 2019.

Reference 1: Morgan S. Pratchett, Ciemon F. Caballes, et al, Thirty Years of Research on Crown-of-Thorns Starfish (1986–2016): Scientific Advances and Emerging Opportunities
Reprinted from: *Diversity* **2017**, *9*(4), 41; doi: 10.3390/d9040041

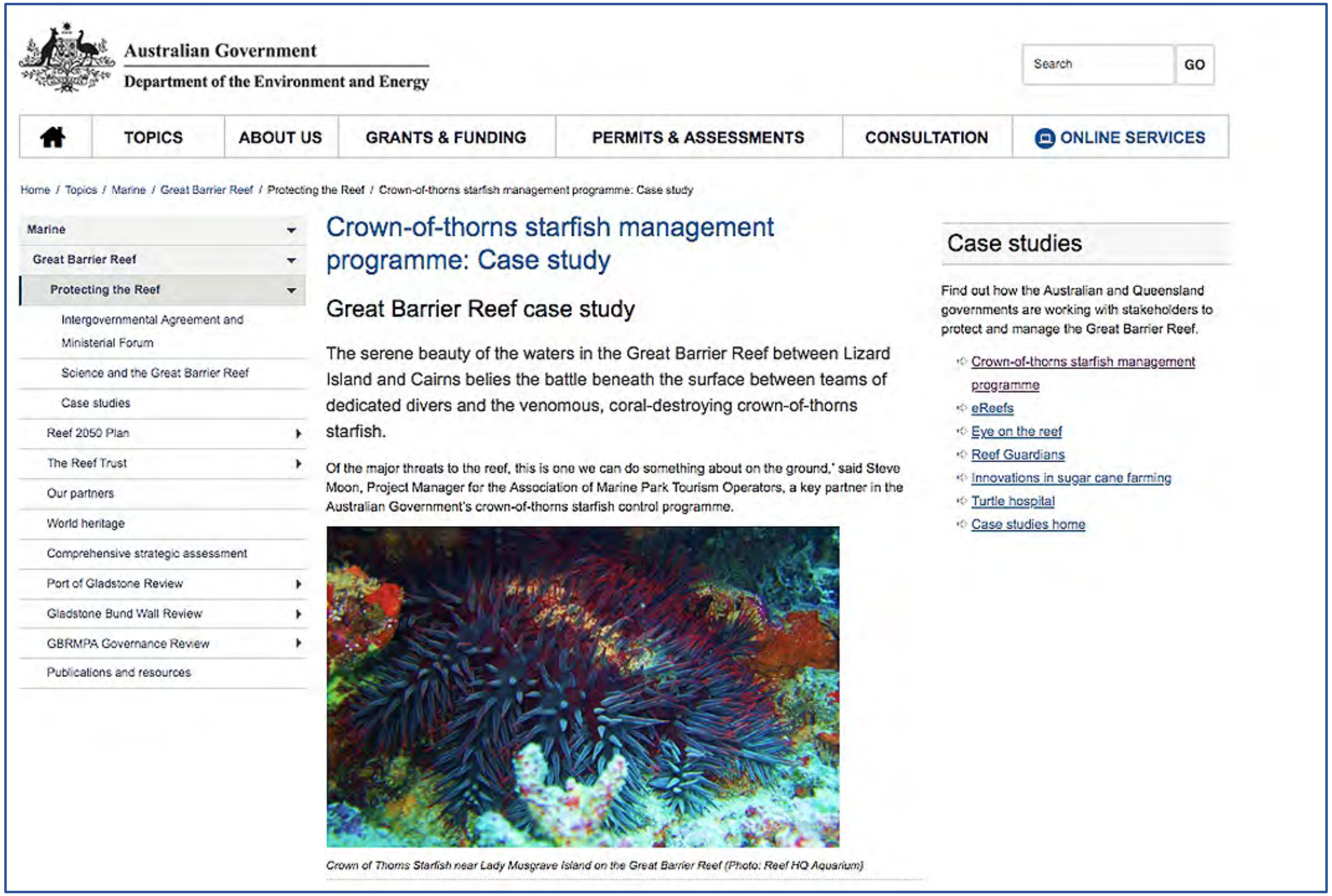
There are now 6 boats patrolling the GBRMP.

Boats inject COTS with white vinegar in the side which kills the COTS within 24-48hrs.

https://www.youtube.com/watch?v=MwvOX3HHifM

Read the a case study on the Crown-of-thorns starfish management programme here:

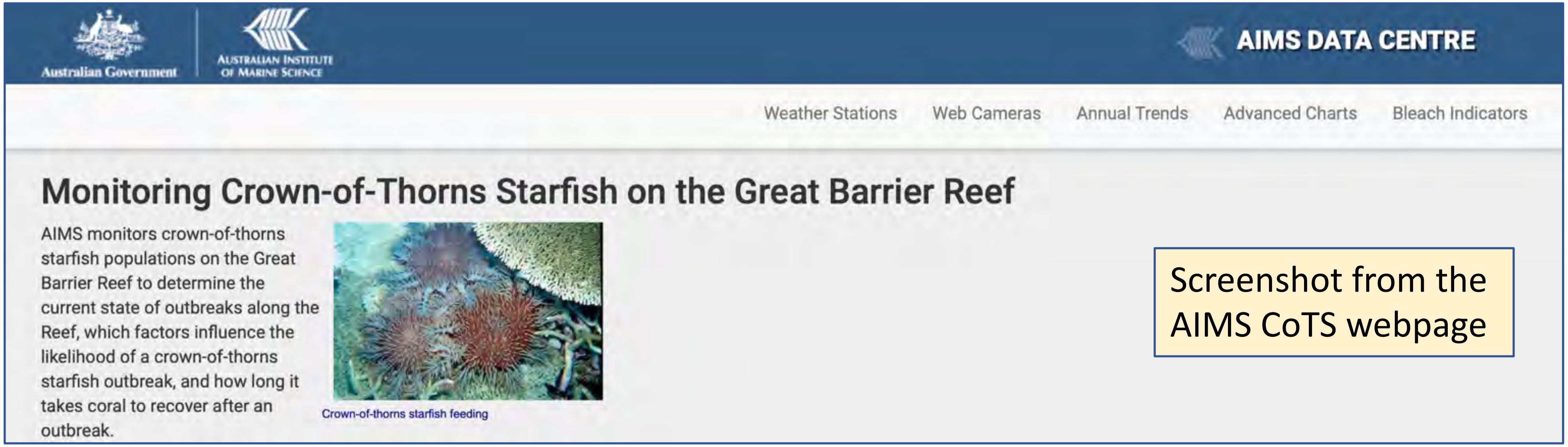
https://www.environment.gov.au/marine/gbr/case-studies/crown-of-thorns



https://www.environment.gov.au/marine/gbr/case-studies/crown-of-thorns

The Australian Institute of Marine Science monitors crown-of-thorns starfish populations on the Great Barrier Reef to determine the current state of outbreaks along the Reef.

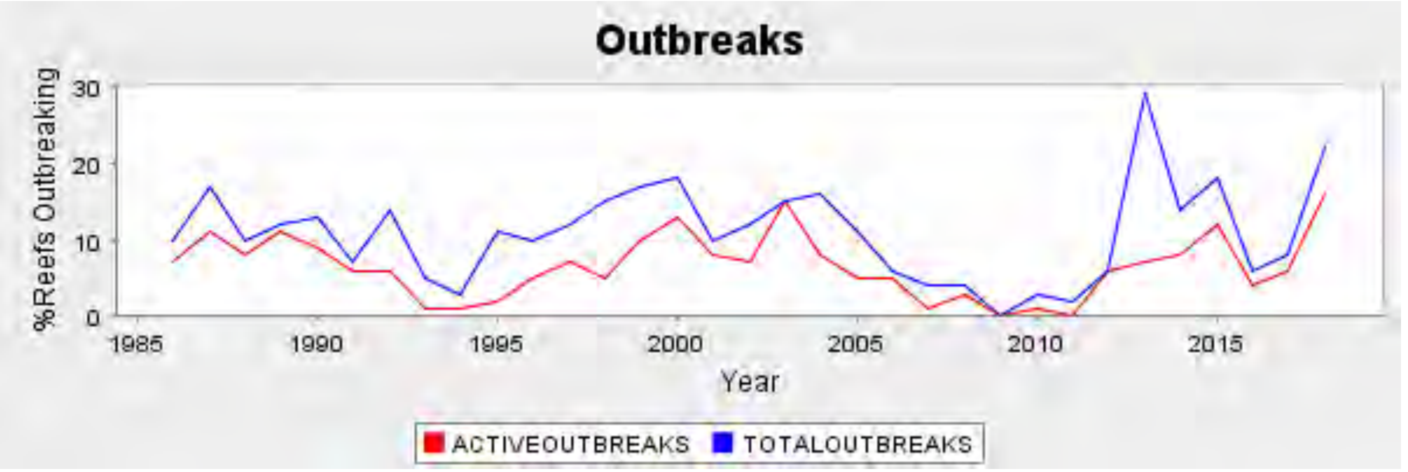
You can learn more about this program here: http://data.aims.gov.au/waCOTSPage/cotspage.jsp



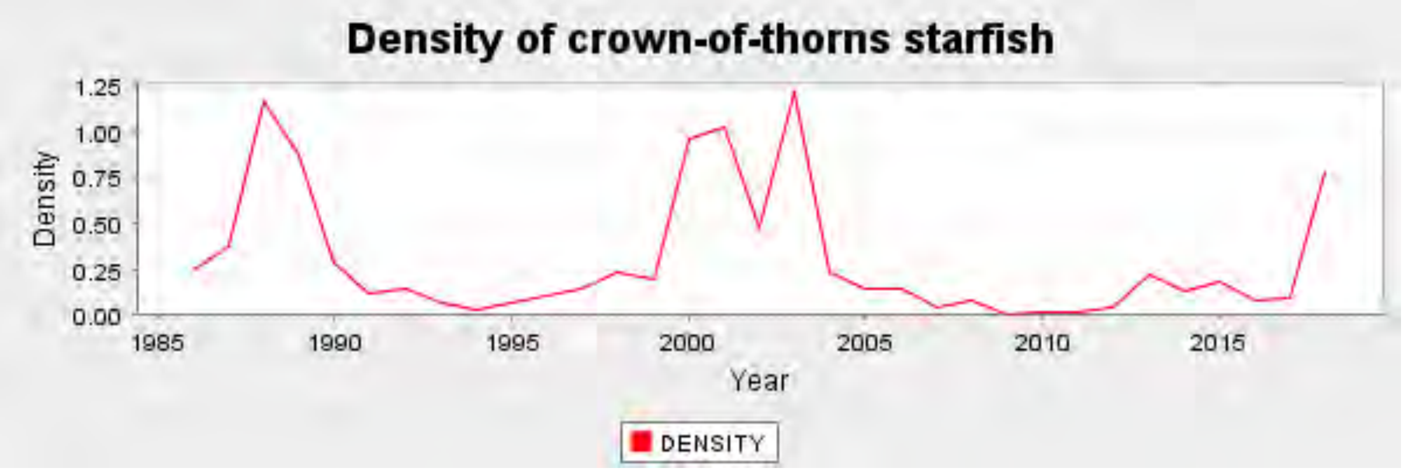
Source: Australian Institute of Marine Science, http://data.aims.gov.au/waCOTSPage/cotspage.jsp

In 1988 CoTS caused widespread destruction of the Central GBR. How do CoTS numbers compare today?

This graph shows historical percentages of reefs with CoTS outbreaks.
In 2018, 22% of reefs have CoTS outbreaks, compared with 10% in 1988.



The second graph shows the average density of CoTS (as counted during a 2 minute manta tow) across the whole Great Barrier Reef. In 2018 the density is 0.78, compared with 1.17 in 1988.



Source: Australian Institute of Marine Science, http://data.aims.gov.au/waCOTSPage/cotspage.jsp

The AIMS CoTS webpage includes information about individual reefs with CoTS outbreaks. For example, Jenkins Reef, in the Swains Group, had an active outbreak when surveyed in 2018. The number of COTS and 5 coral cover is included below:

Survey Method	Measure	2000s Average (range)	2014	2016	2018
Manta tows on reef perimeter	Average percent cover of hard coral	9% (0-20%)	30-40%	50-63%	0-5%
	Crown-of-thorns starfish/tow	0 (0-0)	0	0.03	2.19
	Outbreak Status*		NO	NO	AO
Fixed transects on survey sites	Average percent cover of hard coral	17% (11-22%)	60%	68%	2%
	Total fish species	77 (74-79)	79	74	76

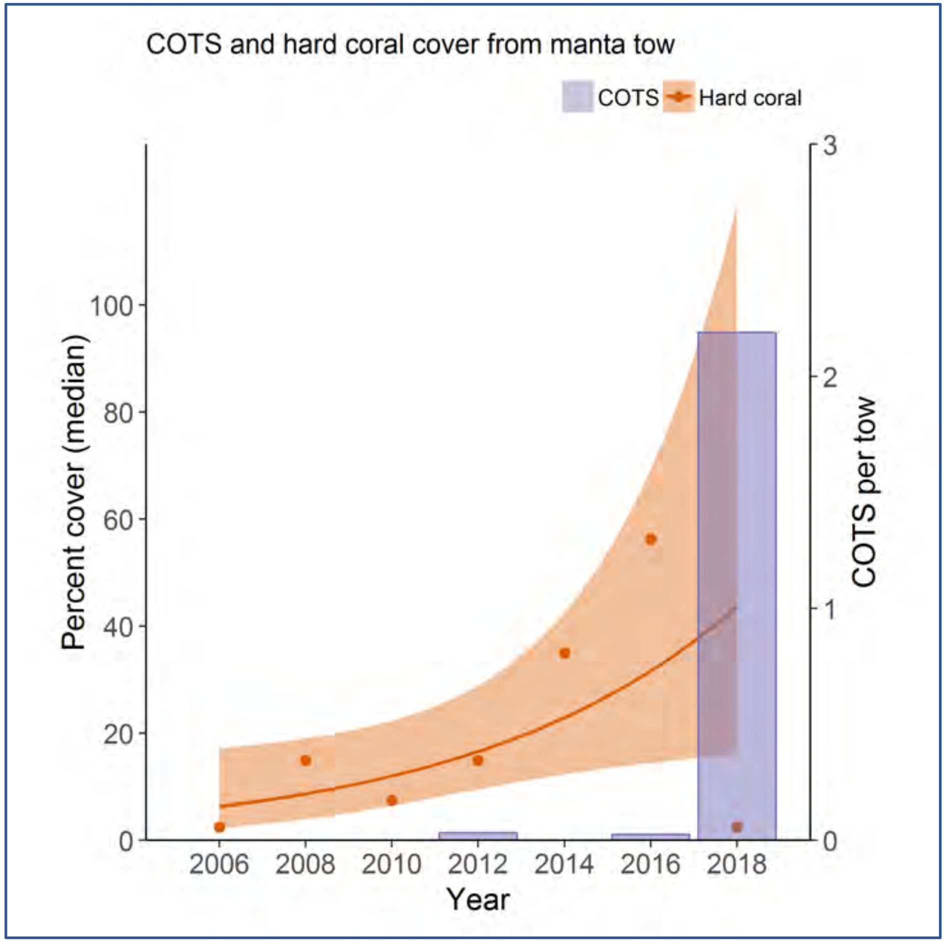
Color coding reflects an assessment of the status of hard coral cover relative to long-term GBR-wide averages:

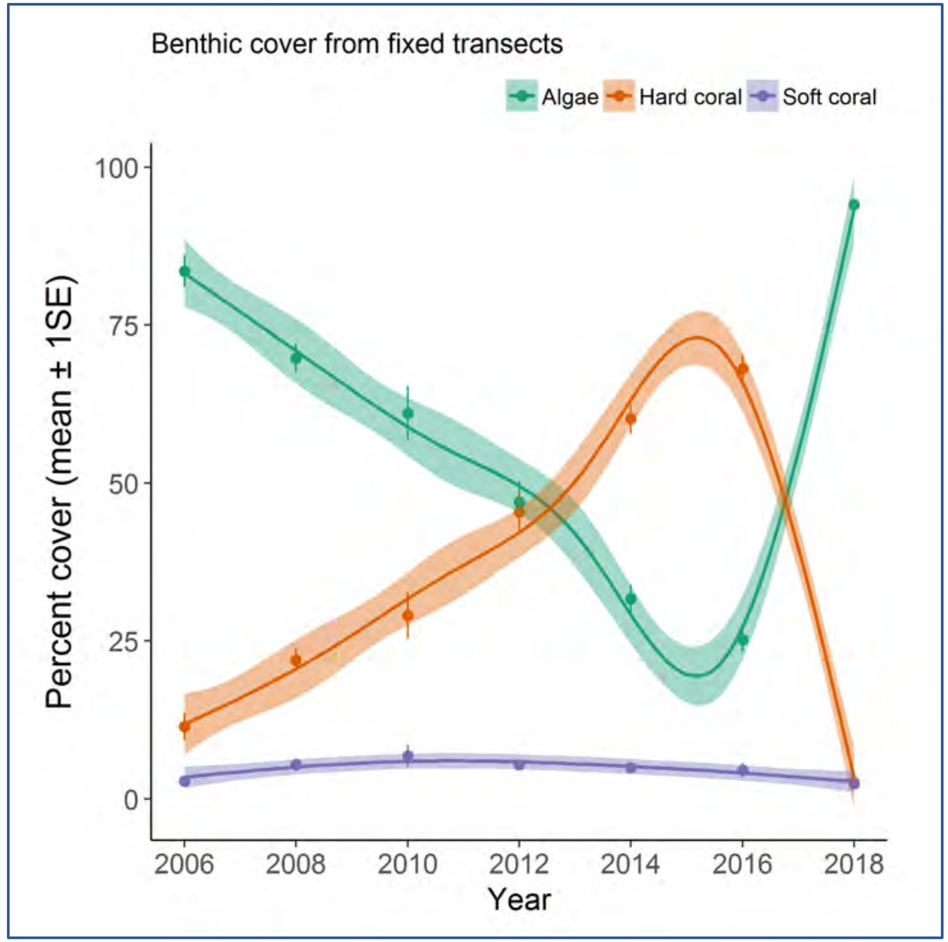
Low (0-10%)	Moderate (10-30%)	High (30-50%)	Very High (50-75%)	Extremely High (75-100%)

* AO = Active outbreak, IO= Incipient outbreak, RE = Recovering from past outbreak, NO = No outbreak after recovering or no history of outbreaks.

Source: Australian Institute of Marine Science, http://apps.aims.gov.au/reef-monitoring/reef/21584S

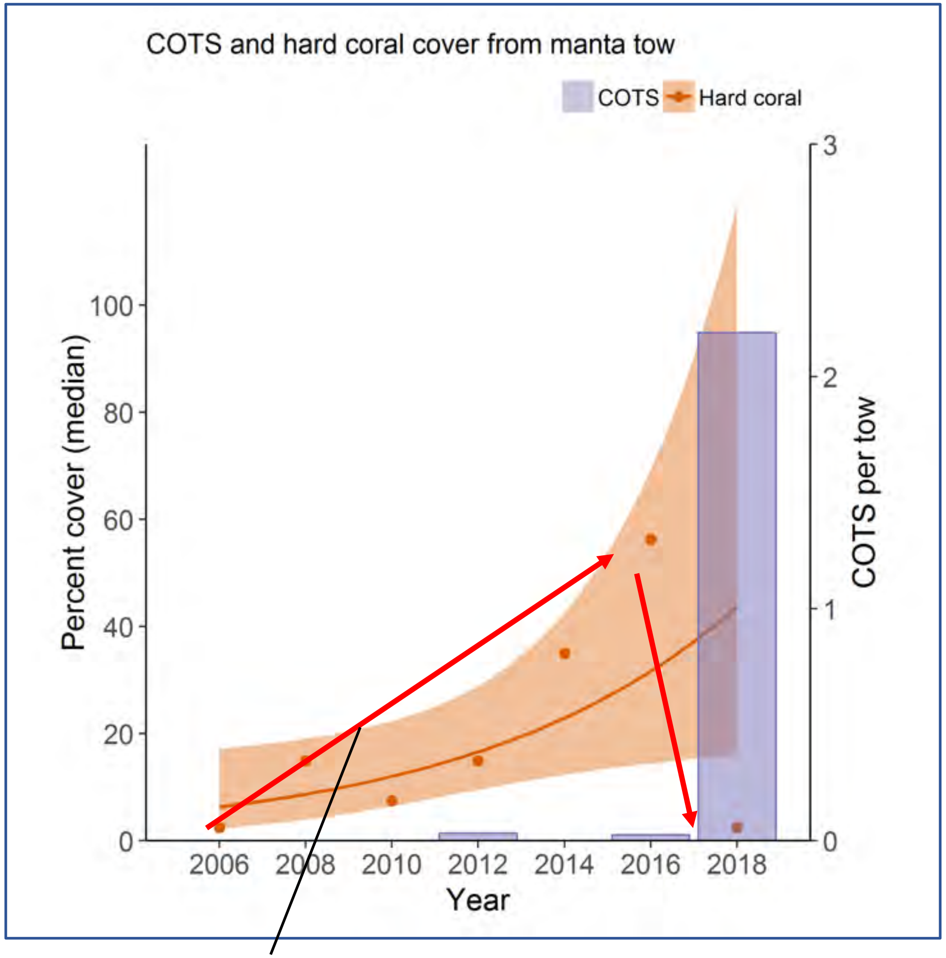
Data on COTS per tow and % coral cover, and benthic cover at Jenkins Reef is presented below:

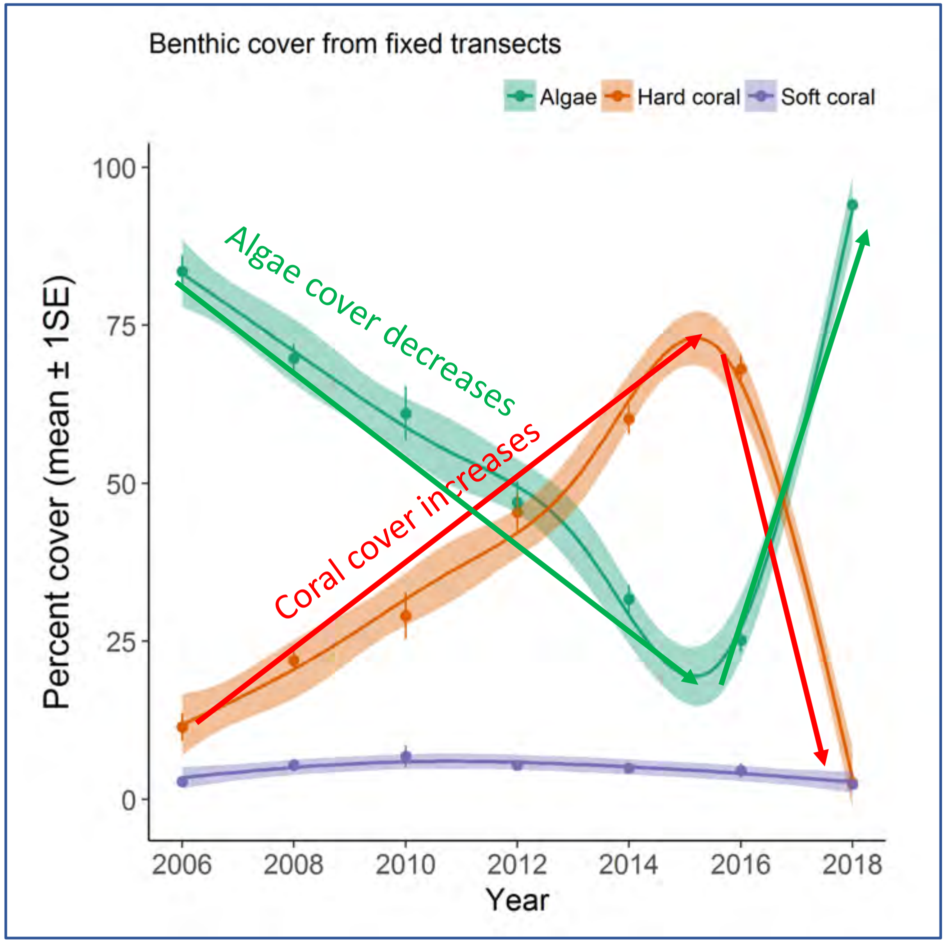




Can you interpret these graphs of benthic cover from 2006- 2018 at Jenkins reef?

Source: Australian Institute of Marine Science, http://apps.aims.gov.au/reef-monitoring/reef/21584S





Hard coral cover increasing from 2006-2016 when CoTS numbers were low, followed by a significant drop in hard coral cover in 2018- coinciding with an increase in CoTS numbers.

Algae cover decreases with increasing hard coral cover- until 2016, when coral cover decreases drastically- with a corresponding increase in algal cover.

Source: Australian Institute of Marine Science, http://apps.aims.gov.au/reef-monitoring/reef/21584S

Further research is required to determine whether increased actions to improve water quality (specifically, addressing land-use practices to reduce nutrient inputs) within reef environments can reduce the frequency or intensity of future CoTS outbreaks.[1]

Close up of crown of thorns starfish's spines

1 Morgan S. Pratchett, Ciemon F. Caballes, et al, Thirty Years of Research on Crown-of-Thorns Starfish (1986–2016): Scientific Advances and Emerging Opportunities
Reprinted from: *Diversity* **2017**, *9*(4), 41; doi: 10.3390/d9040041

Questions

Draw three graphs to show some of the factors that reduce coral cover (e.g. crown-of-thorns) are directly linked to water quality.

Further activities

See

https://coralwatch.org/index.php/education-2/curriculum-materials/marine-science/

by

CORALWATCH

Further references

https://www.qut.edu.au/science-engineering/about/news?news-id=125876

https://www.qut.edu.au/research/article?id=135108

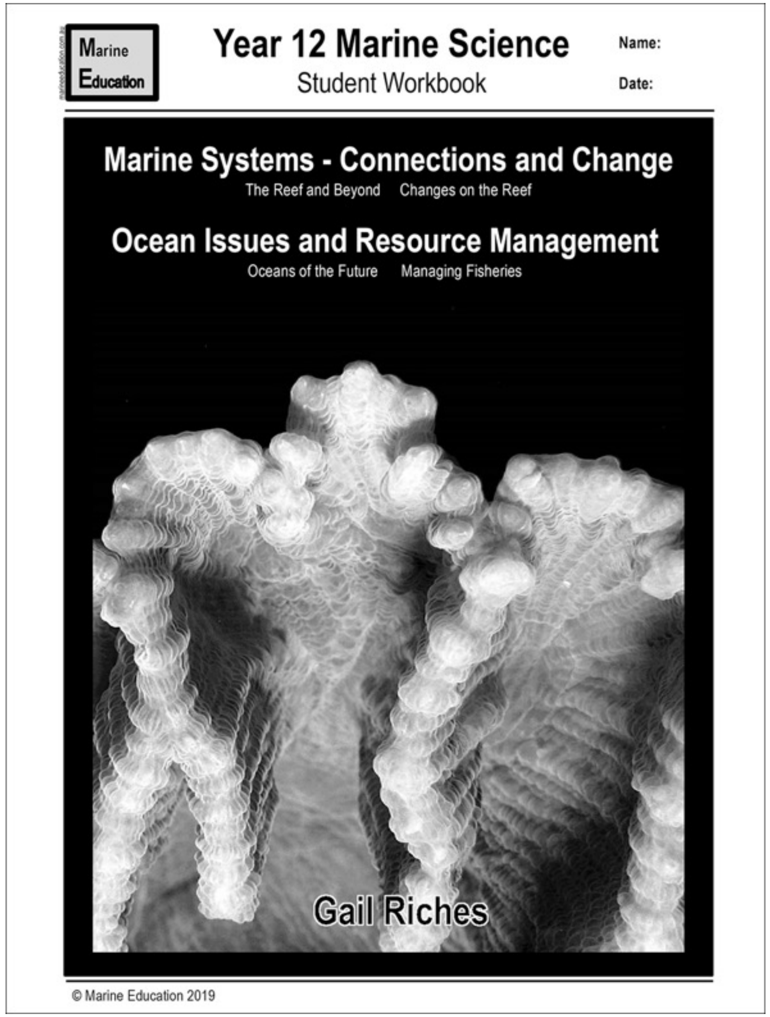
Worksheet

Reef reports

by

Gail Riches

www.marineeducation.com.au



T097 Water quality overall effects

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Syllabus statement

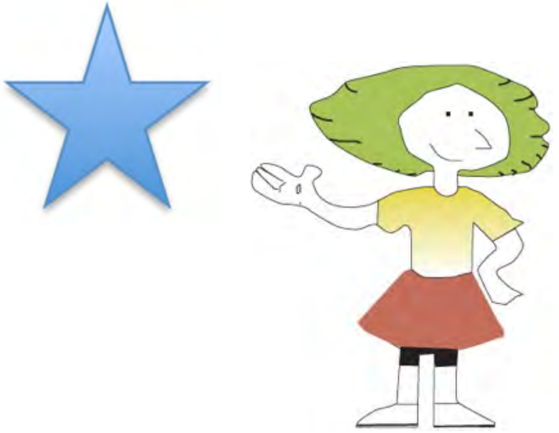
At the end of this topic you should be able to ...

Understand

that the processes in this sub-topic interact to have an overall net effect, i.e. they do not occur in isolation.

Understand

- perceive what is meant by something; grasp; be familiar with (e.g. an idea); construct meaning from messages, including oral, written and graphic communication



Objectives

Explain the effect of a combination of processes operating together.

Create a flow chart to explain how a series of processes can impact on a coral reef.

Review this subtopic: Reef, habitats and connectivity

In this topic, we have covered:

- Corals are habitat formers and ecosystem engineers
- Habitat complexity (rugosity) influences species diversity
- Connectivity helps species replenishment
- Fish lifecycles cross habitats
- Fish, particularly, herbivores benefit coral reefs
- Ecological tipping points
- Hysteresis and reef resilience
- Coral reef diversity measurement techniques
- Reef diversity data analysis and rank abundance
- Reef state is measured by changes in coral cover- causes and trends
- Water quality, CoTS and disease

There are many processes that impact on coral reefs. Here are some:

Image: Adam Richmond, using wordart.com

For clarity

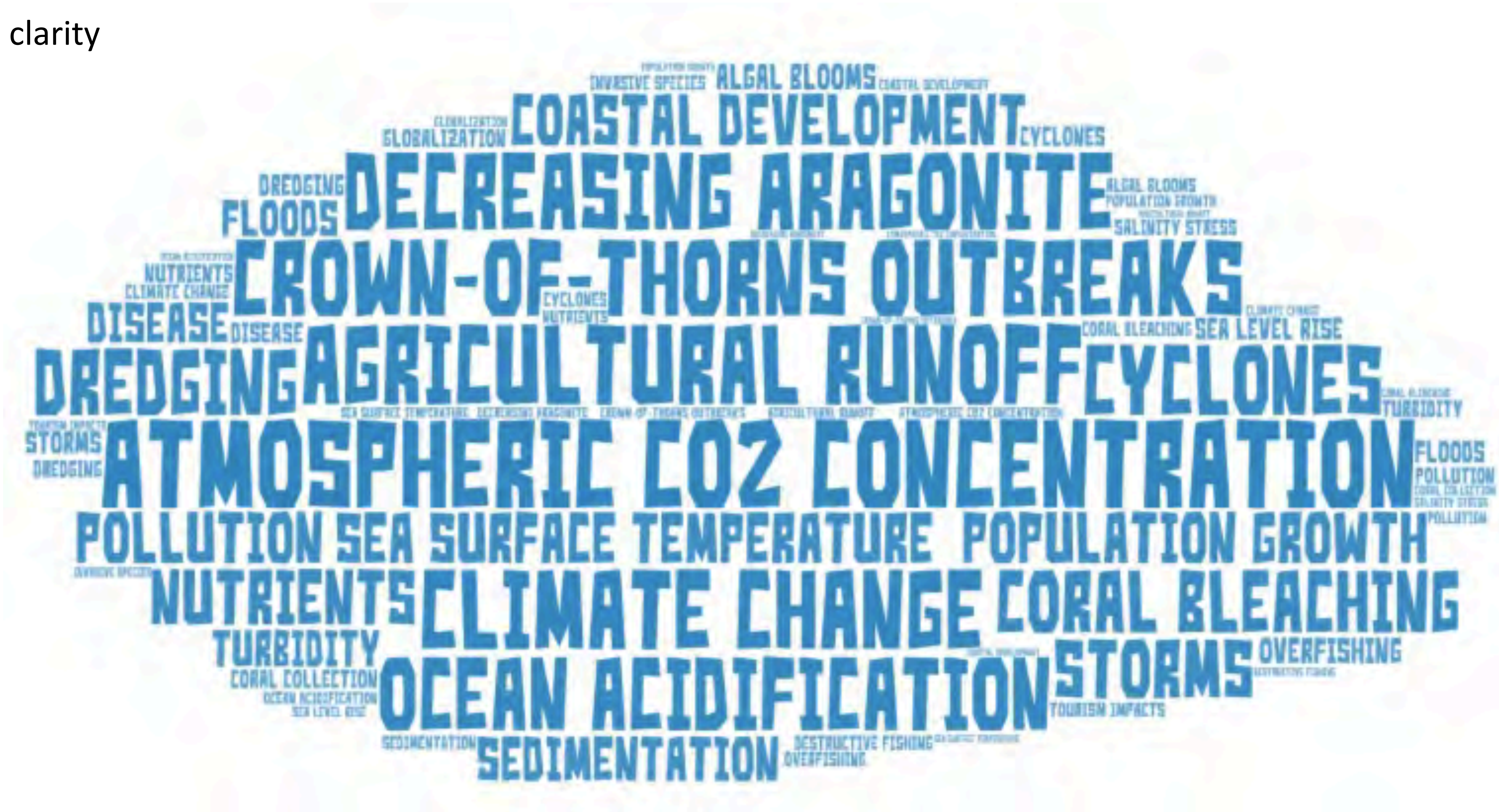


Image: Adam Richmond, using wordart.com

Processes that impact on coral reefs.

Agricultural runoff
Algal blooms
Atmospheric CO_2 concentration increase
Climate change
Coastal development
Coral bleaching
Coral collection
Crown of Thorns outbreaks
Cyclones
Decreasing aragonite concentration
Destructive fishing methods
Disease
Dredging
Floods

Invasive species
Nutrients
Ocean acidification
Overfishing
Pollution
Population growth
Salinity stress
Sea level rise
Sea surface temperature increase
Sedimentation
Storms
Tourism impacts
Turbidity

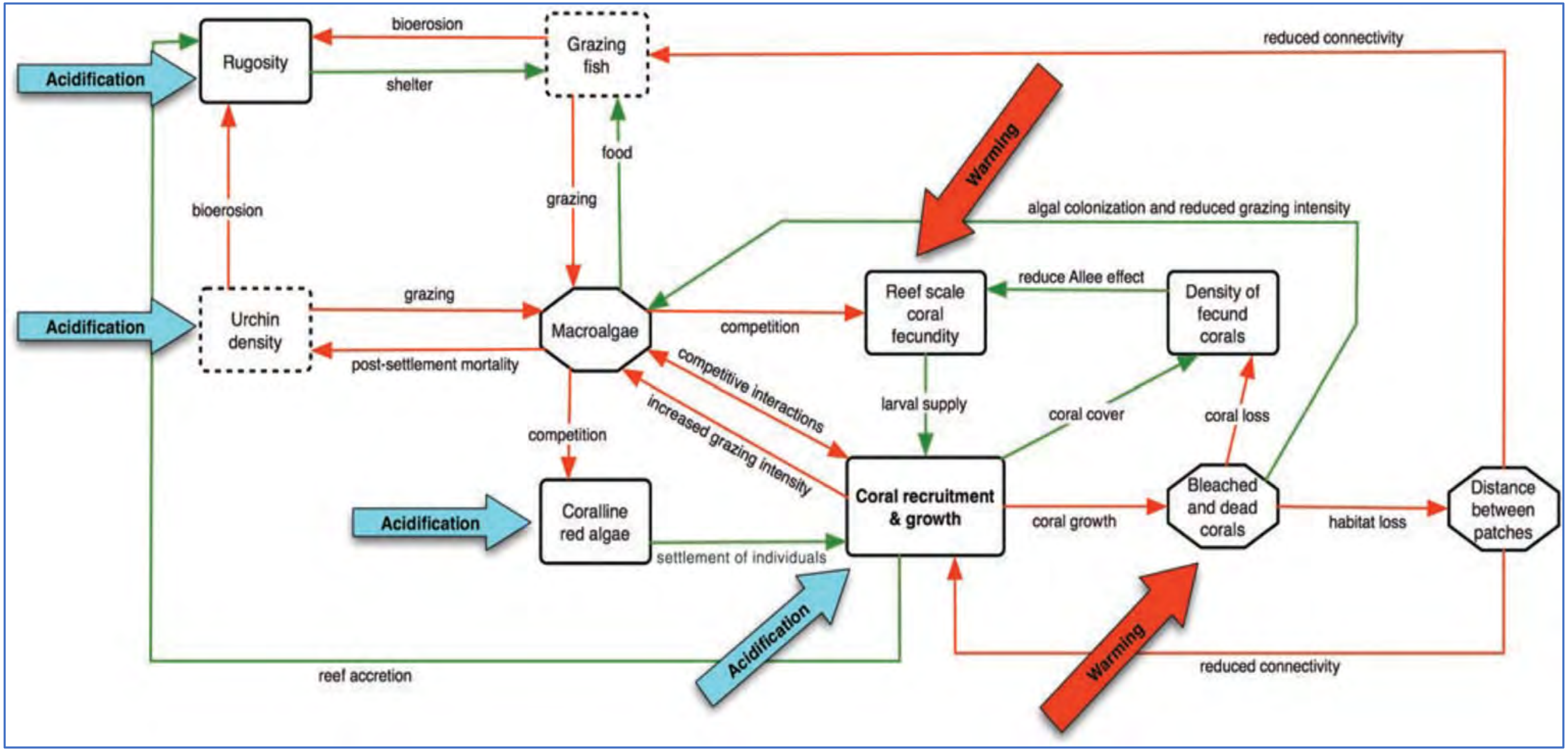
Can you think of any others?

These stressors do not occur in isolation, for example:

A flood event following a storm will result in water with low salinity, high nutrients, pollutants such as pesticides, increased sedimentation and turbidity.

Aerial view of flood plumes after flooding in January 2010

Any one impact will have flow-on effects throughout the coral reef ecosystem.

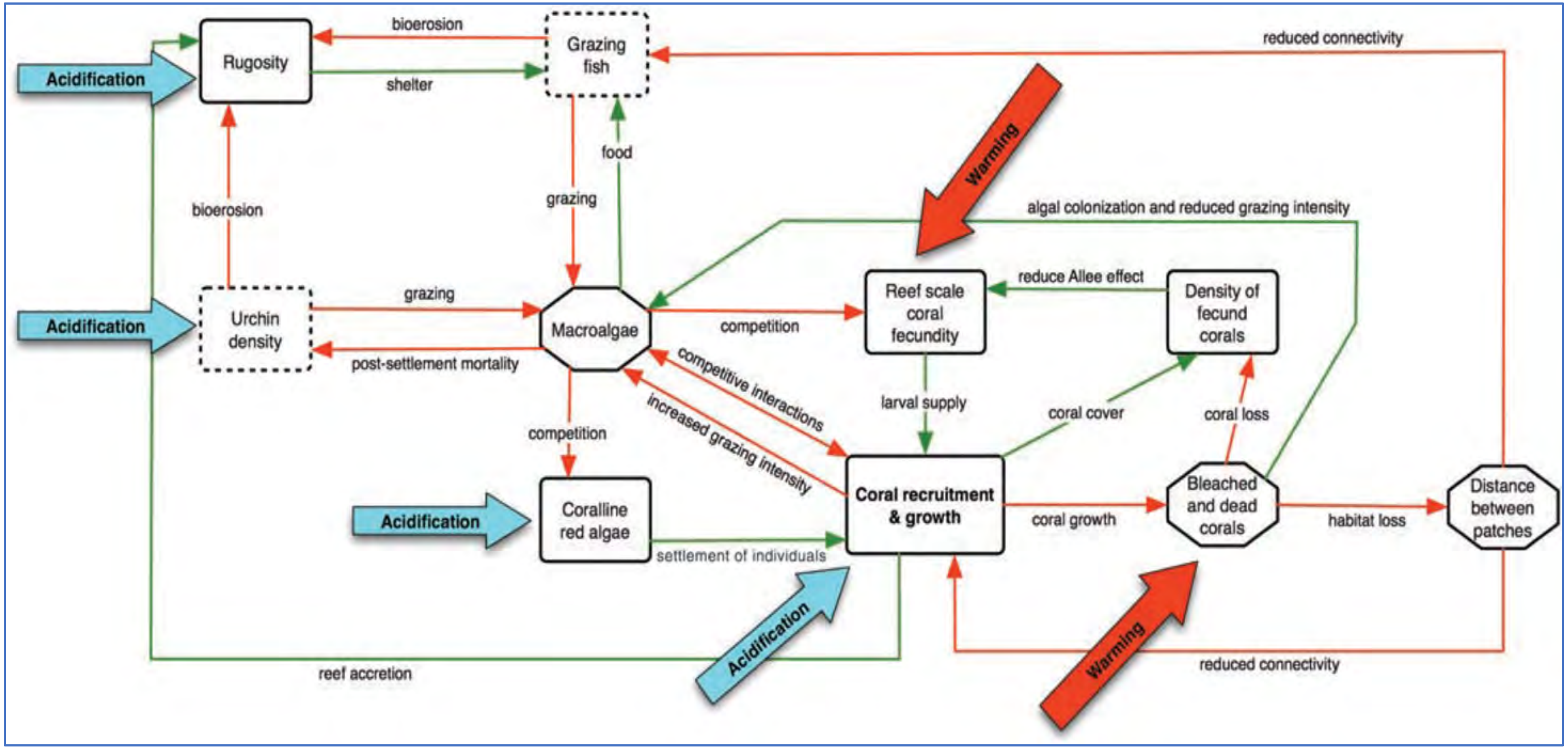


Ecological feedback processes on a coral reef showing pathways of disturbance caused by climate change

Reference: Hoegh-Guldberg, O., Mumby, P., Hooten, A., Steneck, R., Greenfield, P., & Gomez, E. et al. (2007). Coral Reefs Under Rapid Climate Change and Ocean Acidification. *Science*, *318*(5857), 1737-1742. doi: 10.1126/science.1152509

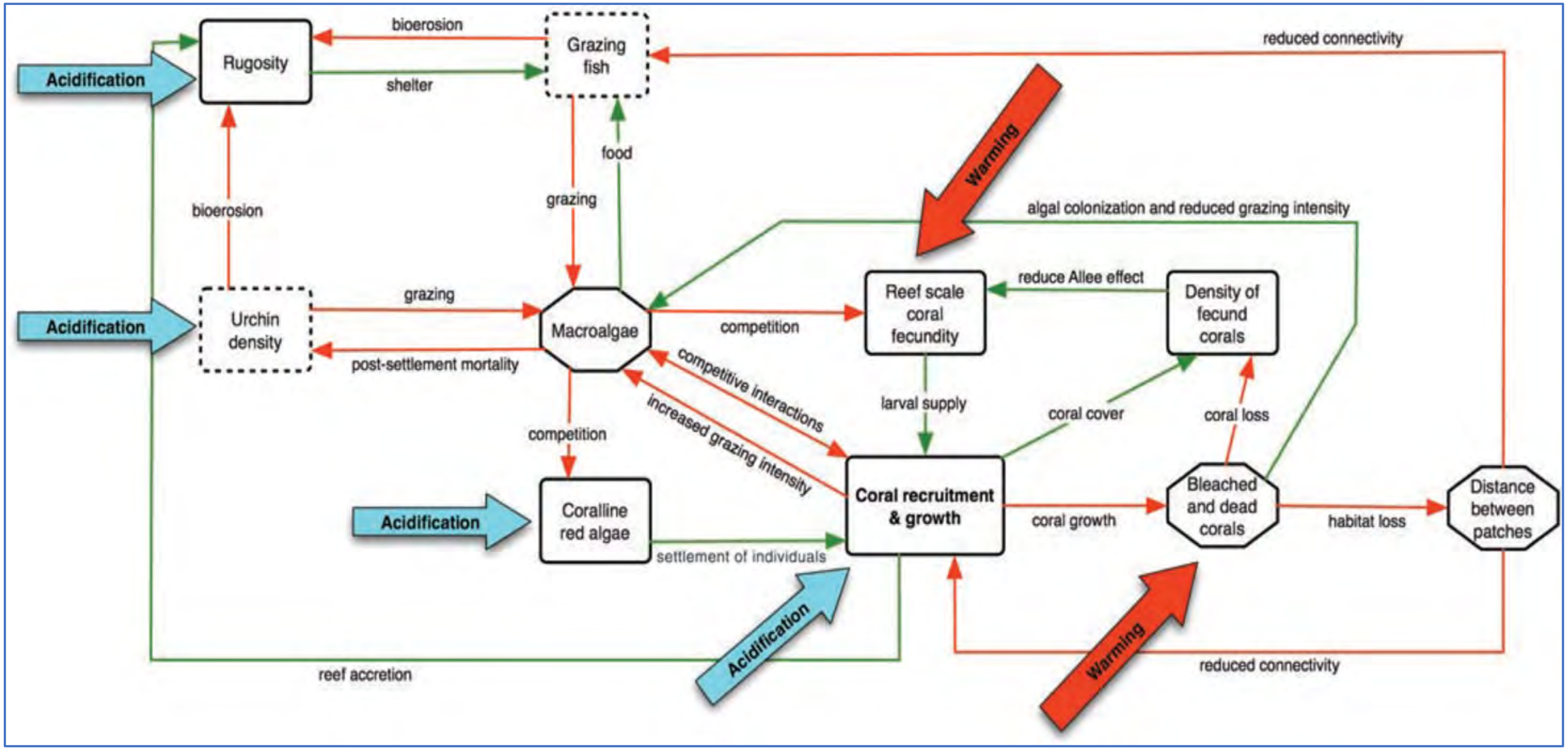
For example, a reduction in numbers of grazing fish will lead to reduced grazing, causing an increase in macroalgae, which will increase competition for corals and coralline red algae. Reduced grazing fish will also reduce bioerosion.

What would be the impact of increasing bleached and dead corals?



Reference: Hoegh-Guldberg, O., Mumby, P., Hooten, A., Steneck, R., Greenfield, P., & Gomez, E. et al. (2007). Coral Reefs Under Rapid Climate Change and Ocean Acidification. *Science*, *318*(5857), 1737-1742. doi: 10.1126/science.1152509

Coral bleaching can result in reduced density of fecund corals, which caused reduces spawning at a reef scale, which reduces larval supply, which reduces coral recruitment and growth. This leads to a decrease in rugosity and shelter for grazing fish, which can lead to increased macroalgae. At the same time, habitat loss reduces connectivity, which further grazing fish.



Reference: Hoegh-Guldberg, O., Mumby, P., Hooten, A., Steneck, R., Greenfield, P., & Gomez, E. et al. (2007). Coral Reefs Under Rapid Climate Change and Ocean Acidification. *Science*, *318*(5857), 1737-1742. doi: 10.1126/science.1152509

What would be the impact of overfishing herbivores?
Or increased coral recruitment?

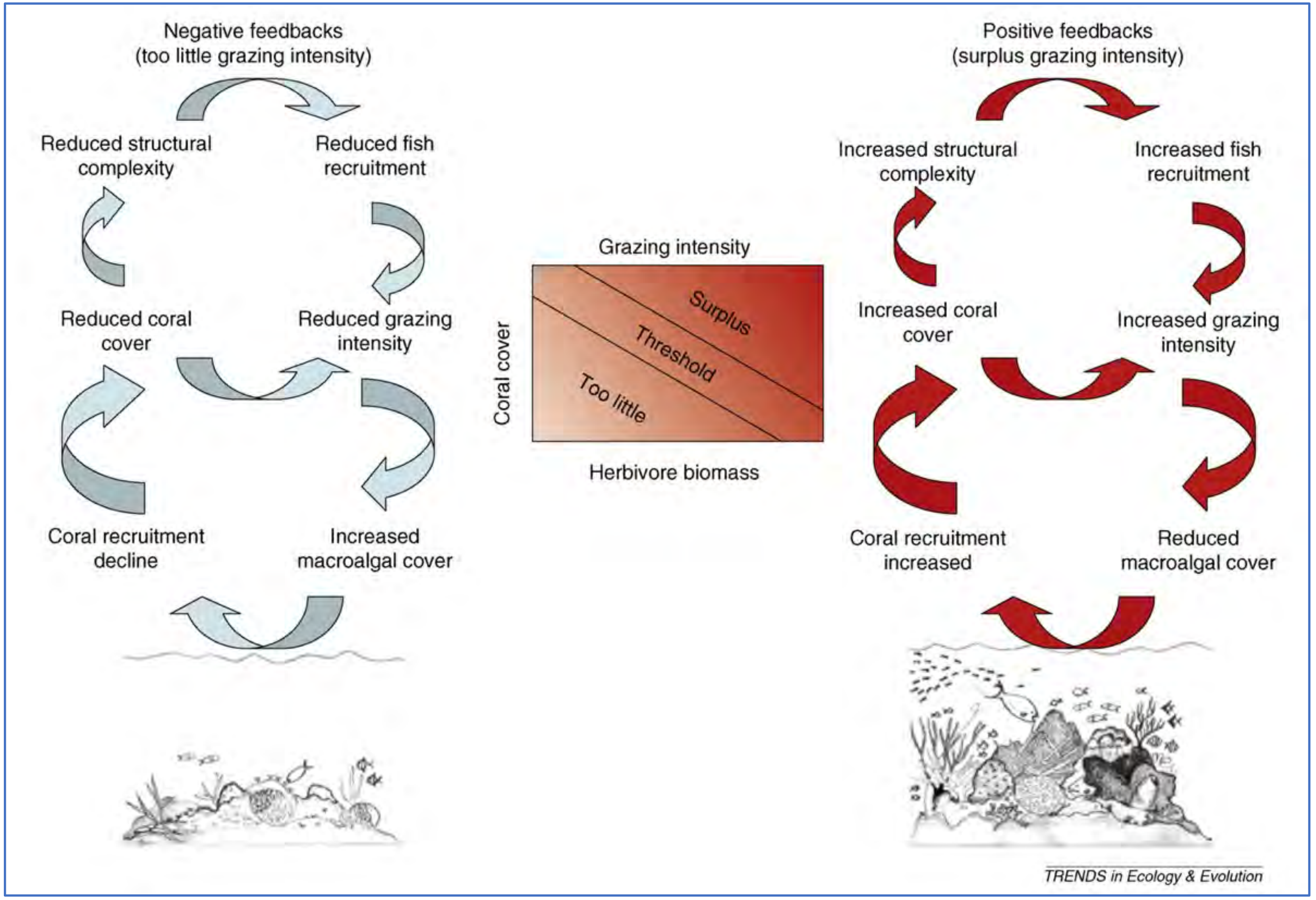


Image: MUMBY, P., & STENECK, R. (2008). Coral reef management and conservation in light of rapidly evolving ecological paradigms. *Trends In Ecology & Evolution*, *23*(10), 555-563. doi: 10.1016/j.tree.2008.06.011 with permission from Elsevier.

Overfishing herbivores will reduce grazing intensity, and reduce fish recruitment, increasing macroalgal cover, reducing coral recruitment and coral cover, reducing coral complexity which will further reduce herbivore numbers.

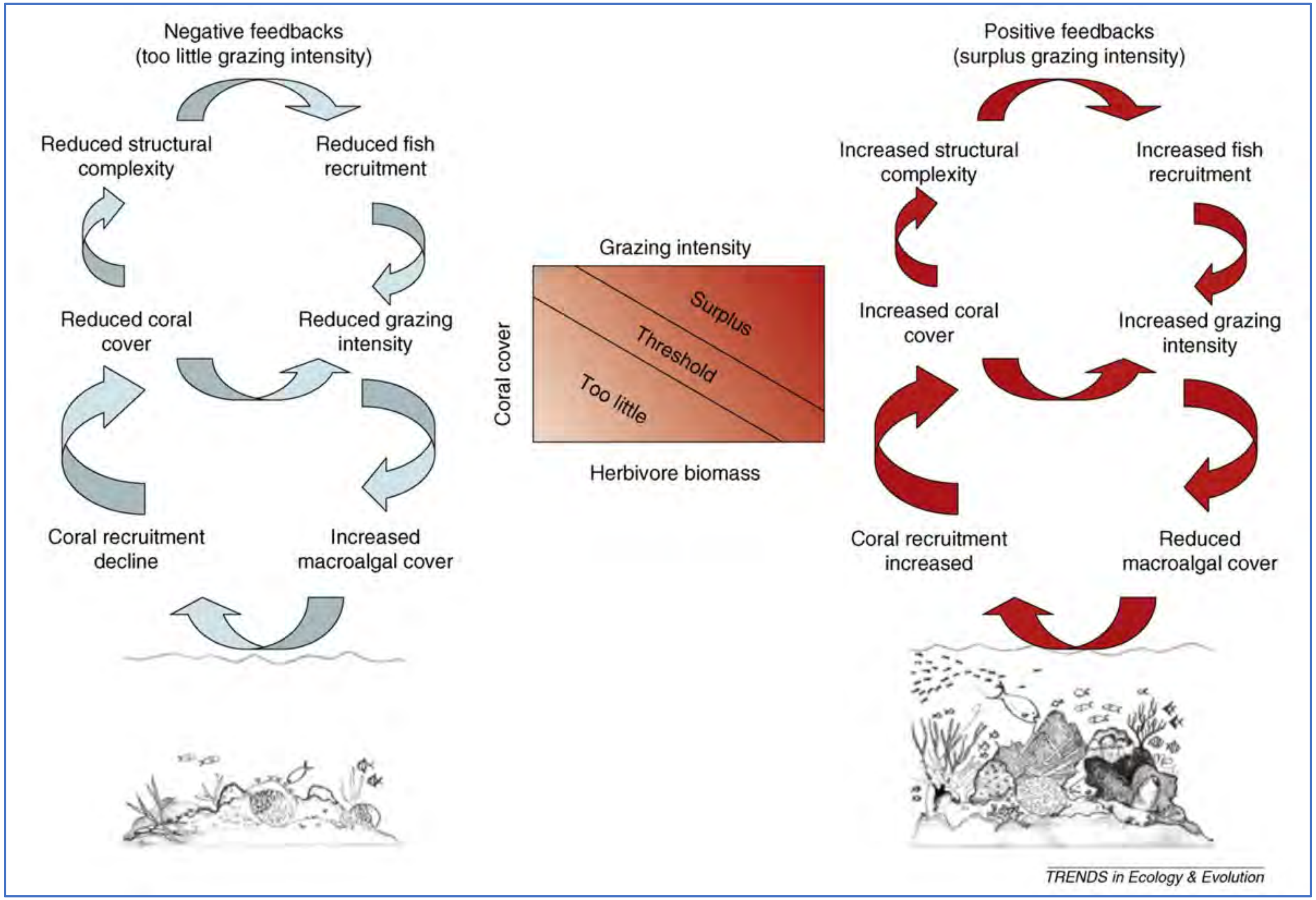


Image: MUMBY, P., & STENECK, R. (2008). Coral reef management and conservation in light of rapidly evolving ecological paradigms. *Trends In Ecology & Evolution*, *23*(10), 555-563. doi: 10.1016/j.tree.2008.06.011 with permission from Elsevier.

Increased coral recruitment will lead to increased coral cover and increased structural complexity. Increased grazing (from increased fish habitat) leads to increased fish recruitment and decreased algal cover- which further increased coral recruitment.

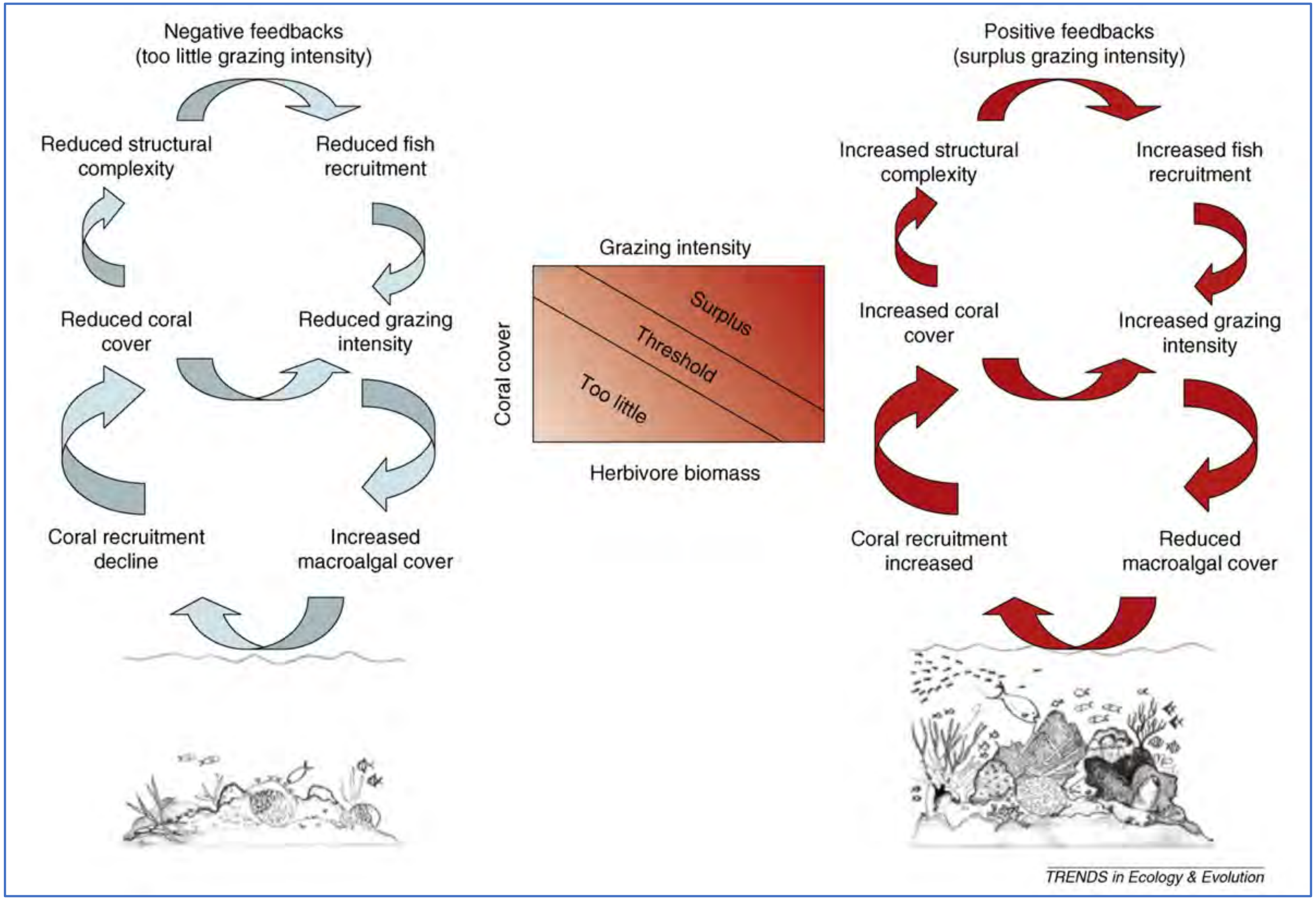


Image: MUMBY, P., & STENECK, R. (2008). Coral reef management and conservation in light of rapidly evolving ecological paradigms. *Trends In Ecology & Evolution*, *23*(10), 555-563. doi: 10.1016/j.tree.2008.06.011 with permission from Elsevier.

Interactions between multiple drivers

The interactions between multiple drivers can be additive, antagonistic or synergistic.

For example, if climate change has effect x on the abundance of corals on a reef

and
overfishing has effect y,

then climate change and overfishing together may have an effect that is

x + y (additive),

less than x + y (antagonistic), or

greater than x + y (synergistic)

Reference: Hughes, T., Barnes, M., Bellwood, D., Cinner, J., Cumming, G., & Jackson, J. et al. (2017). Coral reefs in the Anthropocene. *Nature*, *546*(7656), 82-90. doi: 10.1038/nature22901

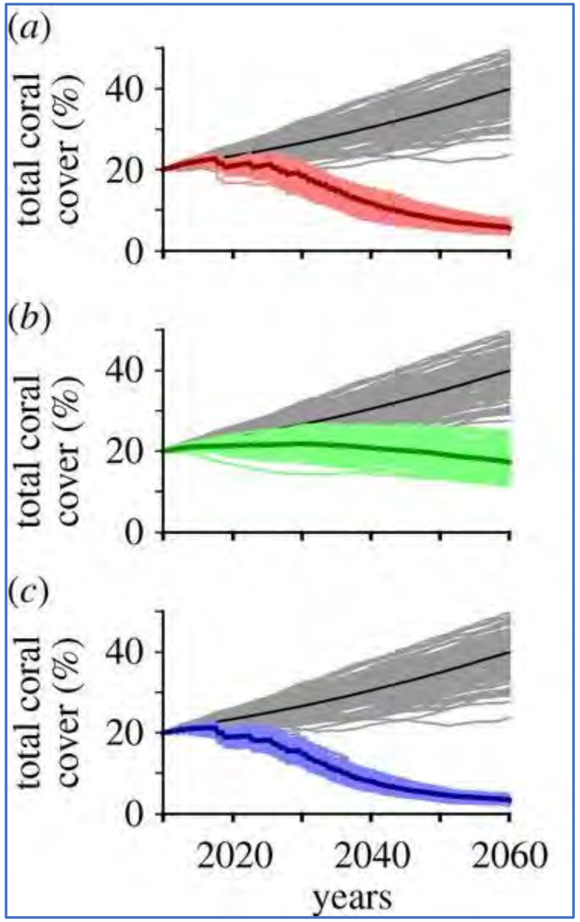
Bozec and Mumby modelled the interaction between acute and chronic impacts on Caribbean coral reefs.

The grey lines show that % coral cover on reefs will increase when not affected by impacts.

The red line shows the impact of an acute stressor (coral bleaching) on coral cover.

The green line shows the impact of another chronic stressor (reduced growth rate) on coral cover.

The blue line shows the additive combined effect on coral cover.



Republish in presentation/slides via Copyright Clearance Center.

Reference

Bozec, Y., & Mumby, P. (2014). Synergistic impacts of global warming on the resilience of coral reefs. *Philosophical Transactions Of The Royal Society B: Biological Sciences*, *370*(1659), 20130267-20130267. doi: 10.1098/rstb.2013.0267
https://royalsocietypublishing.org/doi/full/10.1098/rstb.2013.0267

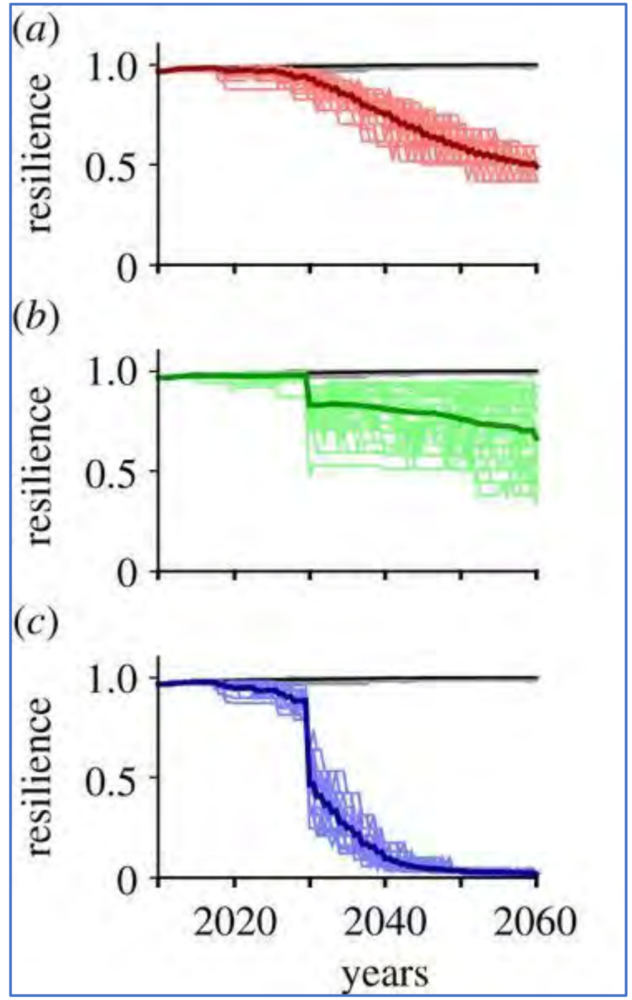
Acute and chronic stressors have a greater impact of reef resilience.

The grey lines acts as a control, reflecting the level of ecological resilience of a reef.

The red line shows the impact of an acute stressor (coral bleaching) on resilience.

The green line shows the impact of a chronic stressors (reduced growth rate) on resilience.

The blue line shows the combined synergistic effect on resilience.



Reference

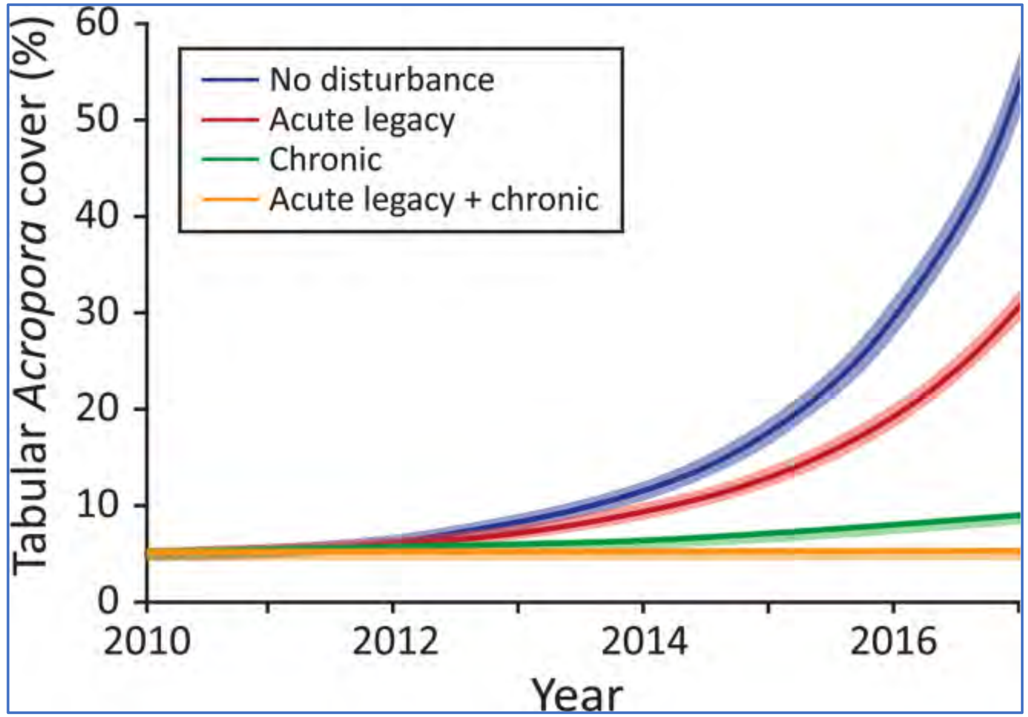
Bozec, Y., & Mumby, P. (2014). Synergistic impacts of global warming on the resilience of coral reefs. *Philosophical Transactions Of The Royal Society B: Biological Sciences*, *370*(1659), 20130267-20130267. doi: 10.1098/rstb.2013.0267

https://royalsocietypublishing.org/doi/full/10.1098/rstb.2013.0267

This graph is from a statistical model, based on observed data of Acropora cover at Penrith Reef, in the southern sector of the Great Barrier Reef.

It shows the individual impacts of:

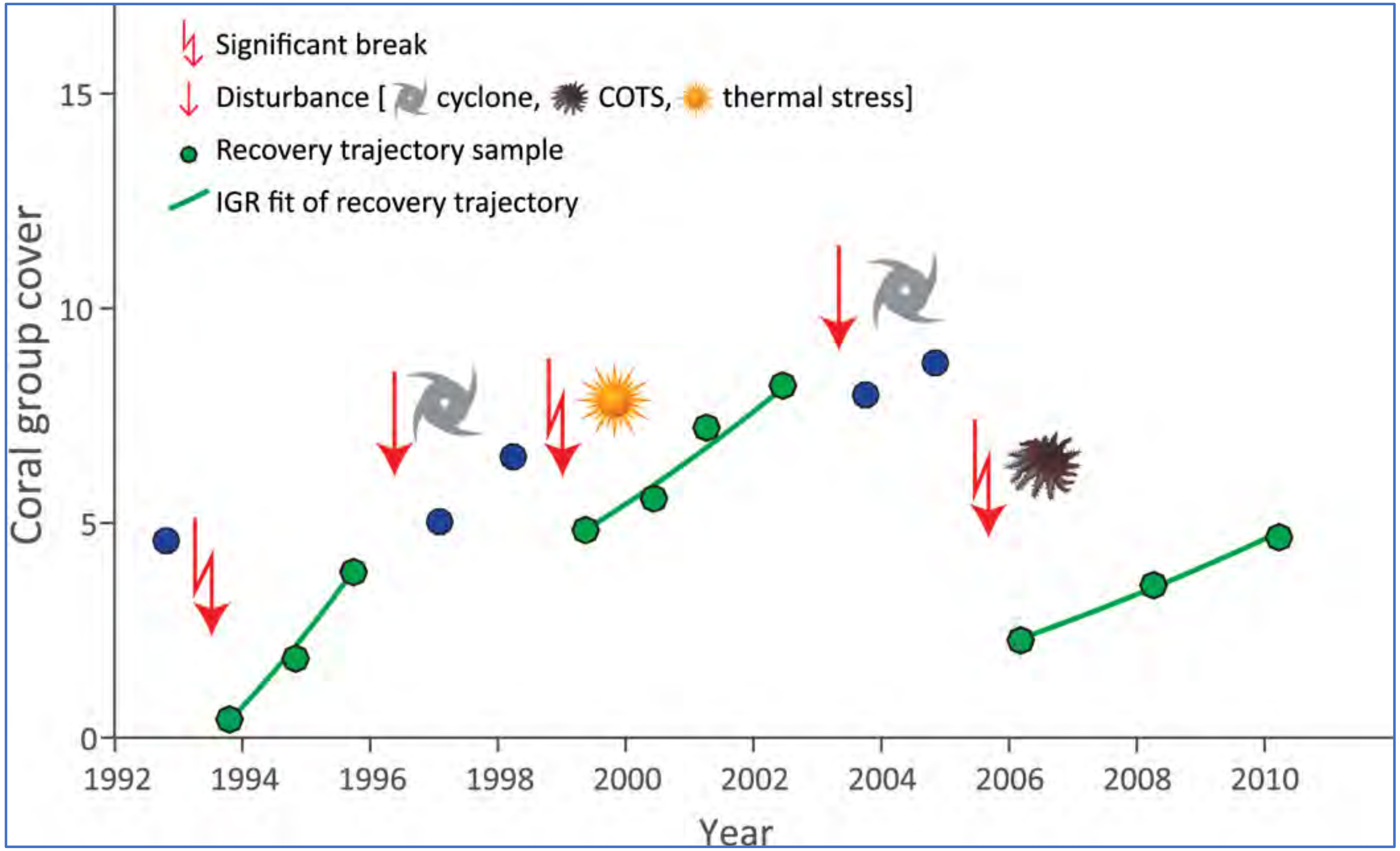
- no disturbance;
- acute disturbances (such as cyclones, CoTS outbreaks and bleaching);
- chronic pressures (water quality, warming); and
- the combined effects of acute and chronic disturbances.



Reference and Image: Ortiz, J., Wolff, N., Anthony, K., Devlin, M., Lewis, S., & Mumby, P. (2018). Impaired recovery of the Great Barrier Reef under cumulative stress. *Science Advances*, *4*(7), eaar6127. doi: 10.1126/sciadv.aar6127, CC BY-NC

Ortiz *et al* analysed coral cover change on the Great Barrier reef attributed to cyclones, CoTS outbreaks and bleaching.

They determined that reductions in recovery rates are (probably) due to cumulative effects of stressors on coral recruitment, growth and partial mortality.



Reference and Image: Ortiz, J., Wolff, N., Anthony, K., Devlin, M., Lewis, S., & Mumby, P. (2018). Impaired recovery of the Great Barrier Reef under cumulative stress. *Science Advances*, *4*(7), eaar6127. doi: 10.1126/sciadv.aar6127, CC BY-NC

Ortiz *et al* proposed that coral recruitment may be reduced on the GBR, by the following combination of factors:

The widespread loss of adult corals on the GBR, will potentially reduce recruitment rates.

Less adult corals are alive- so there are fewer available to spawn

Recruitment might also decline in response to sublethal effects of thermal stress, which can reduce fecundity for several years.

The corals that are alive are stressed and not in breeding condition.

Nutrient and sediment enrichment of coastal waters can impede coral larval settlement and recruitment because of interactions with benthic algae and sediment

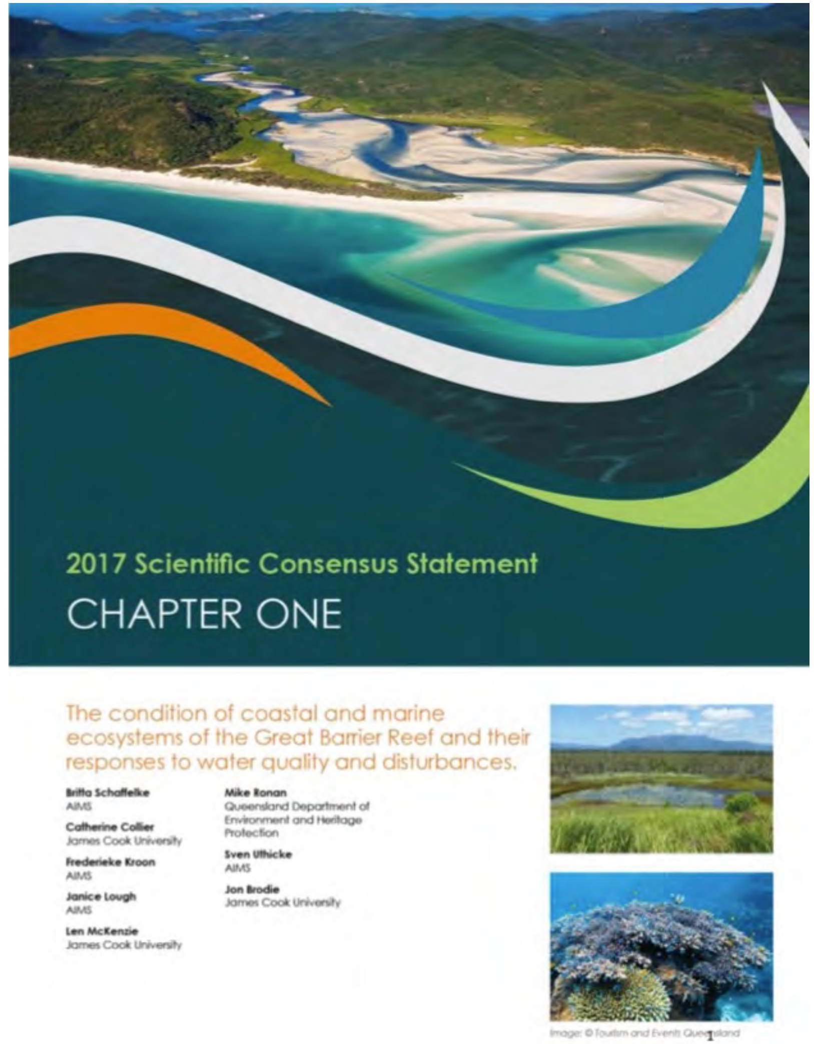
Any larvae that are successfully created are less likely to settle and survive.

Reference:

Ortiz, J., Wolff, N., Anthony, K., Devlin, M., Lewis, S., & Mumby, P. (2018). Impaired recovery of the Great Barrier Reef under cumulative stress. *Science Advances*, *4*(7), eaar6127. doi: 10.1126/sciadv.aar6127, CC BY-NC

“The cumulative impacts of global pressures, in concert with local disturbances (e.g. tropical cyclones) and local anthropogenic pressures such as land run-off, are likely to reduce the resilience of Great Barrier Reef costal and marine ecosystems.”

Download the 2017 scientific consensus statement here:
https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0030/45993/2017-scientific-consensus-statement-summary-chap01.pdf


2017 Scientific Consensus Statement

CHAPTER ONE

The condition of coastal and marine ecosystems of the Great Barrier Reef and their responses to water quality and disturbances.

Britta Schaffelke
AIMS

Catherine Collier
James Cook University

Frederieke Kroon
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Janice Lough
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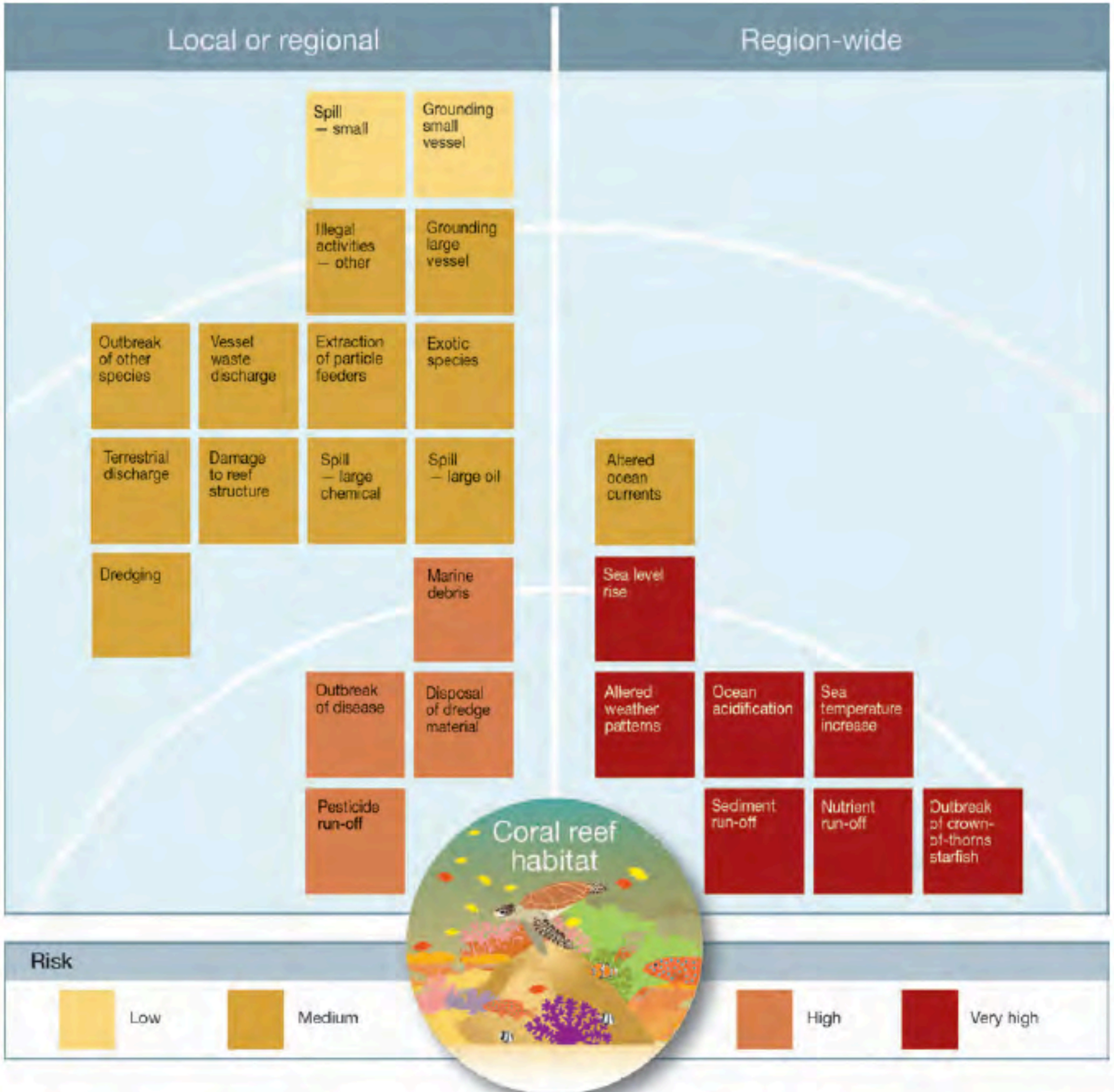
Len McKenzie
James Cook University

Mike Ronan
Queensland Department of Environment and Heritage Protection

Sven Uthicke
AIMS

Jon Brodie
James Cook University

Direct Quote, page 45, Schaffelke, B., Collier, C., Kroon, F., Lough, J., McKenzie, L., Ronan, M., Uthicke, S., Brodie, J., 2017. Scientific Consensus Statement 2017. Scientific Consensus Statement 2017: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 1: The condition of coastal and marine ecosystems of the Great Barrier Reef and their responses to water quality and disturbances. State of Queensland, 2017.



The combination of many threats increases the overall risk to the coral reef habitat.

Image: Great Barrier Reef Marine Park Authority 2014, Great Barrier Reef Outlook Report 2014, GBRMPA, Townsville. CCBY3.0

This figure shows how multiple threats to the Great barrier Reef can overlap and interact to present a serious cumulative risk to local habitats and species.

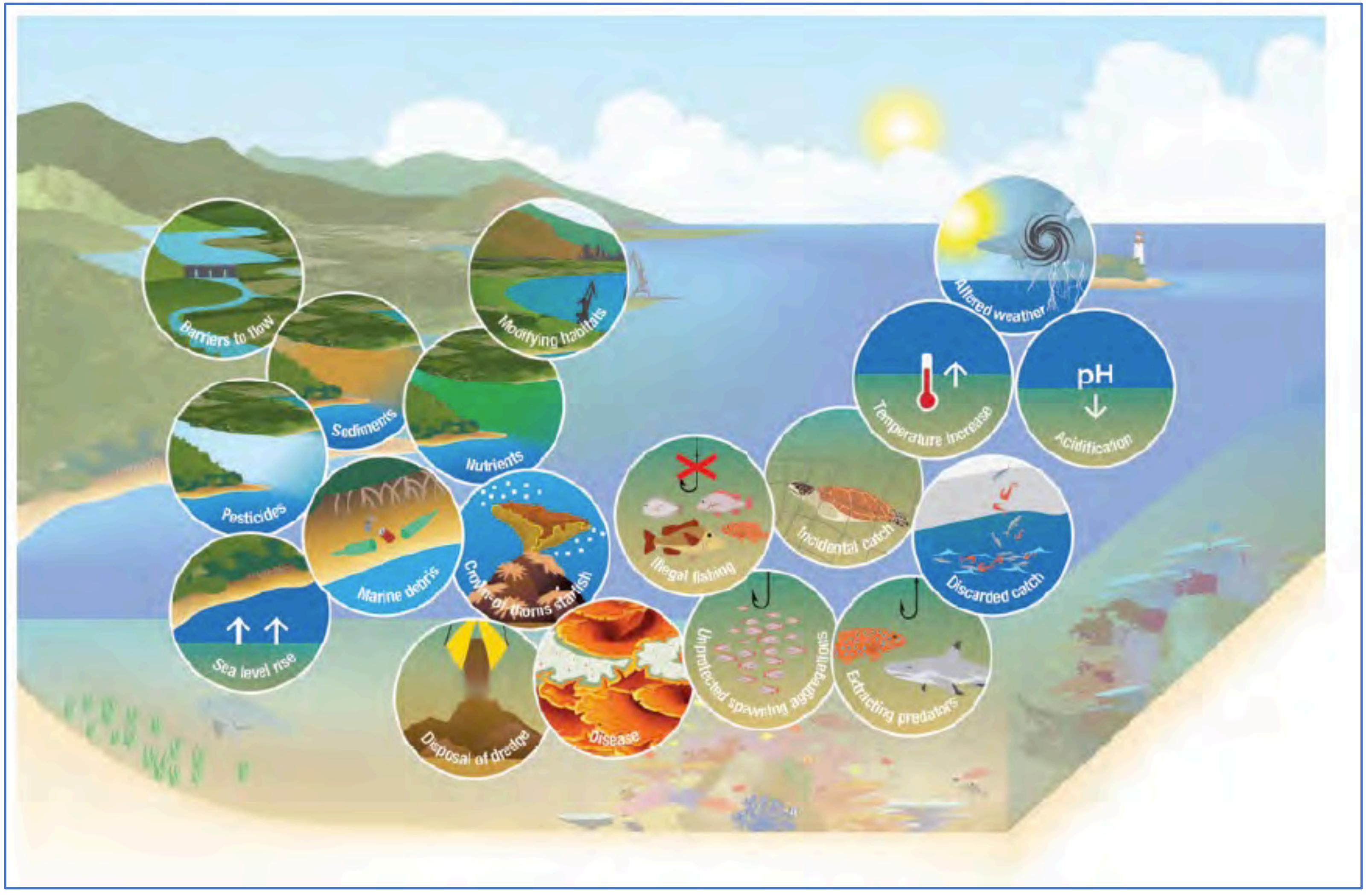
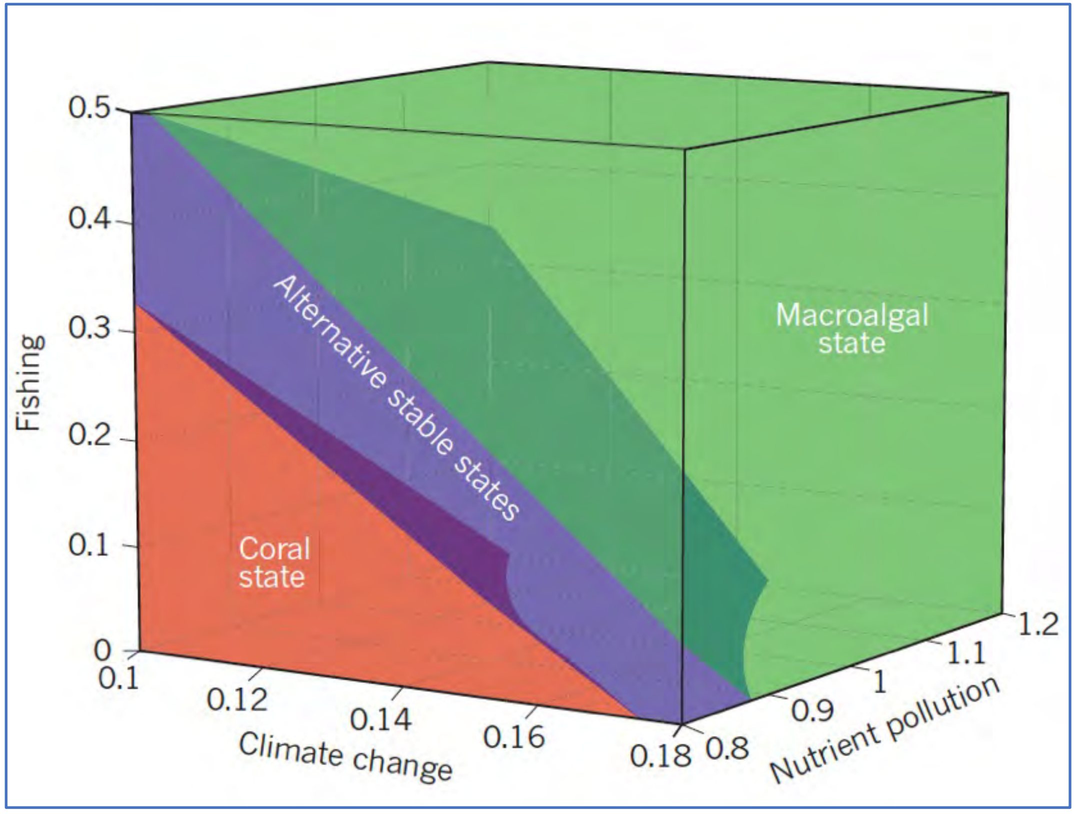


Image: Great Barrier Reef Marine Park Authority 2014, Great Barrier Reef Outlook Report 2014, GBRMPA, Townsville. CCBY3.0

This 3D model shows the response of coral reefs to multiple anthropogenic drivers.

Depending on the strength and interaction between climate change, nutrient pollution and fishing, three outcomes are possible: healthy coral-dominated reefs (red); macroalgal state (green); alternative states (purple).

The coral state collapses if the stress from any single driver is too strong and is eliminated entirely by the cumulative impacts of multiple drivers.



Reference and image:

Hughes, T., Barnes, M., Bellwood, D., Cinner, J., Cumming, G., & Jackson, J. et al. (2017). Coral reefs in the Anthropocene. *Nature*, *546*(7656), 82-90. doi: 10.1038/nature22901

Here is an example of a combination of processes impacting the GBR:

- A slight increase in sea surface temperature stresses coral towards the extremes of tolerance levels.
- This, by itself is survivable: corals can and do recover from bleaching events.
- The concentration of aragonite, required for building a coral skeleton, is also reduced (by decreasing ocean pH), so growth of corals is reduced.
- Increased erosion exceeds net accretion, and coral reef ecosystems may lose their habitat complexity.
- Less complex (rugose) habitats offer less shelter for many species, reducing biodiversity- and housing fewer herbivores.
- A reduced population of herbivores decreases the resilience of a coral reef ecosystem, decreasing the chances of recovery from occasional pulse events.

- The frequency and severity of pulse events seems to be increasing- so there is insufficient recovery time for many coral reef ecosystems.
- Hysteresis means that the reduction or removal of drivers may not lead to a commensurate improvement in ecosystem state- and the coral reef ecosystem may undergo a phase shift to an algal-dominated system.
- Declines in water quality caused by land use, contribute to disease, sedimentation, excess nutrients and may increase CoTS outbreaks.
- By using more energy on calcification, corals have less resources available for recovery and reproduction, which limits the supply of larval recruits.

Questions

1. Explain the effect of a combination of processes operating together.

2. Create a flow chart to explain how a series of processes can impact on a coral reef.

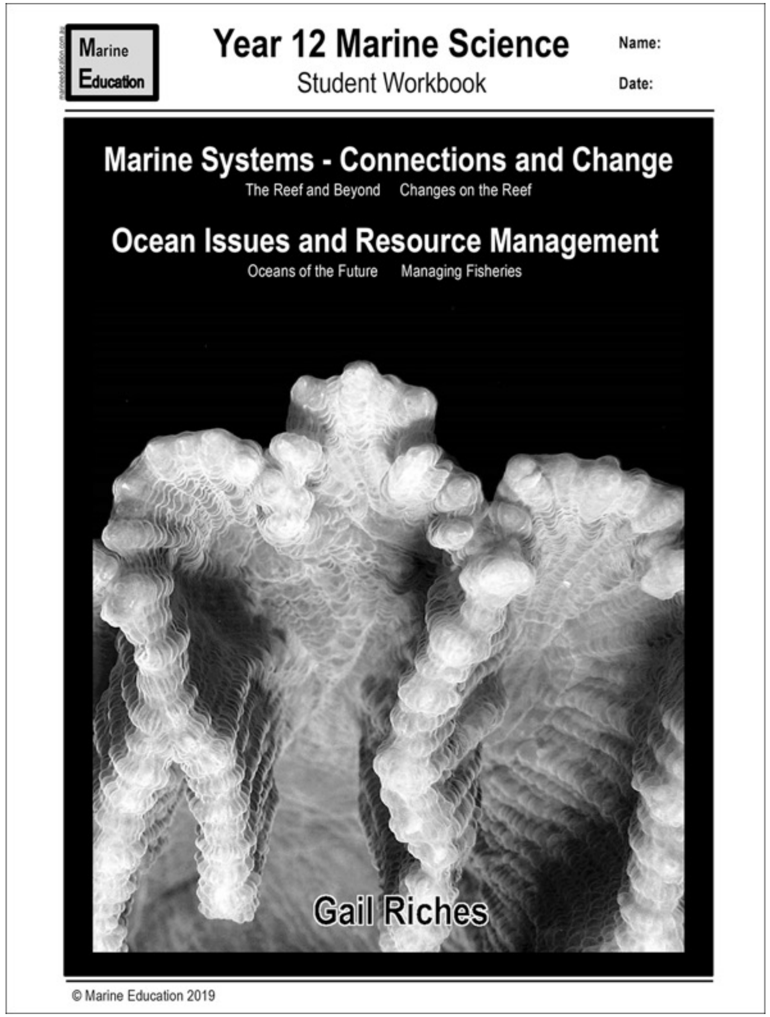
Worksheet

Water Quality Woes

by

Gail Riches

www.marineeducation.com.au



T098 Conduct connectivity experiment

Adam Richmond

Syllabus statement

At the end of this topic you should be able to ...

Examine

the concept of connectivity in a habitat by investigating the impact of water quality on reef health.

Examine (investigate)

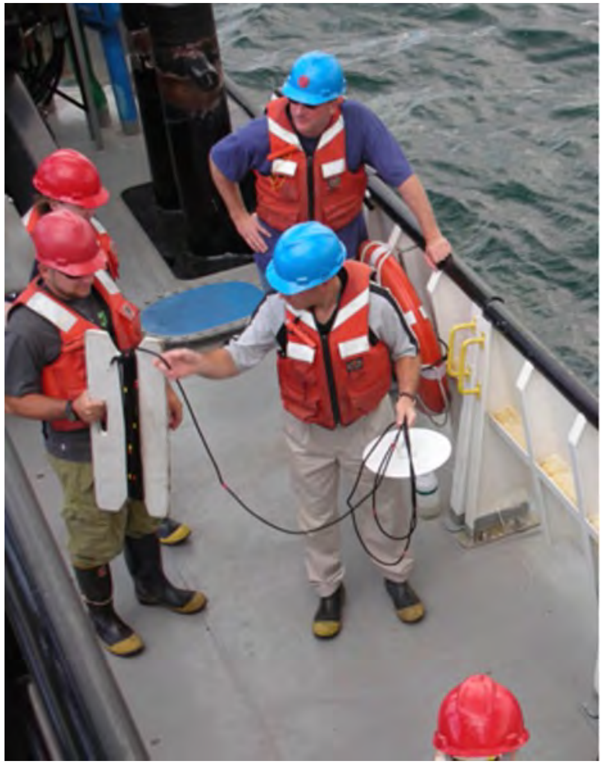
- investigate, inspect or scrutinise;
- inquire or search into;
- consider or discuss an argument or concept in a way that uncovers the assumptions and interrelationships of the issue

Objective

Conduct an investigation into the impact of water quality on reef health.

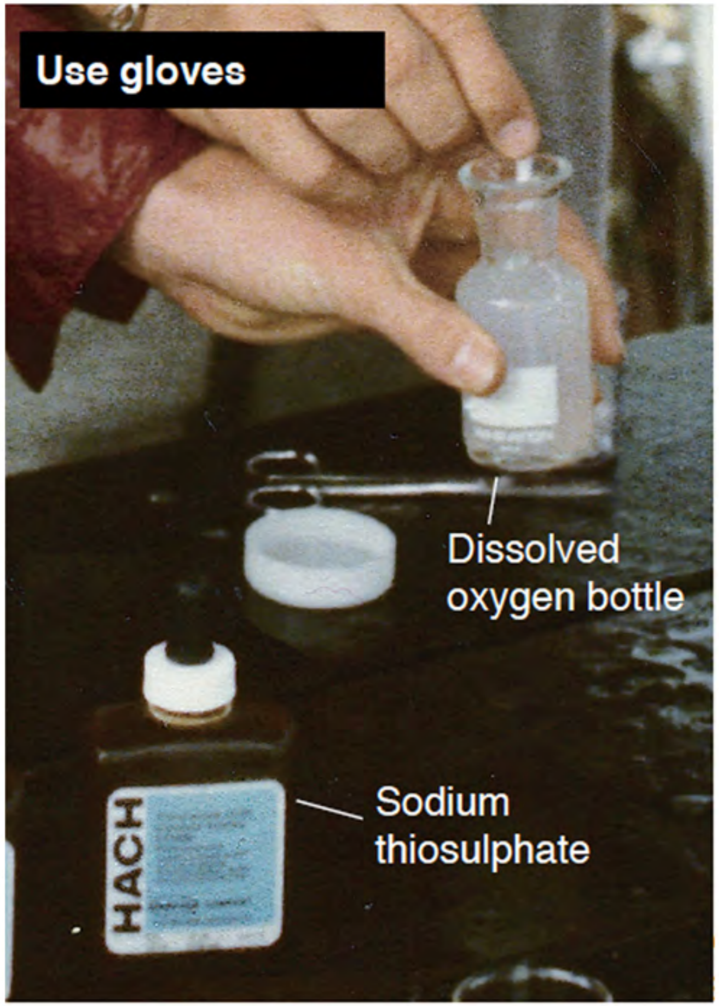
Your investigation will need some reliable data on water quality and reef health.

This presentation contains links to some sources of secondary data as well an excellent workbook mandatory practical.



By U.S. Environmental Protection Agency, Chicago, IL - "Great Lakes Monitoring: Sampling Equipment", Public Domain, https://commons.wikimedia.org/w/index.php?curid=15165068

You may get to do some water quality experiments yourself.



However the syllabus focusses on the reef and correct analysis relies on data sets.

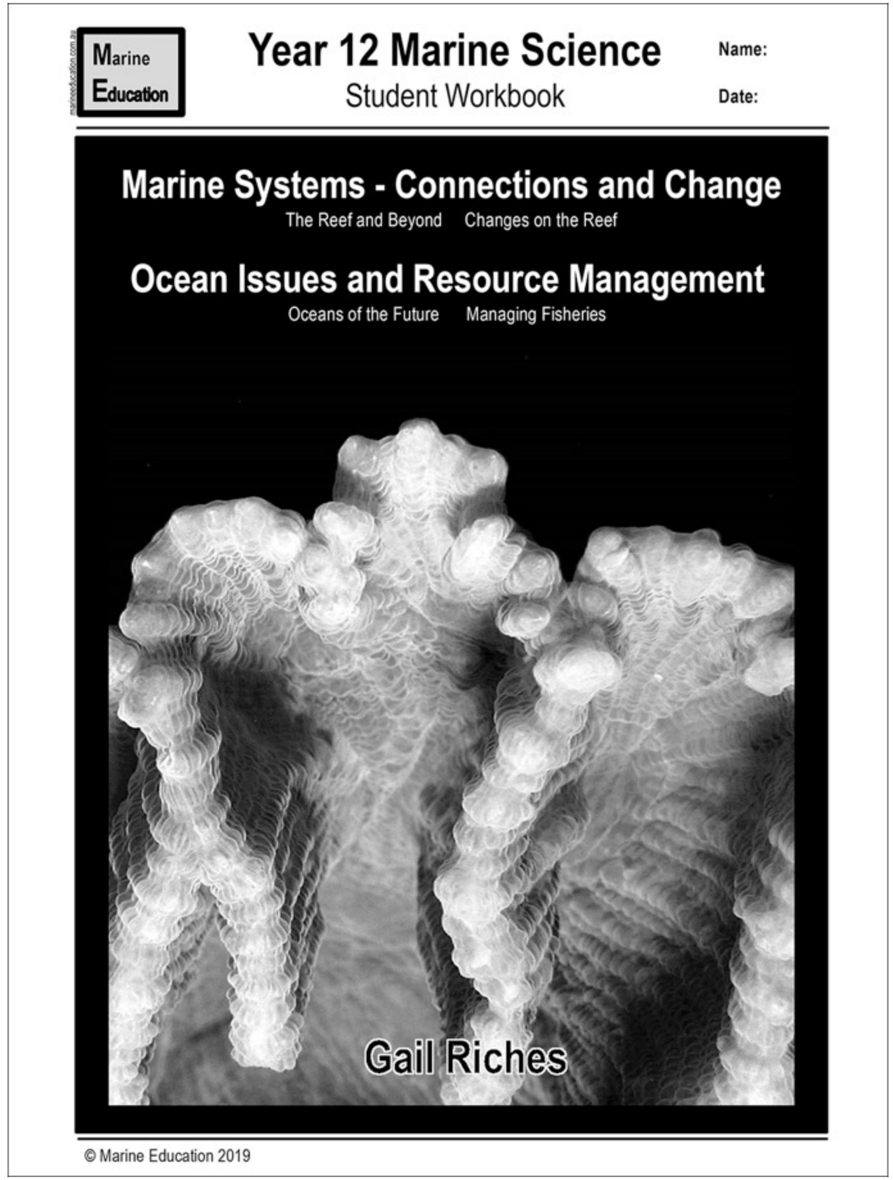
A syllabus mandatory practical using reef data sets can be found at

Marine Education Worksheets

www.marineeducation.com.au

The workbook can be purchased from

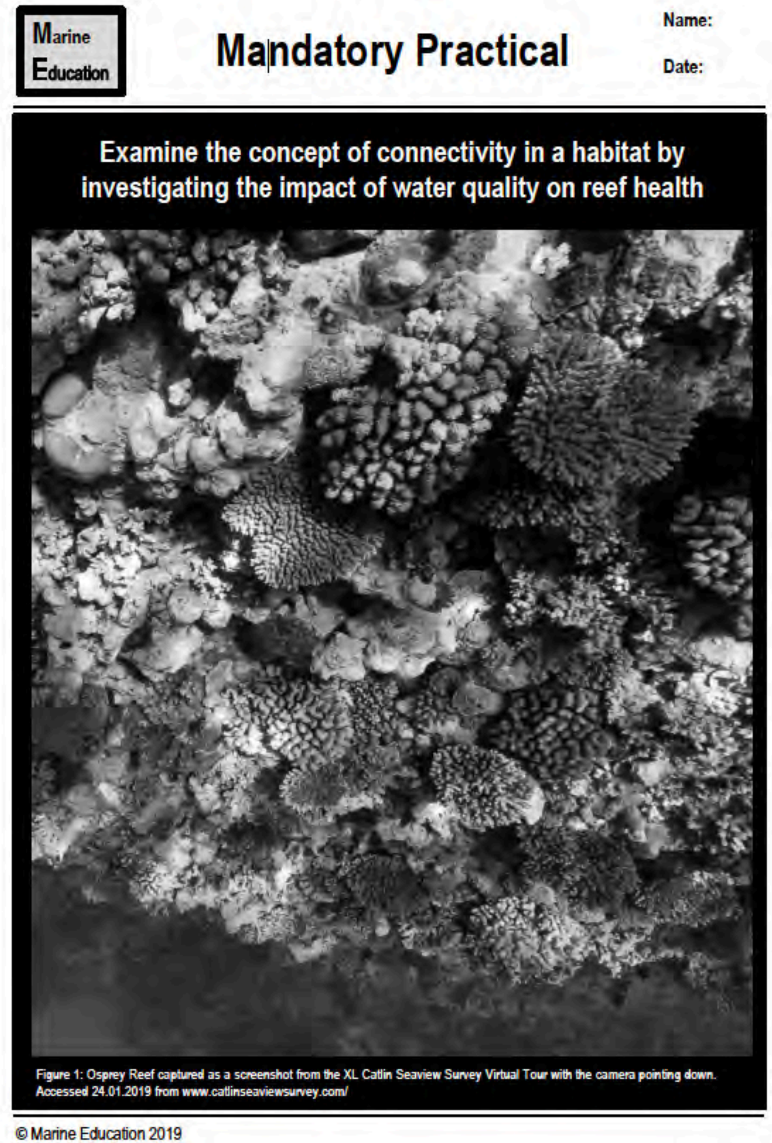
www.marineeducation.com.au



In the workbook practical, photographic transect data and reef ratings are used to examine the concept of connectivity in a habitat by investigating the impact of water quality on reef health.

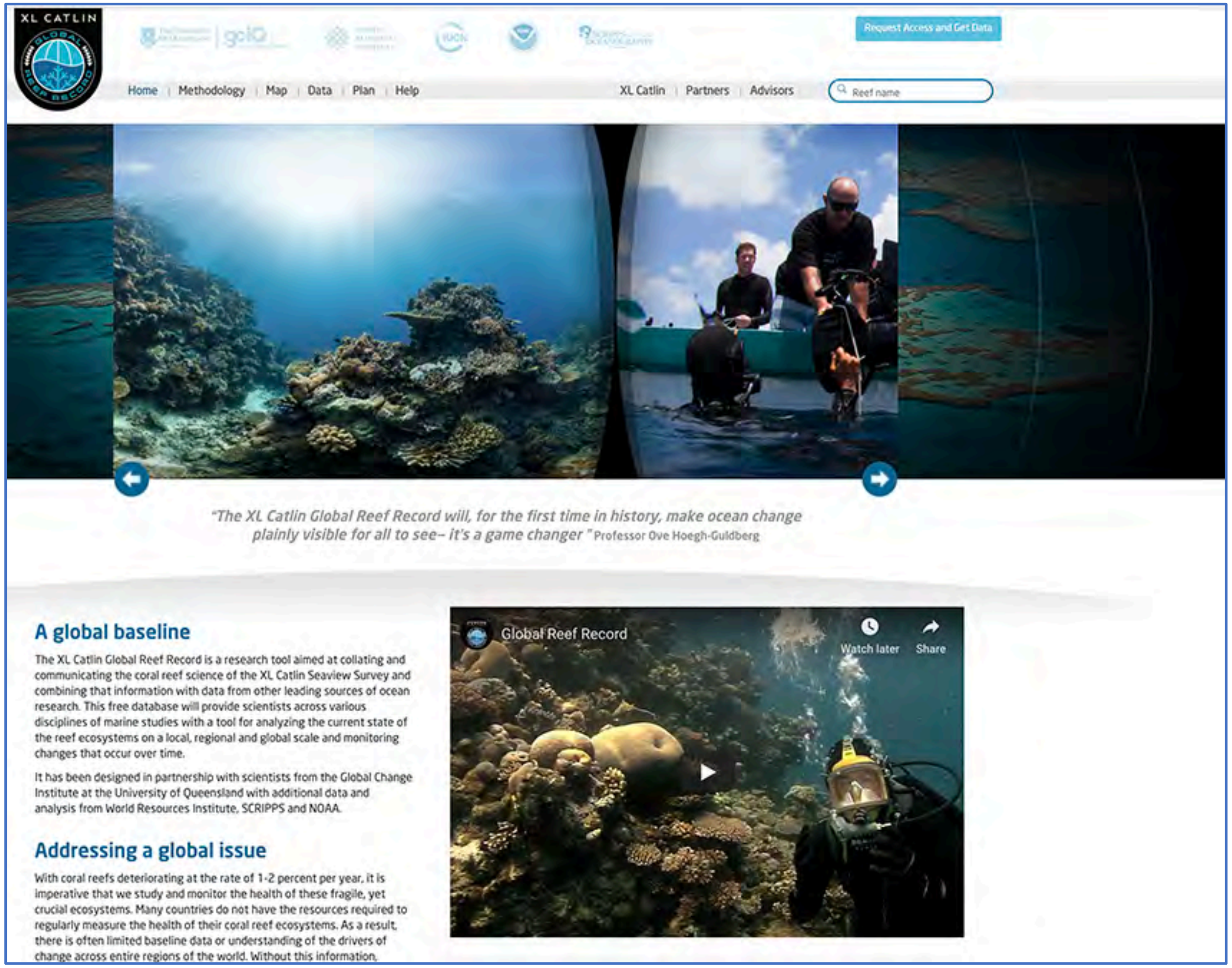
In this practical photographic images from the following reefs are used as sources for data analysis.

a. Agincourt Reef (via Cairns)
b. Lady Elliot Island (via Bundaberg)
c. Magnetic Island (via Townsville)
D. Great Keppel Island (via Yeppoon)



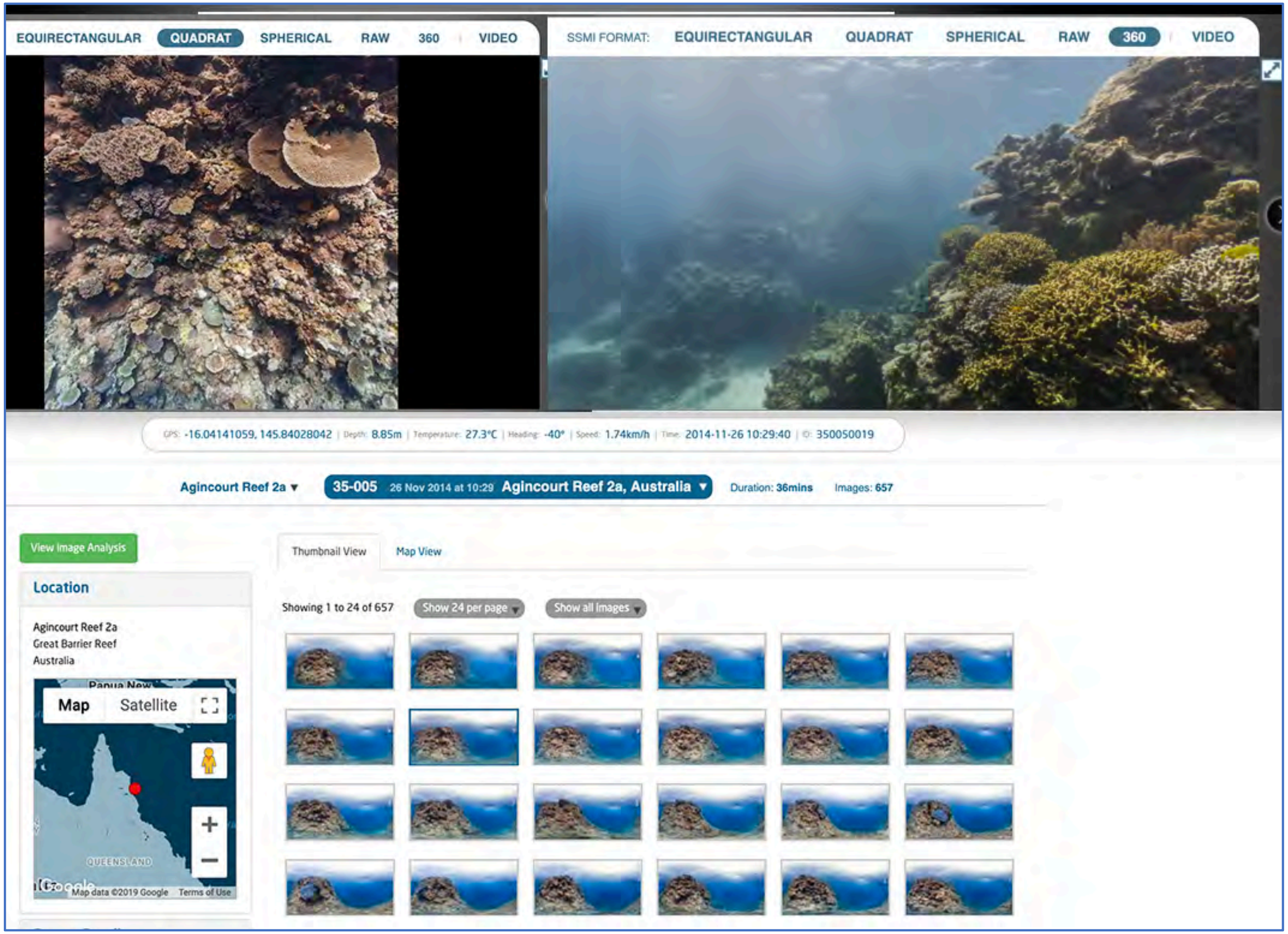
For example the Catlin global reef record survey data can be used to obtain reef transect data.

http://globalreefrecord.org/home_scientific



Underwater Earth Catlin Global Reef Record resources

For example – Argincourt Reef



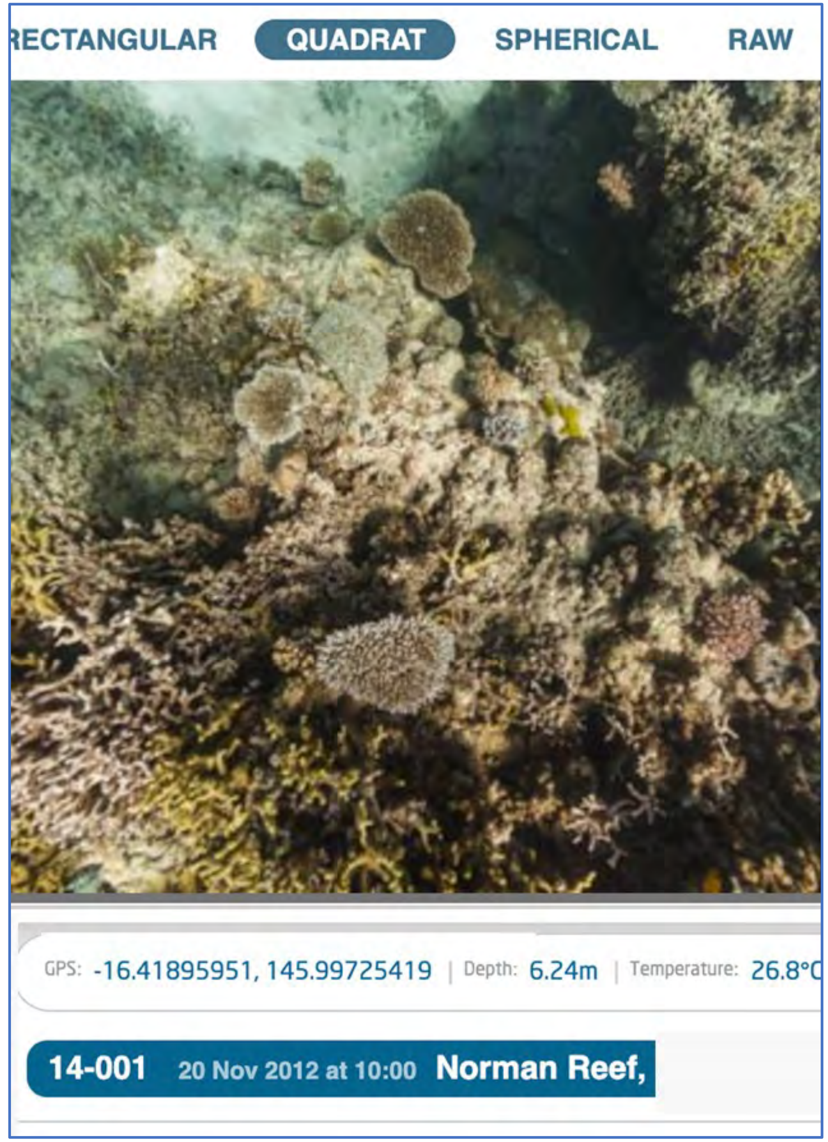
Marine education mandatory practical

www.marineeducation.com.au

"Examine the concept of connectivity in a habitat by investigating the impact of water quality on reef health."

The workbook has student activities in

- Making observations
- Gathering of information
- Research questions
- Experimental design
- Data collection examplar
- Data collection from the 4 reefs
- Data analysis
- Interpretation and evaluation



Other sources of data are

Other data sets can be found at

AIMS

CoralWatch

Reef 2050 Water Quality Improvement Plan

Wet Tropics partnership

Healthy waterways

AIMS

The Australian Institute of Marine Science Data Centre, , AIMS has lots of data available.

For example, you can find the water temperature at Heron Island here: http://data.aims.gov.au/aimsrtds/datatool.xhtml?from=1980-01-01&thru=2019-04-11&period=MONTH&aggregations=AVG&channels=1843

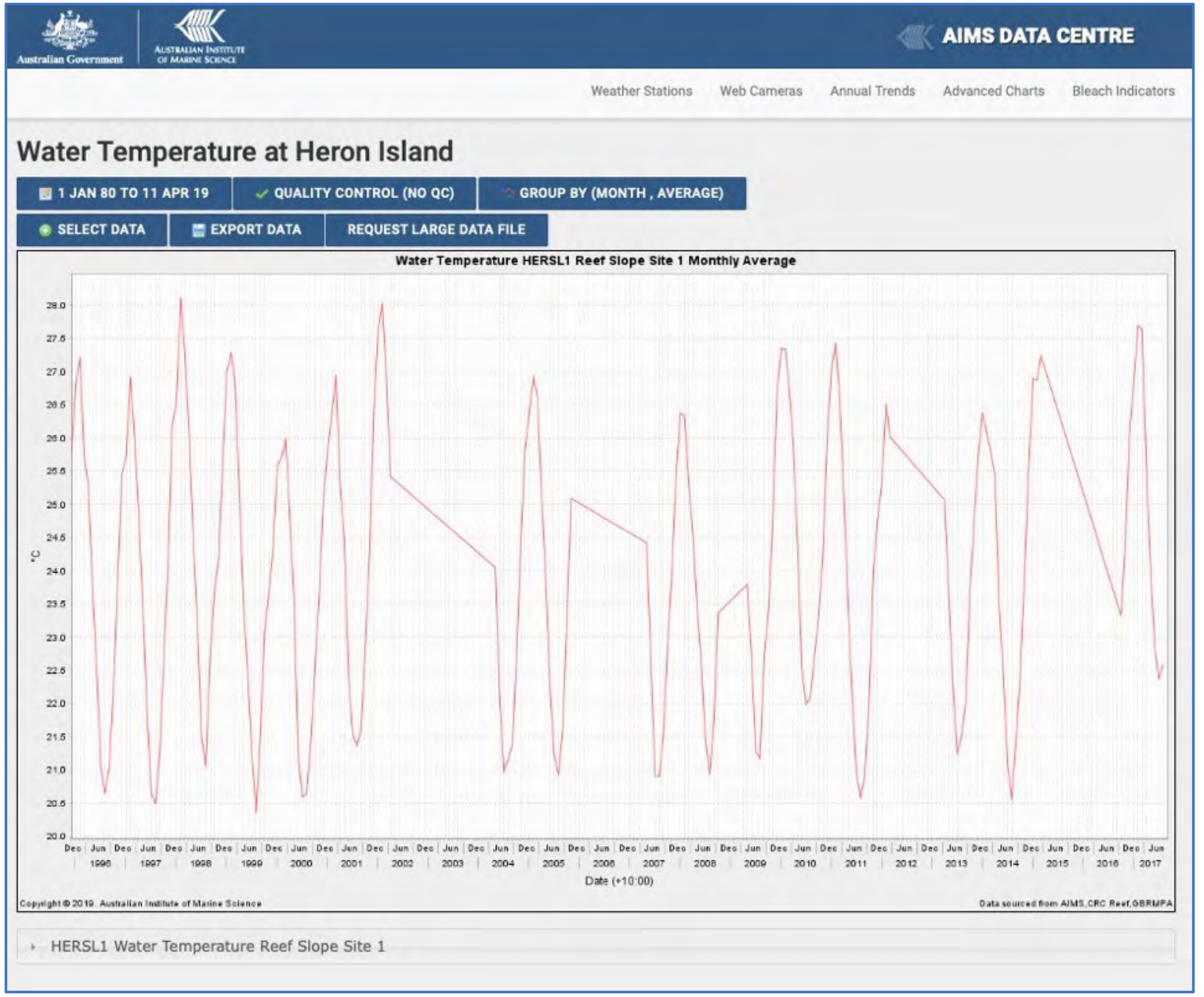
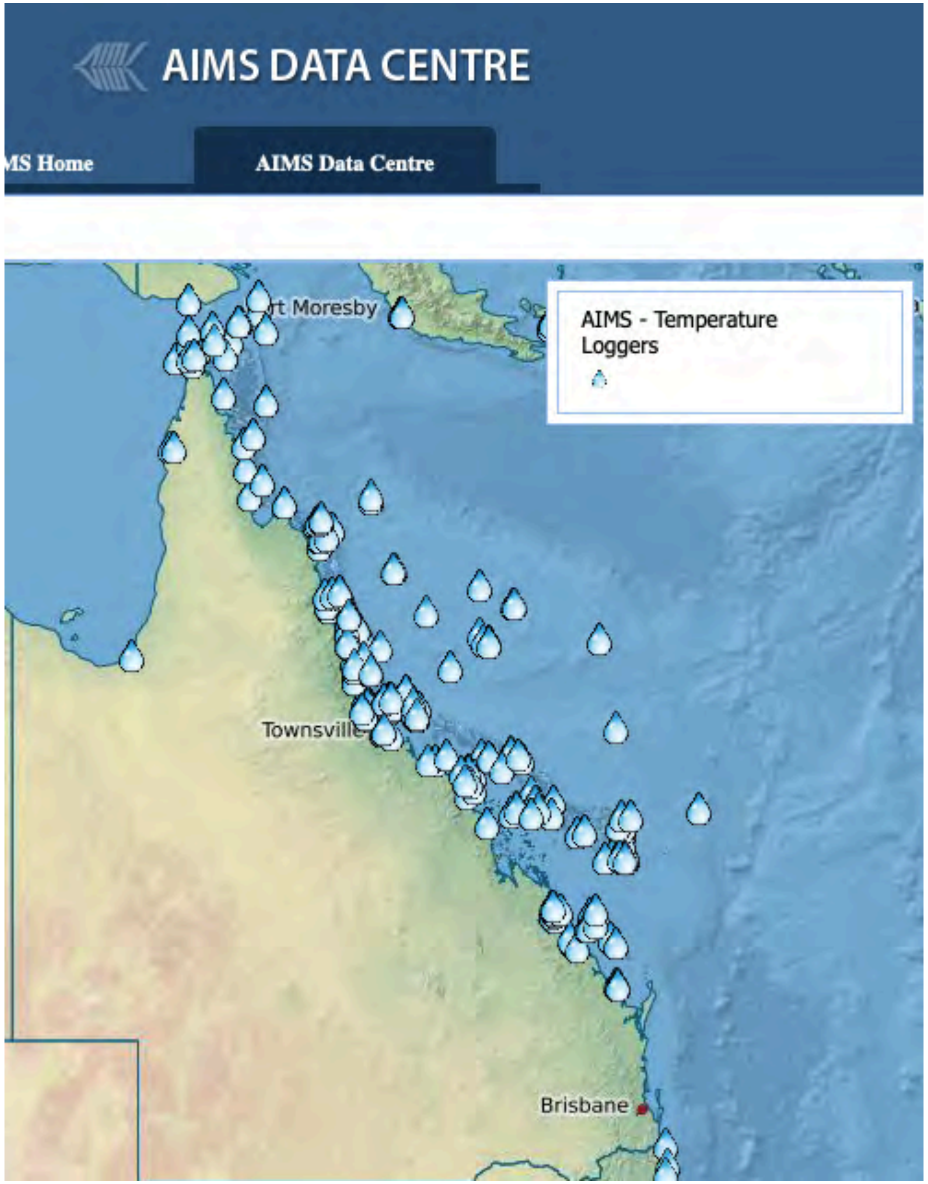


Image copyright Australian Institute of Marine Science, Reproduced with permission.

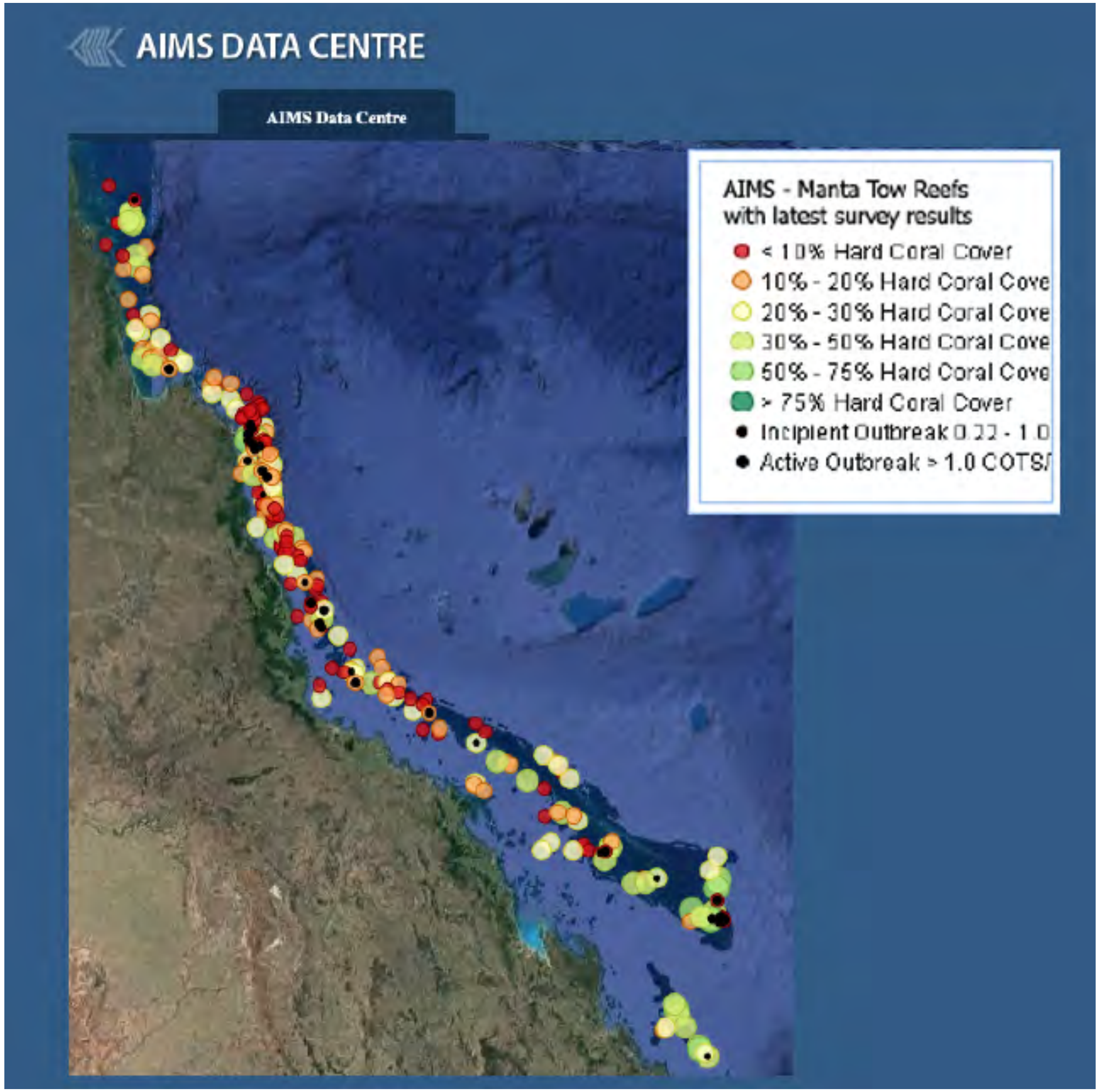
Water temperature data can be accessed for any of these locations.



Aims web link

http://maps.aims.gov.au/index.html?intro=false&z=4&ll=142.91883,-17.51872&l0=aims_aims:AIMS%20-%20Temperature%20Loggers,ea_World_NE2-coast-cities-reefs_Baselayer

You can find the location of current and past COTS outbreaks here:



Aims web link

http://maps.aims.gov.au/index.html?intro=false&z=6&ll=147.72168,-17.66615&l0=aims_aims:MantaTowReefs,g_SATELLITE

Information about bleaching risk and water temperature is available here:

http://data.aims.gov.au/aimsrtds/coralbleaching.xhtml

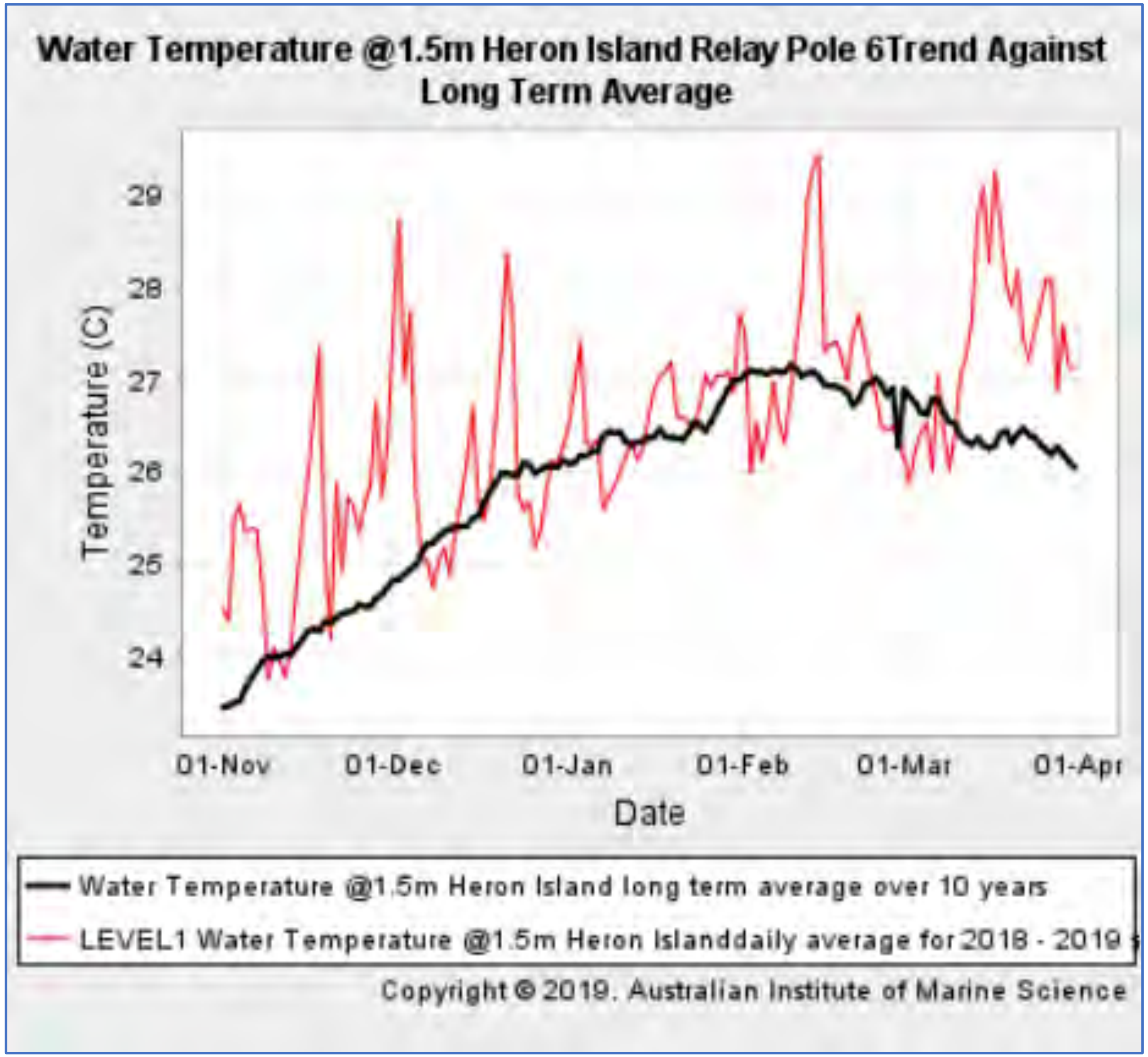


Image copyright Australian Institute of Marine Science, Reproduced with permission.

You can download the latest survey report from the Long term monitoring program here:

https://www.aims.gov.au/docs/research/monitoring/reef/latest-surveys.html#Annual%20summary%20reports

This is only a section of the summary for the Cairns sector in 2018.

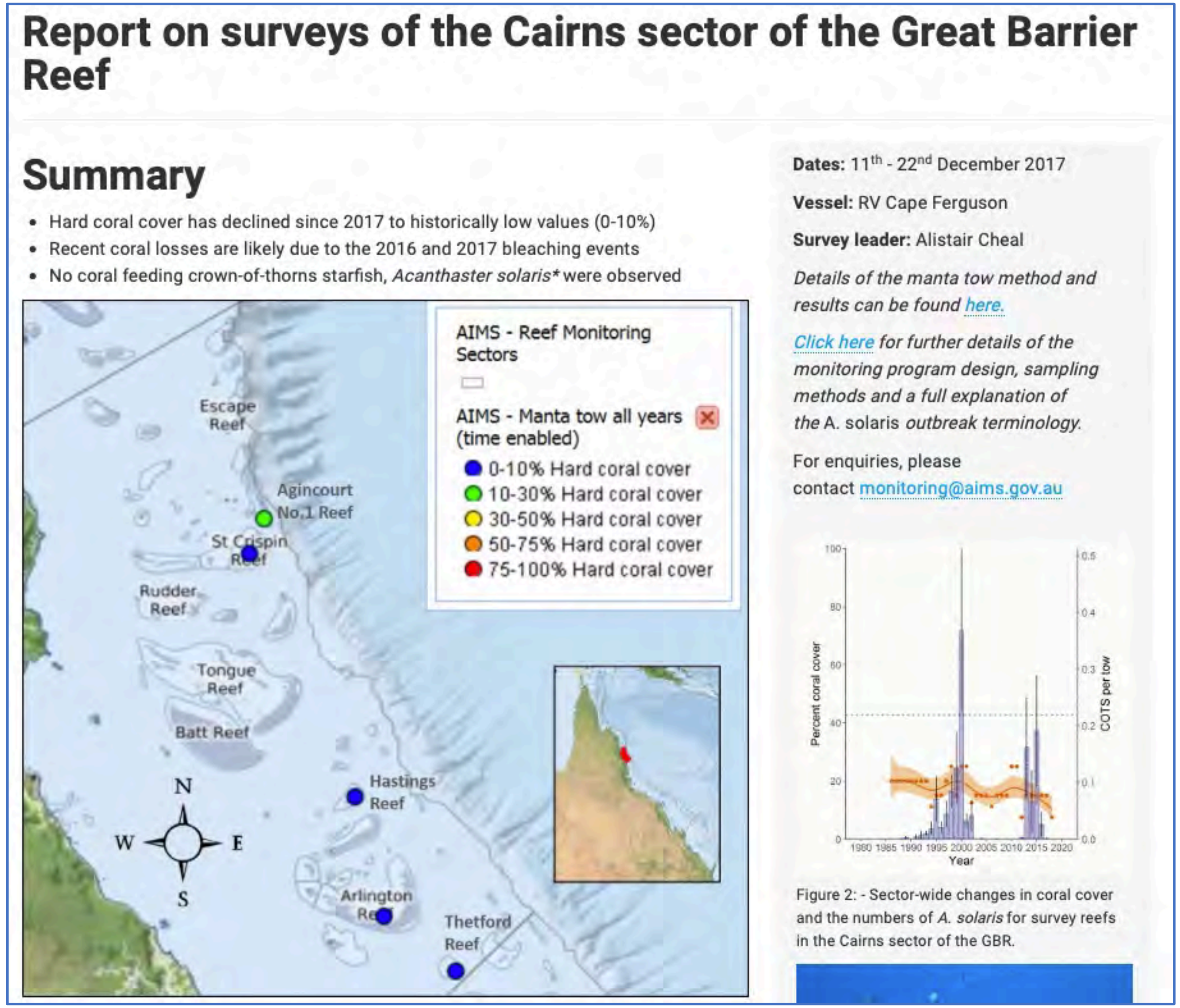
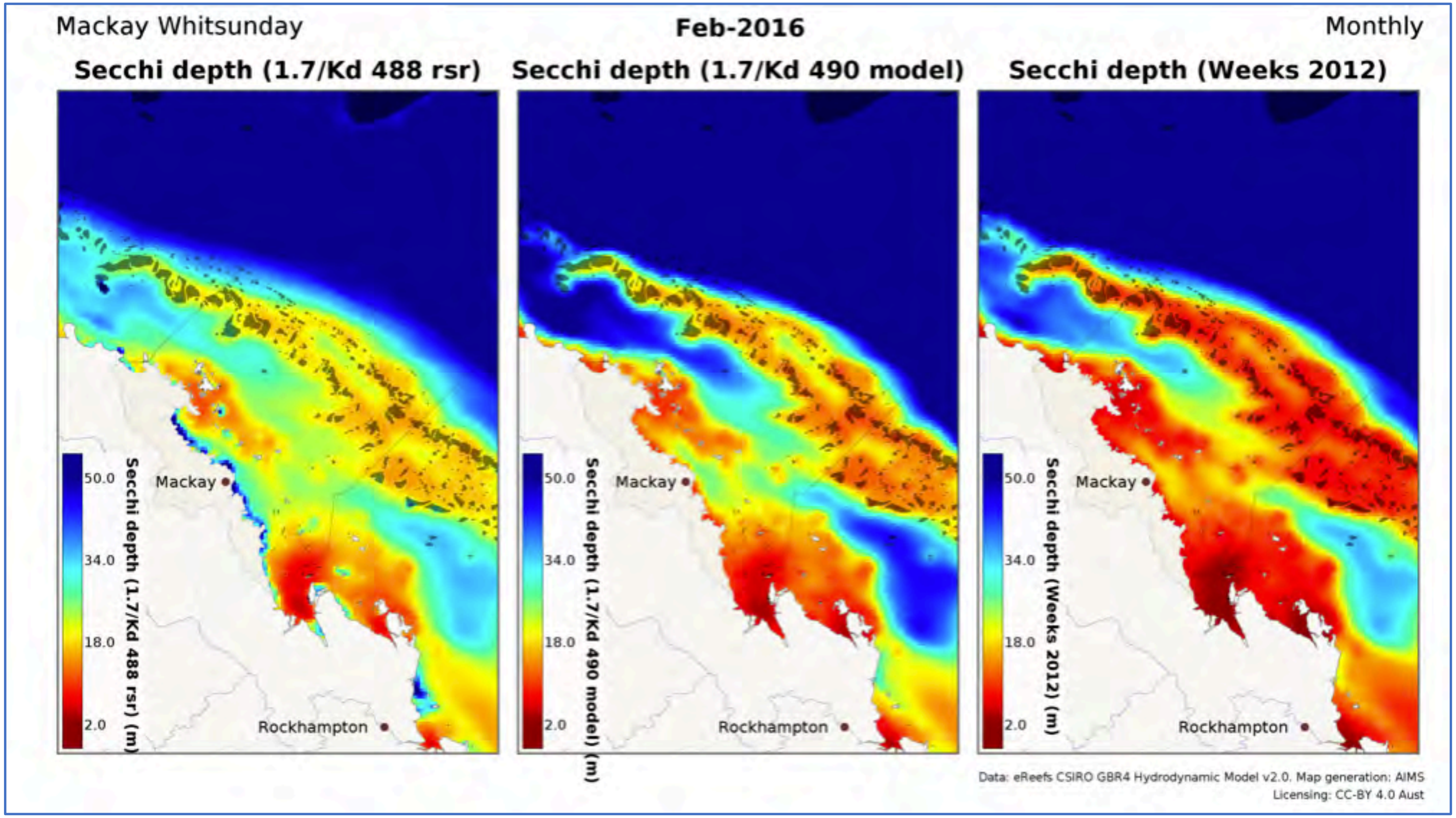


Image: Australian Institute of Marine Science. CCBY. Available: https://www.aims.gov.au/reef-monitoring/cairns-sector-2018

AIMS e-Reefs

The AIMS eReefs Visualisation Portal lets you see current environmental conditions on the Great Barrier Reef and what has happened in the past.



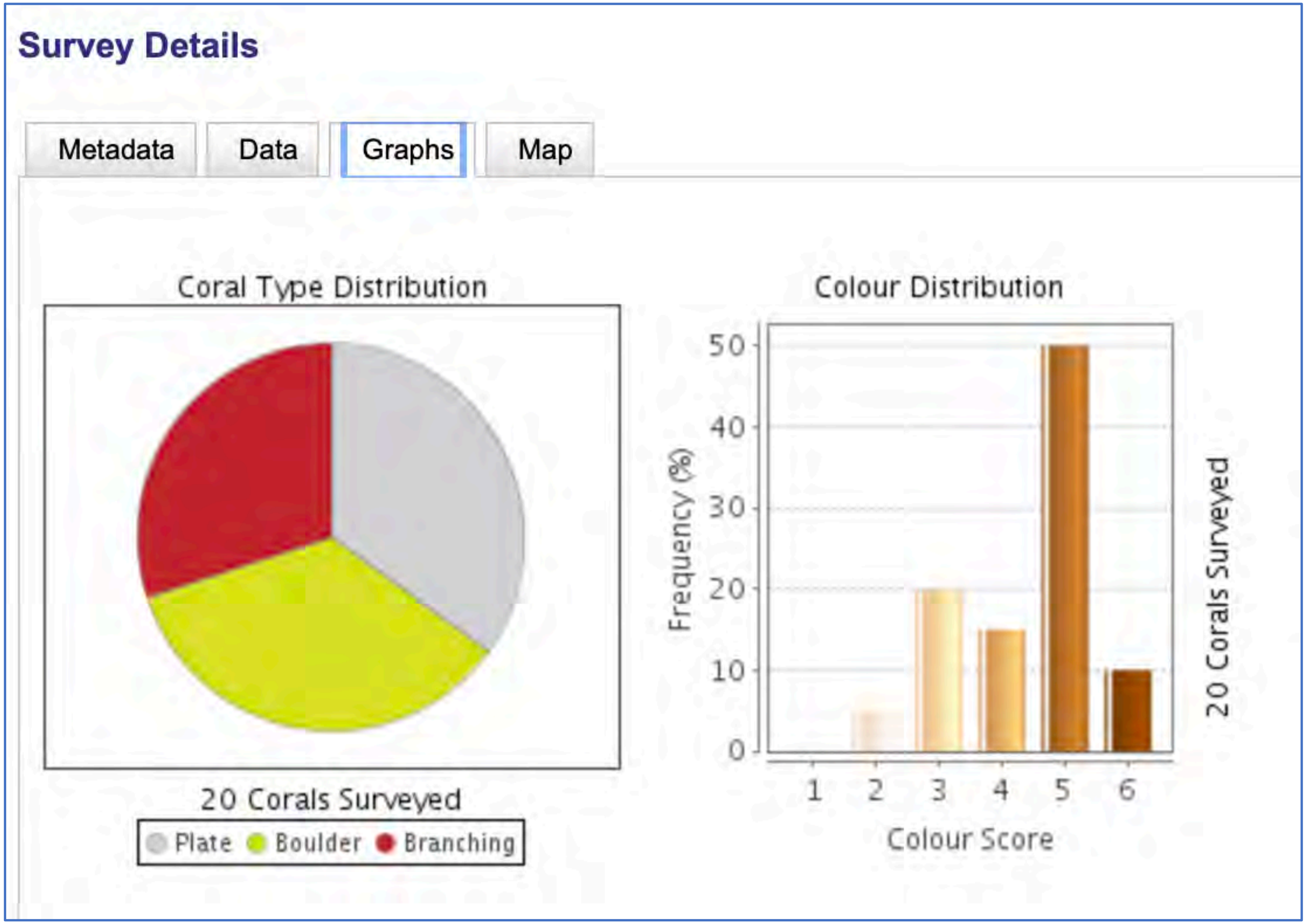
Secchi depth in Mackay/ Whitsunday region in February 2016

Available: https://aims.ereefs.org.au/aims-ereefs/secchi-kd488_secchi-surf_secchi#frame=Monthly;region=mackay-whitsunday;year=2016;month=2 Licence CC BY 4.0 AUS

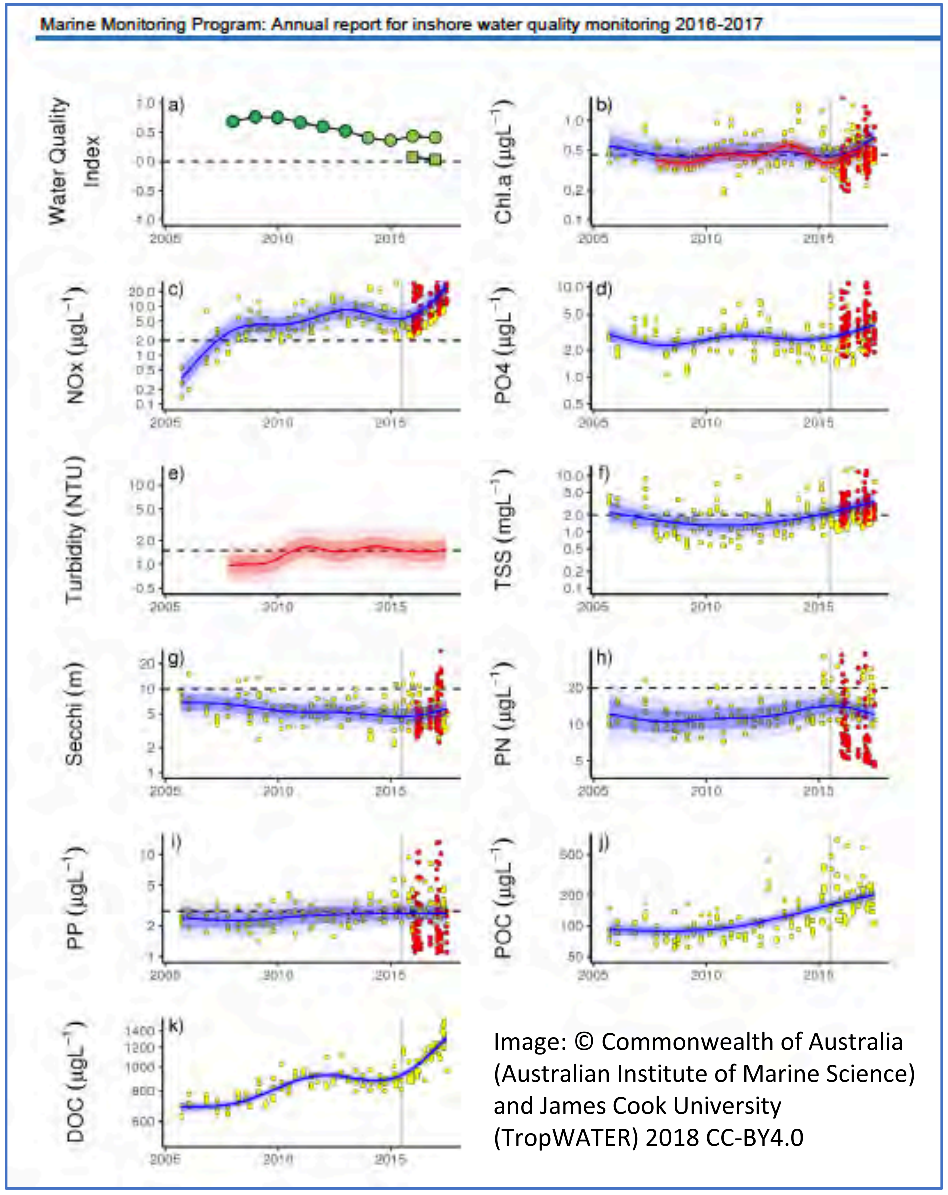
CoralWatch

This information can be compared with CoralWatch data. Search for your reef here:

https://coralwatch.org/index.php/data/



GBRMPA Marine Monitoring Program



The Annual Report for inshore water Quality monitoring can be downloaded here:
http://elibrary.gbrmpa.gov.au/jspui/browse?type=series&order=ASC&rpp=20&value=Marine+Monitoring+Program+-+Inshore+Water+Quality

The graphs to the left show water quality data for the Russell-Mulgrave sub-region in 2016-2017.

This was from page 89 of 318.

This a very comprehensive report!

NRM Regions

Natural Resource Management (NRM) regions have their own reports.

Region	Regional NRM organisation
Border Rivers Maranoa–Balonne	Queensland Murray Darling Committee
Burdekin	NQ Dry Tropics
Burnett Mary	Burnett Mary Regional Group
Cape York	Cape York Natural Resource Management
Condamine	Condamine Alliance
Desert Channels	Desert Channels Queensland
Fitzroy	Fitzroy Basin Association
Mackay Whitsunday	Reef Catchments
Northern Gulf	Northern Gulf Resource Management Group Ltd
South East Queensland	South East Queensland Catchments
Southern Gulf	Southern Gulf Catchments
South West Queensland	South West NRM Ltd
Torres Strait	Torres Strait Regional Authority
Wet Tropics	Terrain NRM

Most of these NRM regions will have their own Health Report cards:

Data sourced from

Reef 2050 Water Quality Improvement Plan

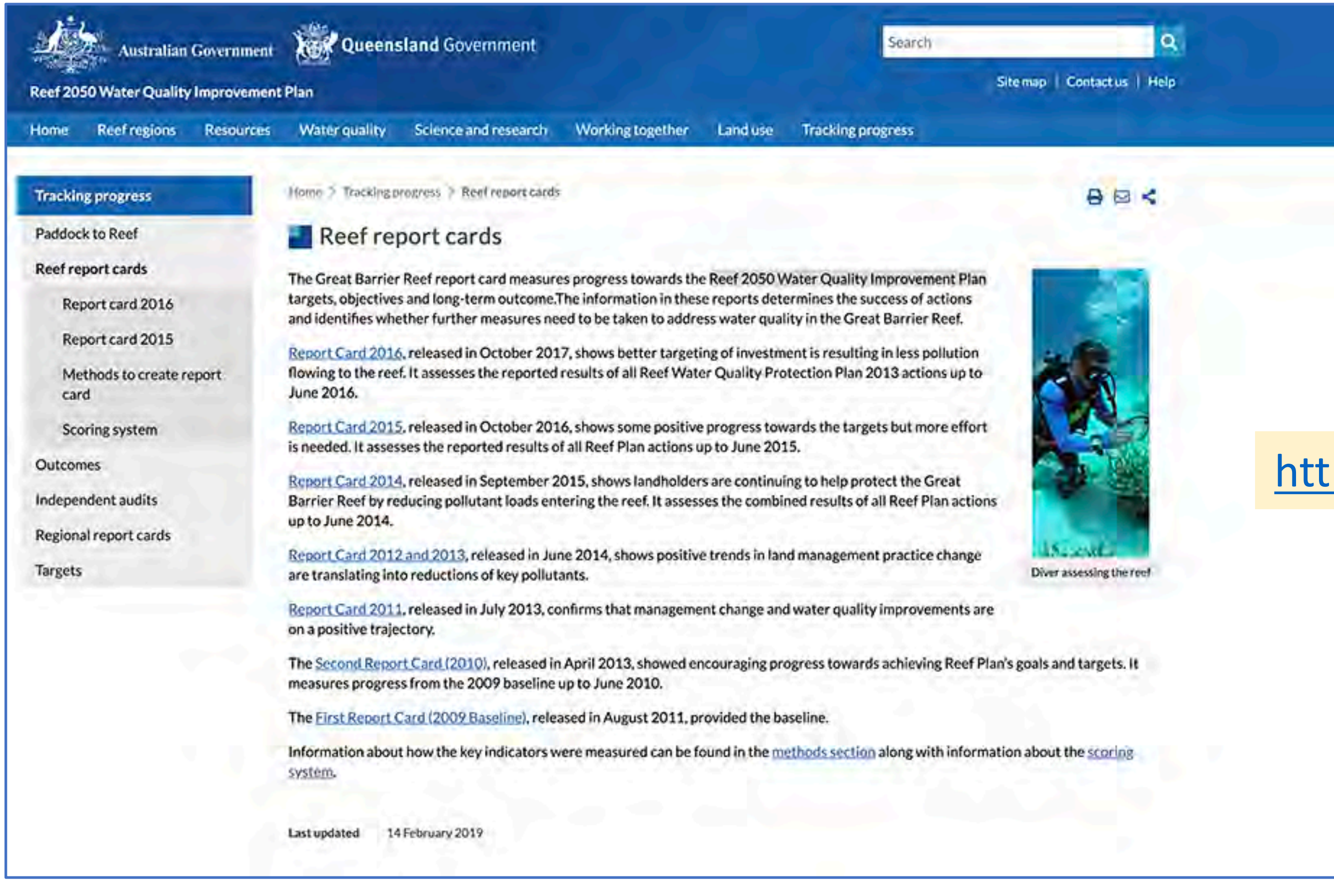
https://www.reefplan.qld.gov.au/tracking-progress/reef-report-card

Fitzroy Basin Ecosystem Health Report

Image: Screen shot from https://riverhealth.org.au/report_card/ehi/ CC BY 3.0

Wet Tropics Waterways partnership

https://wettropicswaterways.org.au


Australian Government | Queensland Government
Reef 2050 Water Quality Improvement Plan
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Home | Reef regions | Resources | Water quality | Science and research | Working together | Land use | Tracking progress

Tracking progress
- Paddock to Reef
- Reef report cards
  - Report card 2016
  - Report card 2015
  - Methods to create report card
  - Scoring system
- Outcomes
- Independent audits
- Regional report cards
- Targets

Home > Tracking progress > Reef report cards

Reef report cards

The Great Barrier Reef report card measures progress towards the Reef 2050 Water Quality Improvement Plan targets, objectives and long-term outcome.The information in these reports determines the success of actions and identifies whether further measures need to be taken to address water quality in the Great Barrier Reef.

Report Card 2016, released in October 2017, shows better targeting of investment is resulting in less pollution flowing to the reef. It assesses the reported results of all Reef Water Quality Protection Plan 2013 actions up to June 2016.

Report Card 2015, released in October 2016, shows some positive progress towards the targets but more effort is needed. It assesses the reported results of all Reef Plan actions up to June 2015.

Report Card 2014, released in September 2015, shows landholders are continuing to help protect the Great Barrier Reef by reducing pollutant loads entering the reef. It assesses the combined results of all Reef Plan actions up to June 2014.

Report Card 2012 and 2013, released in June 2014, shows positive trends in land management practice change are translating into reductions of key pollutants.

Report Card 2011, released in July 2013, confirms that management change and water quality improvements are on a positive trajectory.

The Second Report Card (2010), released in April 2013, showed encouraging progress towards achieving Reef Plan's goals and targets. It measures progress from the 2009 baseline up to June 2010.

The First Report Card (2009 Baseline), released in August 2011, provided the baseline.

Information about how the key indicators were measured can be found in the methods section along with information about the scoring system.

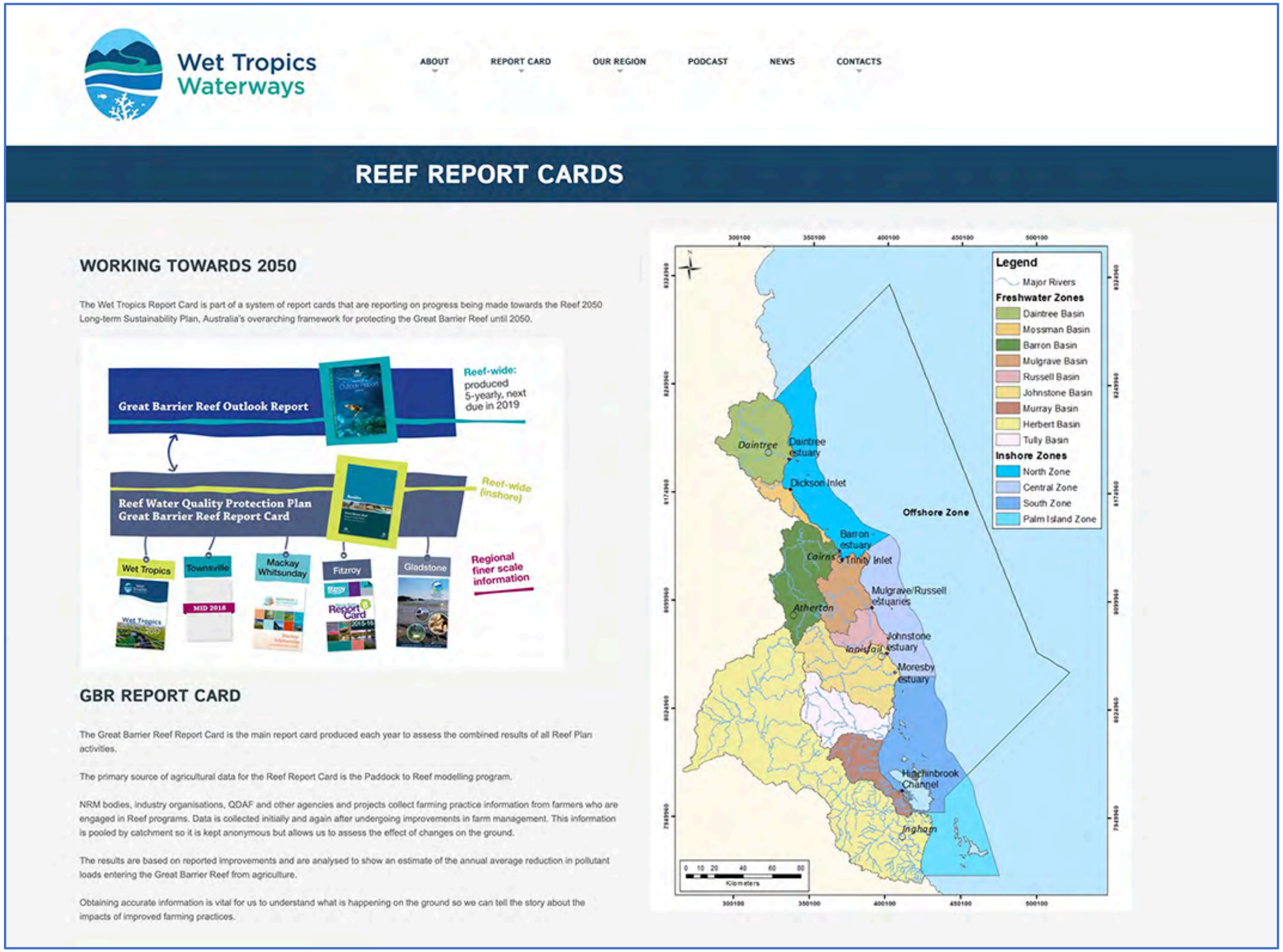
Diver assessing the reef

Last updated 14 February 2019

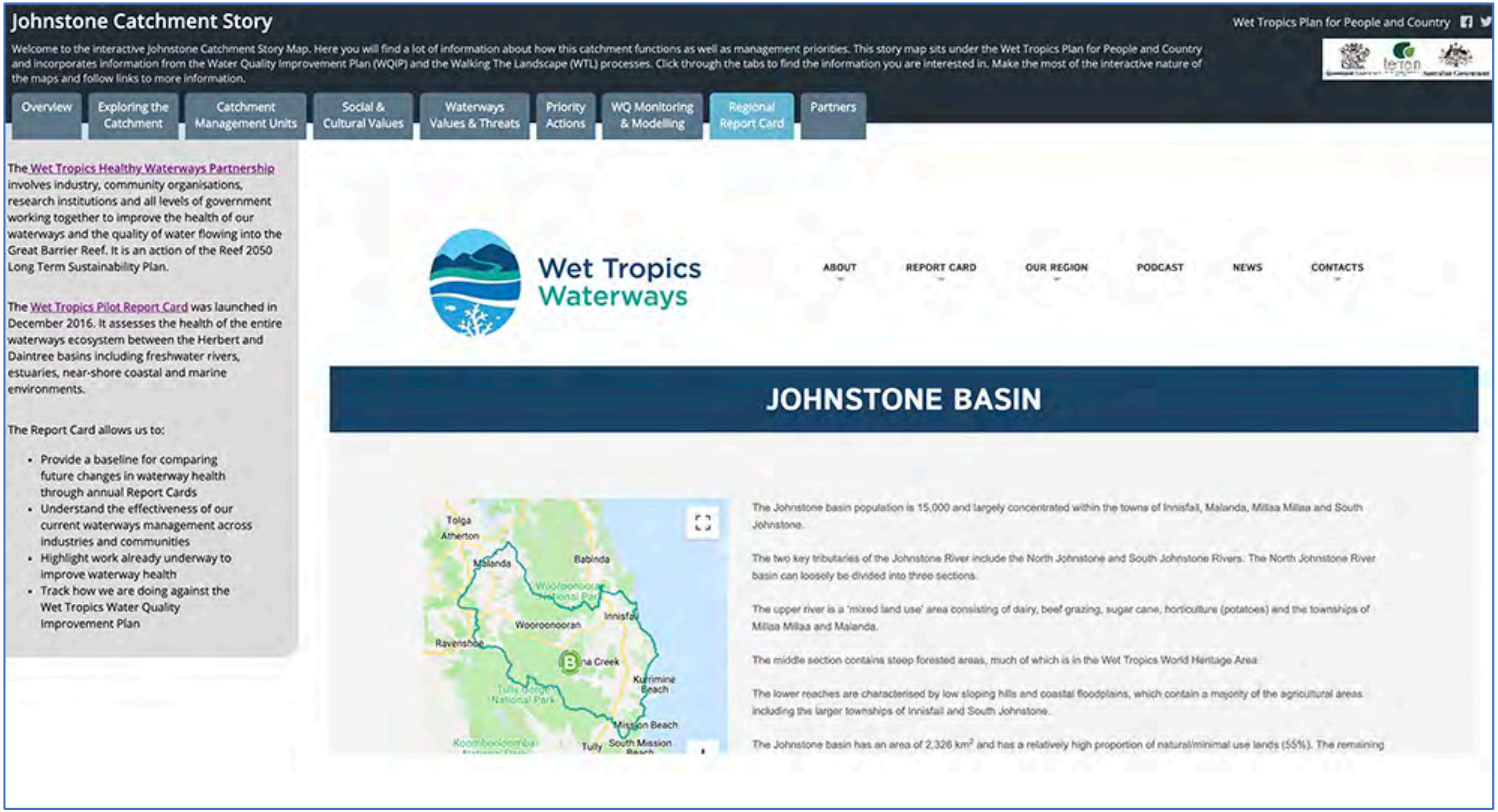
The Partnership is an initiative of the Reef 2050 Long-Term Sustainability Plan.

https://www.reefplan.qld.gov.au/

One of the aims of the Partnership's aim is to coordinate the pooling of shared water quality monitoring data.

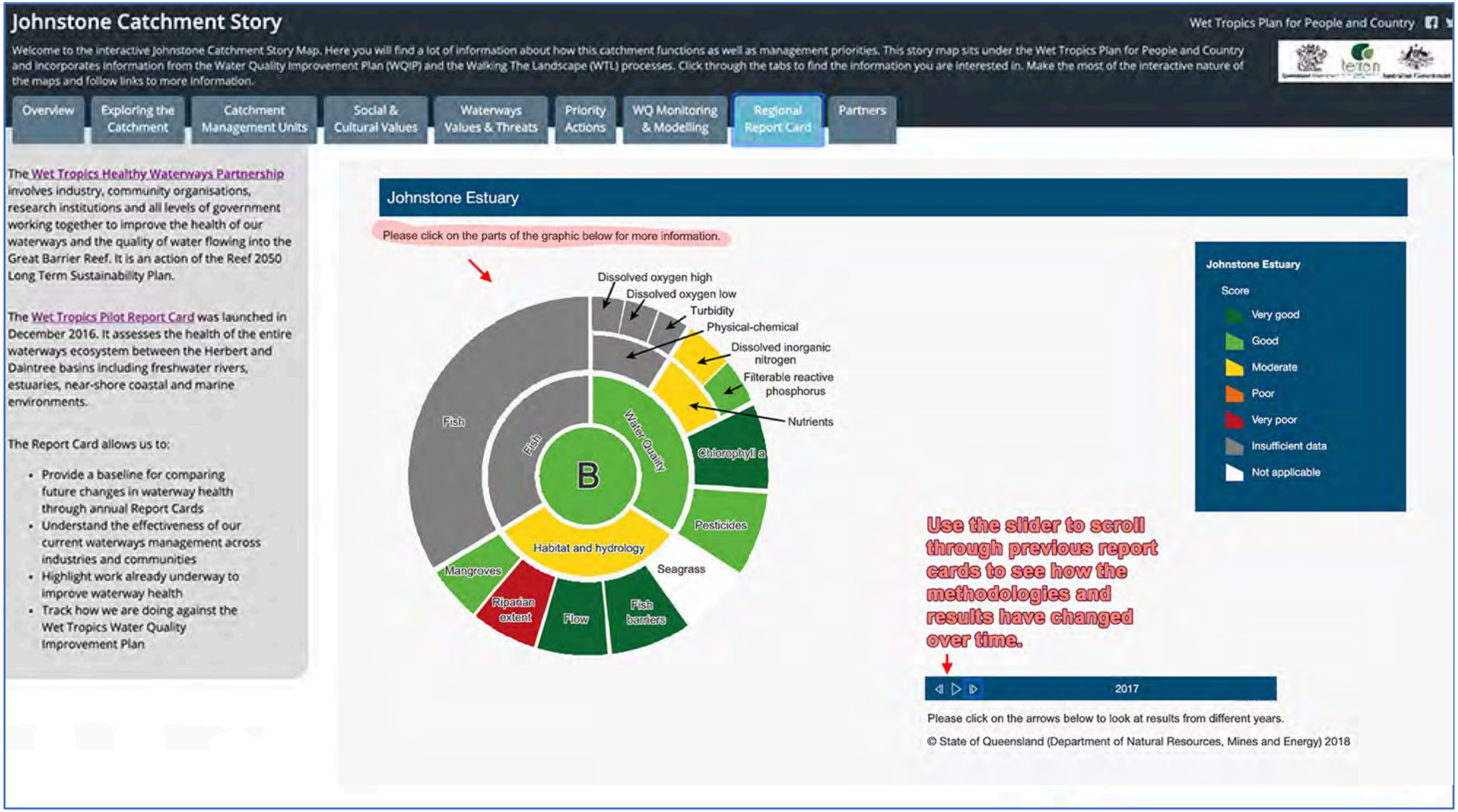


Example



Johnstone Catchment Story
Wet Tropics Plan for People and Country
Welcome to the interactive Johnstone Catchment Story Map. Here you will find a lot of information about how this catchment functions as well as management priorities. This story map sits under the Wet Tropics Plan for People and Country and incorporates information from the Water Quality Improvement Plan (WQIP) and the Walking The Landscape (WTL) processes. Click through the tabs to find the information you are interested in. Make the most of the interactive nature of the maps and follow links to more information.
Overview
Exploring the Catchment
Catchment Management Units
Social & Cultural Values
Waterways Values & Threats
Priority Actions
WQ Monitoring & Modelling
Regional Report Card
Partners
The Wet Tropics Healthy Waterways Partnership involves industry, community organisations, research institutions and all levels of government working together to improve the health of our waterways and the quality of water flowing into the Great Barrier Reef. It is an action of the Reef 2050 Long Term Sustainability Plan.
The Wet Tropics Pilot Report Card was launched in December 2016. It assesses the health of the entire waterways ecosystem between the Herbert and Daintree basins including freshwater rivers, estuaries, near-shore coastal and marine environments.
The Report Card allows us to:
• Provide a baseline for comparing future changes in waterway health through annual Report Cards
• Understand the effectiveness of our current waterways management across industries and communities
• Highlight work already underway to improve waterway health
• Track how we are doing against the Wet Tropics Water Quality Improvement Plan
Wet Tropics Waterways
ABOUT
REPORT CARD
OUR REGION
PODCAST
NEWS
CONTACTS
JOHNSTONE BASIN
Tolga
Atherton
Malanda
Babinda
Innisfail
Wooroonooran
Ravenshoe
Kurrimine Beach
Mission Beach
Tully
South Mission Beach
The Johnstone basin population is 15,000 and largely concentrated within the towns of Innisfail, Malanda, Millaa Millaa and South Johnstone.
The two key tributaries of the Johnstone River include the North Johnstone and South Johnstone Rivers. The North Johnstone River basin can loosely be divided into three sections.
The upper river is a 'mixed land use' area consisting of dairy, beef grazing, sugar cane, horticulture (potatoes) and the townships of Millaa Millaa and Malanda.
The middle section contains steep forested areas, much of which is in the Wet Tropics World Heritage Area.
The lower reaches are characterised by low sloping hills and coastal floodplains, which contain a majority of the agricultural areas including the larger townships of Innisfail and South Johnstone.
The Johnstone basin has an area of 2,326 km² and has a relatively high proportion of natural/minimal use lands (55%). The remaining

Report card



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Poster and report cards

You can download this poster showing other report cards at:

https://wettropicswaterways.org.au/wp-content/uploads/2018/12/Wet-tropics-report-card-2018-131118-WEB-view.pdf

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Wet Tropics Waterway grades 2016-2017

Reef and Rivers Podcast

Another resource you might find useful is the "Reef and Rivers Podcast", which is a series of short interviews with some people around the wet tropics region who are involved in activities aimed at improving waterway and reef health.

You can find the podcast here:

https:wettropicswaterways.org.au/podcast/

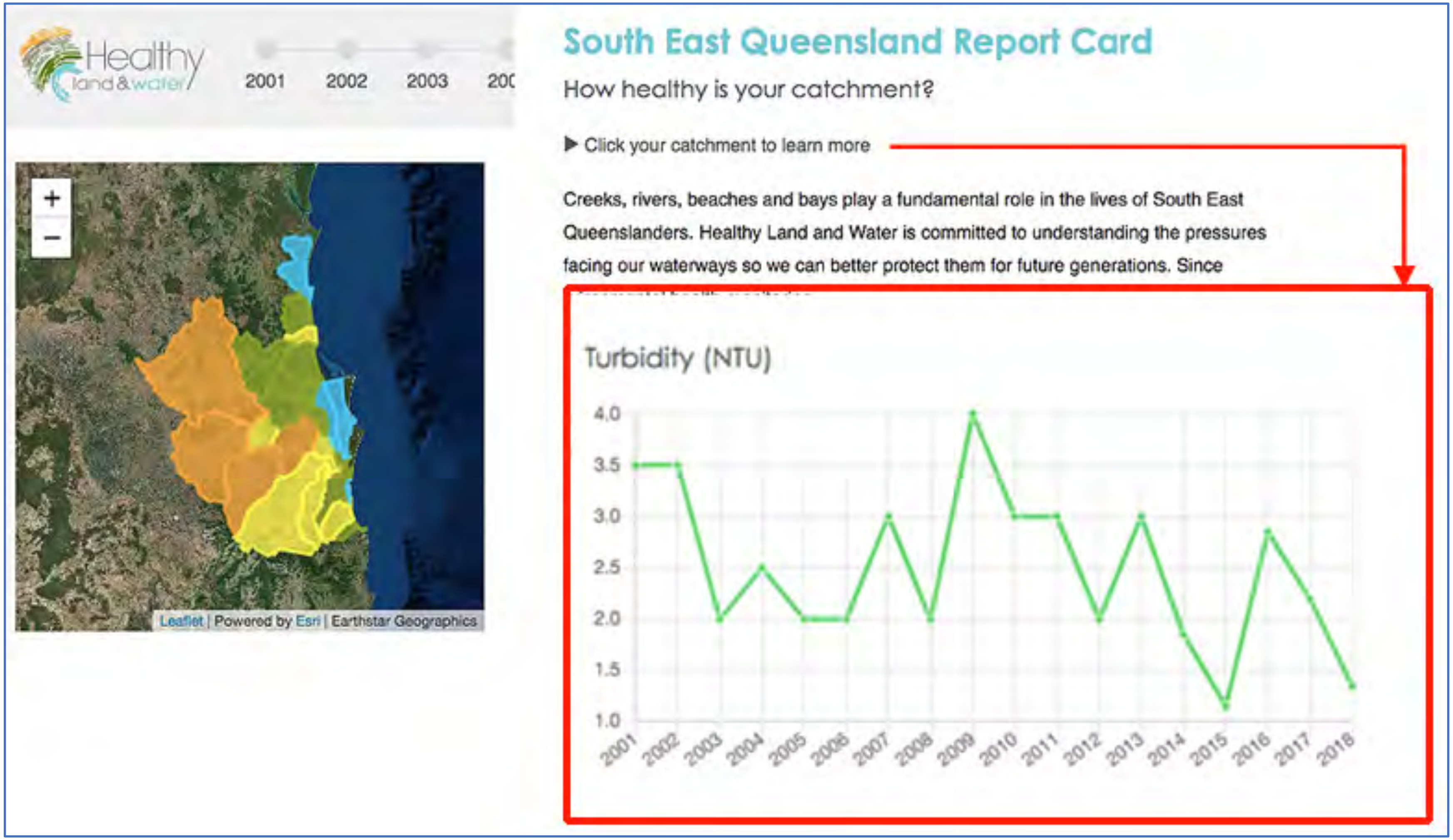
or on iTunes.

Note to teachers:

You can download the individual mp3's to embed in a powerpoint, for use on websites or other materials.

For South East Queensland Water Quality data go to

https://reportcard.hlw.org.au/



Worksheet

Mandatory practical

by

Gail Riches

www.marineeducation.com.au