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Education

Year 12 Marine Science
ANSWER BOOK

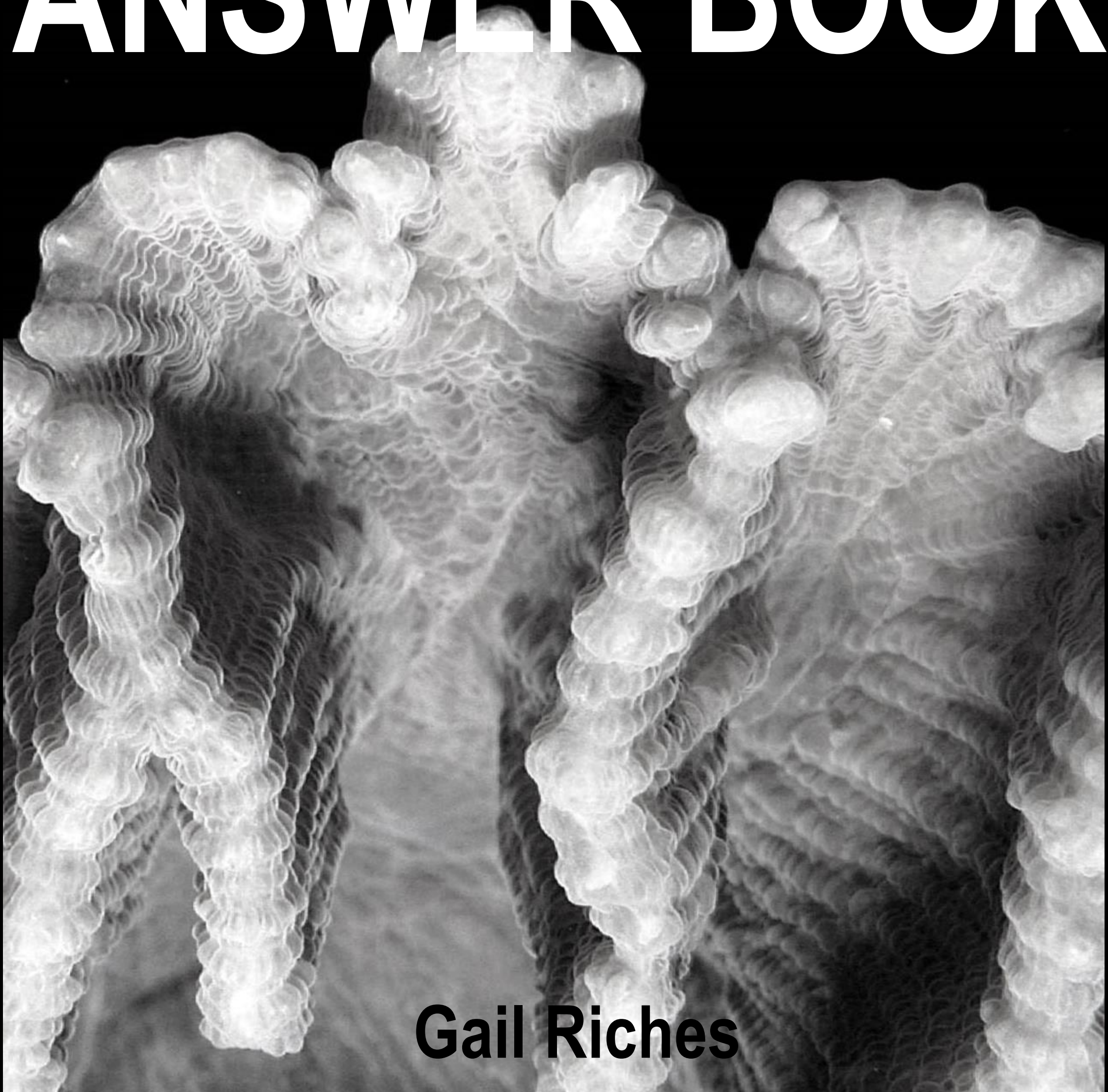
Name:

Date:

Marine Systems - Connections and Change
The Reef and Beyond   Changes on the Reef

Ocean Issues and Resource Management
Oceans of the Future   Managing Fisheries

ANSWER BOOK



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Edited by Maria Bavins

Course Overview and Learning Objectives derived from Marine Science 2019 v1.2 General Senior Syllabus[1]
Front Page Photograph: *Pectinia lactuca* Detail of Valley. PAPUA NEW GUINEA. Photograph: Neville Coleman[2]

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[1] Queensland Curriculum and Assessment Authority (2018). *Marine Science 2019 v1.2: General Senior Syllabus. QCAA.*
Accessed 10 February 2019. https://www.qcaa.qld.edu.au/senior/senior-subjects/sciences/marine-science/syllabus
[2] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). Corals of the World.
Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/pectinia-lactuca/

Interested persons are invited to contact the author for information or to indicate errors and omissions.

Foreword

The Great Barrier Reef is known throughout the world as one of the greatest natural ecosystems on our planet. It is the largest and most spectacular structure built by living organisms on Earth, its size impossible to truly comprehend.

When I first started working on The Reef nearly 50 years ago, I thought it would always be there, a source of wonderment for unending generations to come. I was wrong. Reefs have been among the first victims of environmental upheavals for all geological time and now they are entering another crisis. Global warming from anthropogenic CO_2 is killing corals at an unprecedented rate. The reason became clear to scientists over 20 years ago: it is all to do with the symbiosis between the corals and the unicellular algae – zooxanthellae – in their tissues. These zooxanthellae provide the nutrients that power the growth of corals and are essential to the very existence of reefs. Although corals are animals, this symbiosis allowed them to grow as if they were plants, powered by sunlight through photosynthesis. For millions of years, this coral/algal symbiosis has been incredibly successful. Over the past 100,000 years, corals around the globe have selected the type of zooxanthellae that give them 'the biggest bang for their buck' – the maximum amount of food possible. This has made them closely attuned to temperature, just as we are. If that temperature is exceeded, they become sick because their algae produce too much oxygen. In response, the corals rid themselves of their zooxanthellae just as we destroy pathogens in our bodies. However, that can be suicidal because corals cannot live for long without their algae; they turn pale ('bleach') and die. When this happens to most corals on a reef, we call it mass bleaching.

Mass bleaching, devastating though it is, is not the only crisis being created by CO_2. When dissolved in seawater, CO_2 forms carbonic acid which makes the ocean less alkaline – less super-saturated with aragonite, the most soluble form of calcium carbonate and the form corals use to build their skeletons. On current predictions, by the middle of this century or earlier, corals will be suffering from an osteoporosis-like condition or will not be able to grow skeletons at all.

The consequences of mass bleaching and ocean acidification are far more serious than most people realise because it is not just the corals that die, it is the entire reef ecosystem as that is entirely dependent on healthy corals. Reefs have by far the most diverse ecosystems of the entire marine realm. At least ⅓ of all marine species are dependent on reefs during some part of their life cycle. Should we lose our coral reefs, an ecological collapse of most ocean ecosystems will follow as all are closely interlinked. The geological record shows that the demise of reefs in the past has been the precursor to four of the earth's five mass extinctions.

Of course, this reads like a nightmare fairytale and perhaps you think that it can't be that serious. But this is not a fairytale, it is solid science and the facts have been known without question for at least a decade. If climate change continues unabated, young people today could inherit a world very different from that to which we are all accustomed.

We must do whatever we can to enhance the survival of corals by countering plagues of Crown-of-Thorns starfish and by closely monitoring all aspects of reef water quality. In short, we must keep the Great Barrier Reef as healthy as possible to enable it to recover from times of stress. Young people today have a critical role to play in this because The Reef's future will soon be in their hands.

Charlie Veron

'Charlie' Veron, commonly called The Godfather of Coral, was the first full-time scientist to work on the Great Barrier Reef, eventually becoming Chief Scientist of the Australian Institute of Marine Science. He has published widely on reefs and their corals, see Veron (2008) A Reef in Time: the Great Barrier Reef From Beginning to End and www.coralsoftheworld.org for further information.

Course Overview

Name:

Date:

Marine Science

Year 11 (last booklet)

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

Assessment

- **Data Test 10%**
- **Student Experiment 20%**
- **Research Investigation 20%**
- **Exam 50%**

Year 12 (this booklet)

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

Assessment

- **Data Test 10%**
- **Student Experiment 20%**
- **Research Investigation 20%**
- **Exam 50%**

Syllabus Objectives

1. Describe and explain scientific concepts, theories, models and systems and their limitations
2. Apply understanding of scientific concepts, theories, models and systems within their limitations
3. Analyse evidence
4. Interpret evidence
5. Investigate phenomena
6. Evaluate processes, claims and conclusions
7. Communicate understandings, findings, arguments and conclusions

Underpinning factors

1. Literacy
2. Numeracy
3. 21st Century Skills (critical thinking, communication, personal and social skills, creative thinking, collaboration and teamwork, information and communication technologies (ICT) skills)

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Future Scenarios: Evaluate future scenarios for a named marine system through the analysis of different atmospheric condition datasets T127	118
Trends though Time: Compare historical geological data (e.g. of coral cores) with changes in land use practices and global carbon dioxide and temperature levels T128	119
Shell Shock: Recognise that ocean acidification has indirect consequences on the ocean and its uses T129	120
The Way the Wind Blows: Identify the factors between the atmosphere and the oceans that drive weather patterns and climate (e.g. temperature, wind speed and direction, rainfall, breezes and barometric pressure) T130	121
Our Changing Climate in a Nutshell: Understand that average global temperature increases impact on marine environments by altering thermal regimes and changing physical and chemical parameters of the ocean (e.g. aragonite saturation levels and rising sea levels) T131	122
Topic 2: Managing Fisheries	
Subject Matter: Fisheries and Population Dynamics	
Gone Fish'n: Understand that the term *fishery* has a variety of meanings and that there are three main types (i.e. artisanal, recreational and commercial) T132	125
QUITE A CATCH: ESTIMATING GLOBAL FISH STOCKS	126
Packets of Protein: Understand the significance of wild caught fish as the major source of protein globally T133	127
Gone OverFish'n: Understand that the world's fisheries are in decline T134	128
Fertilizing the Ocean: Explain how distribution of fish populations are determined by temperature, primary productivity and nutrient dispersal, and these are influenced by currents, upwelling and seasonal factors T135	129
Rugosity Rocks: Assess rugosity data and link this to fish diversity T136	130
We are what we eat: Assess the impact of bioaccumulation through the food web into edible seafood T137	131
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Cognitive Verbs

Name:

Date:

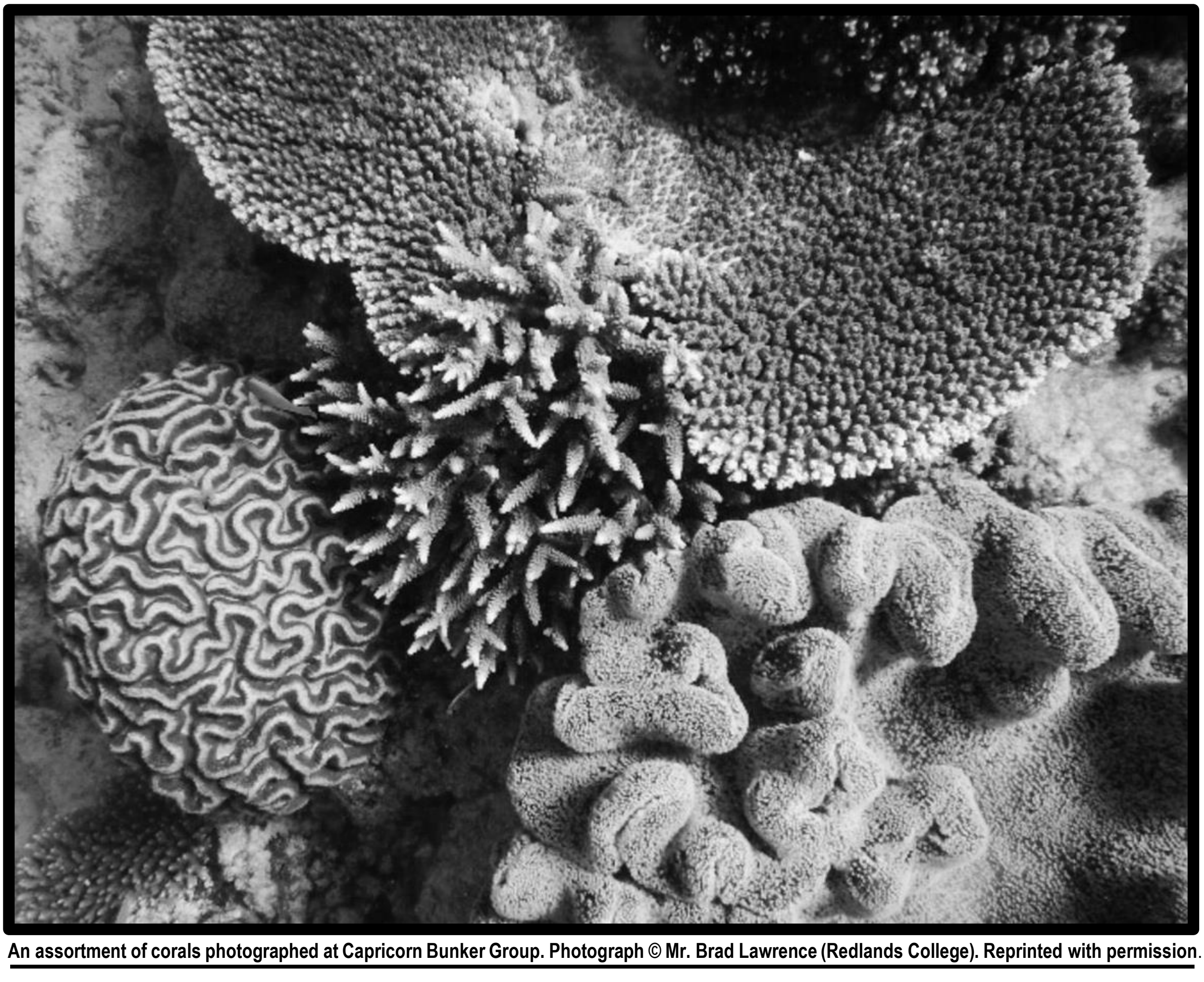
Verb	Description
Analyse	Dissect to ascertain and examine constituent parts and/or their relationships; break down or examine in order to identify the essential elements, features, components or structure; determine the logic and reasonableness of information; examine or consider something in order to explain and interpret it, for the purpose of finding meaning or relationships and identifying patterns, similarities and differences
Apply	Use knowledge and understanding in response to a given situation or circumstance; carry out or use a procedure in a given or particular situation
Appraise	Give reasons for or against something; challenge or debate an issue or idea; persuade, prove or try to prove by giving reasons
Assess	Measure, determine, evaluate, estimate or make a judgement about the value, quality, outcomes, results, size, significance, nature or extent of something
Calculate	Determine or find (e.g. a number, answer) by using mathematical processes; obtain a numerical answer showing the relevant stages in the working; ascertain/determine from given facts, figures or information
Classify	Arrange, distribute or order in classes or categories according to shared qualities or characteristics
Compare	Display recognition of similarities and differences and recognise the significance of these similarities and differences
Contrast	Display recognition of differences by deliberate juxtaposition of contrary elements; show how things are different or opposite; give an account of the differences between two or more items or situations, referring to both or all of them throughout
Describe	Give an account (written or spoken) of a situation, event, pattern or process, or of the characteristics or features of something
Determine	Establish, conclude or ascertain after consideration
Distinguish	Recognise as distinct or different; note points of difference between; discriminate; discern; make clear a difference/s between two or more concepts or terms
Evaluate	Make an appraisal by weighing up or assessing strengths, implications and limitations; make judgements about ideas, works, solutions or methods in relation to selected criteria; examine and determine the merit, value or significance of something, based on criteria
Examine	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
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
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 & state a distinguishing factor or feature
Infer	Derive or conclude something from evidence and reasoning, rather than from explicit statements; listen or read beyond what has been literally expressed; imply or hint at
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; or give meaning to, information presented in various forms, such as words, symbols, pictures or graphs
Justify	Give reasons or evidence to support an answer, response or conclusion; show or prove how an argument, statement or conclusion is right or reasonable
Organise	Arrange, order; form as or into a whole consisting of interdependent or coordinated parts, especially for harmonious or united action
Pattern	A repeated occurrence or sequence
Predict	Give an expected result of an upcoming action or event; suggest what may happen based on available information
Recall	Remember; present remembered ideas, facts or experiences; bring something back into thought, attention or into one's mind
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
Relationship	In science, connections or associations between ideas or between components of systems and structures
Trend	General directions in which something is changing
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

Unit 3 Marine Systems

Connections and Change

Topic 1:
The Reef and Beyond

Coral reef distribution
Coral reef development
Reef, habitats and connectivity



An assortment of corals photographed at Capricorn Bunker Group. Photograph © Mr. Brad Lawrence (Redlands College). Reprinted with permission.

Formula for Life – Identify the distribution of coral reefs globally and in Australia TO70

Name:

Date:

The distribution of coral reefs is dependent on the ability for corals to do their thing - to turn calcium and carbonate ions, that are *dissolved* in seawater, into *solid* calcium carbonate or **coral skeleton**; a process known as **calcification.** Notably, only **reef-building corals** (as opposed to *non* reef-building corals) can grow their skeletons fast enough to actually build a coral reef. This is because reef-building corals are given a helping hand by hosting **algae** (zooxanthellae) in their tissues. The algae carry out photosynthesis and, in doing so, 'feed' the corals with lots of energy, so the corals can grow fast enough to build a coral reef. Thus, the distribution of coral reefs is dependent on, *not only* the needs of the corals (e.g. calcium and carbonate ions, suitable substrate), but *also* the needs of the algae. The needs of the algae include warm water (but not too warm) and plenty of sunlight (e.g. shallow and clear water).

Reef-building corals need (their algae to have) warm, shallow, clear water to build reefs. For example, the table below features estimates of how warm the water needs to be, and what temperatures are too warm[1].

Table 1: Sources of models used to calculate minimum and maximum temperatures for reef-building corals[1]

Source	Scale	Min. °C	Max. °C
Reynolds & Marsico, 1993 (K97)	Weekly	18.1	31.5
Reynolds & Marsico, 1993 (K99)	Weekly	16.0	34.4
Locarnini *et al.,* 2010	Annually	21.7	29.6
NOAA 01 SST V2	Weekly	15.7	35.5

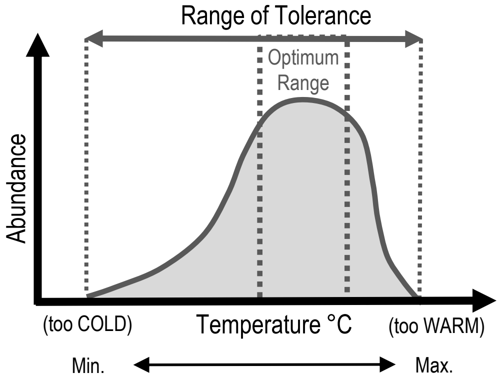
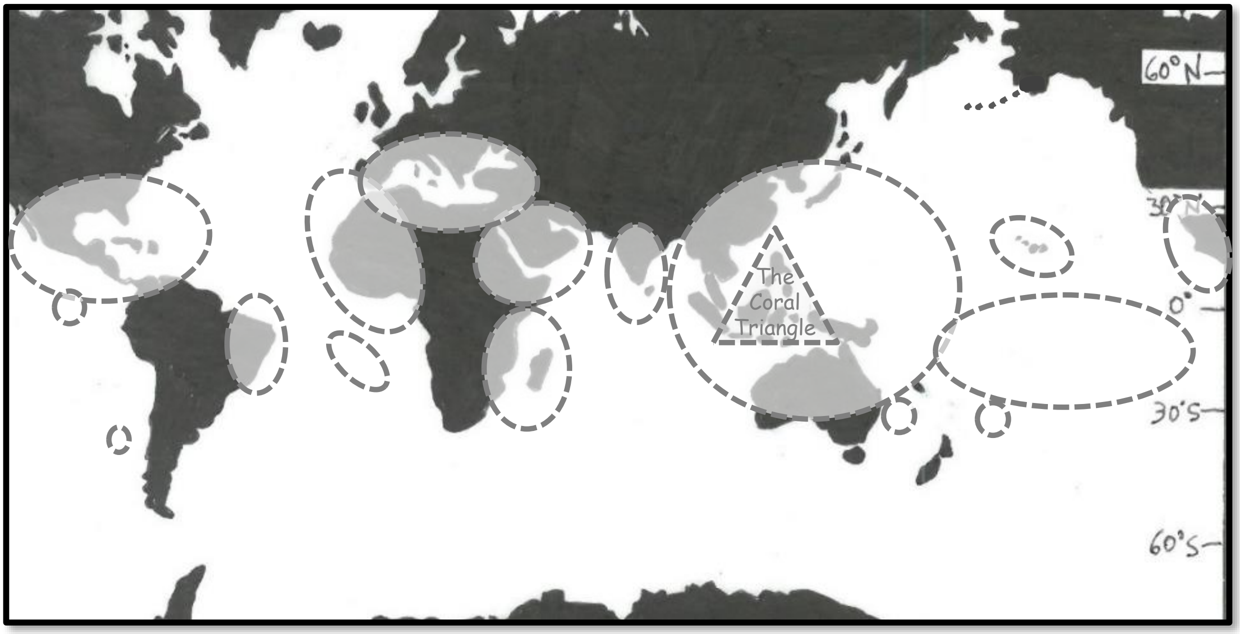


Figure 1: Corals like warm water, but not too warm[2]

Activity: Shade the distribution of coral reefs, globally and in Australia, on the map below.

Hint: go to **www.windy.com** to view temperatures from all around the world (you will need to zoom *out* and change the display from wind to temperature). Then, go to **Google Maps** (*satellite* view) to find areas that are also shallow enough for reefs to form.



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[1] Adapted from: Guan, Y., Hohn, S. and Merico, A. (2015). Suitable Environmental Ranges for Potential Coral Reef Habitats in the Tropical Ocean. *PLoS ONE 10(6). DOI: 10.1371/journal.pone.0128831*

[2] Adapted from: Buddemeier, R.W. and Smith, S.V. (1999). Coral Adaptation and Acclimatization: A Most Ingenious Paradox. *Amer. Zool., 39(1):1-9. DOI: 10.1093/icb/39.1.1*

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Paleo-perspectives – Identify abiotic factors that have affected the geographic distribution of corals over geological time including dissolved oxygen, light availability, salinity, temperature, substrate, aragonite and low levels of nitrates and phosphates TO71

Name:

Date:

Corals likes 👍 and dislikes 👎

Imagine you are holding a coral fossil in your hand that is 120 million years old. Imagine the conditions at that place and time (for it to be alive). Corals *like* certain conditions. Corals like 👍 warm, salty water with lots of oxygen, light, aragonite and low levels of nitrates and phosphates. Corals *dislike* 👎 water that is too warm, too acidic and oxygen deficient (e.g. conditions during the P-T mass extinction event ~251mya).

Activity: Describe the abiotic conditions that killed all corals (and ~90% of marine life) **~251mya**

35-40°C water, that was too acidic, and oxygen deficient (from lots of CO2).

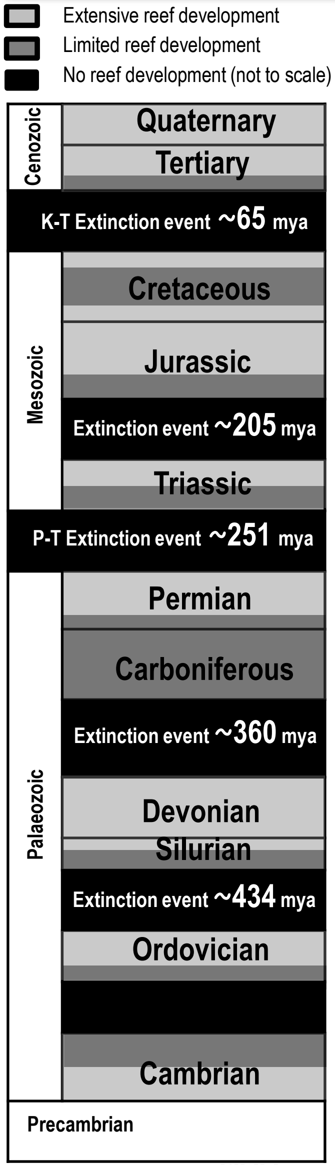

Figure 1: Reefs over time[1][2][3]

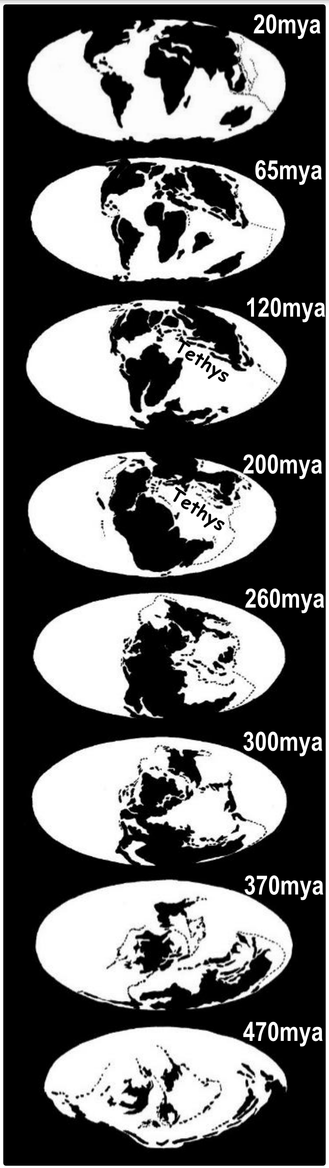

Figure 2: World maps over time[4]

Tethys Sea corals on Mt. Everest!

Many coral fossils have been found where the **Tethys Sea** used to be. The Tethys Sea was an ancient ocean that existed from 250mya to 50mya. At one time it separated into Gondwana and Laurasia. Fossils from the Tethys Sea are now scattered from the depths of the Caspian Sea to the highest Himalayan peaks. Imagine hiking Mt Everest and finding a coral fossil!

Imagine you are holding a coral fossil in your hand from the Tethys Sea 120mya. Q. What conditions were necessary for that coral to form? (*hint:* title) **Ans.**

- Lots of dissolved oxygen
- Lots of calcium and carbonate ions (Ωara>3.3 – see next page)
- Warm temperatures
- Shallow, clear, sunlit water
- Salty water (fresh water kills coral)
- Low levels of nitrates and phosphates (excess nutrients kill coral)

Q. Why does the Tethys Sea *not* exist anymore? Ans.

Tectonic plate movement and continental drift

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[1] Adapted from Laurie, Dr J. (Editor), *et al.,* (2013). *Geological Timewalk.* Geoscience Australia, Canberra. Accessed 22.11.18 from: https://d28rz98at9flks.cloudfront.net/69795/69795_Timewalk_WCAG.pdf

[2] Adapted from Veron, J. E. N. (2008). Mass extinctions and ocean acidification: biological constraints on geological dilemmas. *Coral Reefs. 27:459–472. DOI 10.1007/s00338-008-0381-8*

[3] Adapted from: Brannen, P. (2017). *The Ends of the World*. Oneworld Publications. London. England. Page 5.

[4] Traced from screenshots of video from: TheBentastic (2009). *Earth's history in the last 600 million years.* Youtube. Accessed 22.11.18 from www.youtube.com/watch?v=cQVoSyVu9rk

WHAT IS ARAGONITE?

Name:

Date:

Aragonite is Calcium Carbonate (what coral skeletons are made of)

Coral skeletons are made of calcium carbonate. The chemical formula for calcium carbonate is $CaCO_3$. However, there are 3 different types of calcium carbonate (with that same formula) – aragonite, calcite *and* vaterite! Scleractinian corals are made from the 'aragonite version' of calcium carbonate. Hence the name.

Q. What is the name, and chemical formula, for aragonite? Ans. Calcium Carbonate $CaCO_3$

Now take a closer look at the formula and you will see that it is made of two parts put together. Calcium ions (Ca^{2+}) and carbonate ions ($CO_3{}^{2-}$). *Note:* ions are atoms or molecules that carry a (+ or -) charge.

Q. What ions combine to make aragonite? Ans. Calcium ions and Carbonate ions

Coral is made by combining (dissolved) calcium and carbonate ions to make (solid) calcium carbonate.

Calcium ions + Carbonate ions ⟷ Calcium Carbonate

$$Ca^{2+}_{(aq)} + CO_3{}^{2-}_{(aq)} \longleftrightarrow CaCO_{3\,(s)}$$

Left of the arrow features ions that are dissolved in seawater. **Right** of the arrow features solid calcium carbonate (i.e. coral). *Note*: the reaction can go both ways. Hence, the arrow points both ways. When the solution (left of arrow) is **supersaturated** with lots of dissolved ions, the arrow points right. When the solution (left of arrow) is **undersaturated** with dissolved ions, the arrow points left ($CaCO_3$ dissolves!).

Q. What determines the direction of the arrow in the reaction above? Ans.

The concentration of ions in seawater (the saturation of the solution)

Hence, corals need the arrow to be pointing to the right to make their skeletons, and thus coral reefs. The question remains, do they have enough ions? Well, calcium ions are always in ample supply, so no worries there. Carbonate ions, however, can be in short supply. Particularly when carbon dioxide levels in the atmosphere get too high and change the chemistry of the ocean. E.g. if there is too much CO_2 in the atmosphere, the carbonate ion supplies in the ocean become dangerously low. In which case, corals do not have enough carbonate ions to make their skeletons strong enough, or to calcify (grow) at a rate fast enough to build reefs. Which is not good news! Scientists use the **aragonite saturation state "Ωara"** to track the saturation of carbonate ions in seawater (and thus the potential calcification rate in corals) over time. Whereby, if the saturation of carbonate ions ($CO_3{}^{2-}$) decreases, **Ωara** decreases. **Ωara** is then used to map the distribution of coral reefs in the past, and to predict where reefs will be (or not be) in the future[1].

$$\Omega_{ara} = \frac{[Ca^{2+}]\,[CO_3{}^{2-}]}{K_{sp}}$$

when Ca^{2+} and Ksp (the stoichiometric solubility product) are kept constant.....

When $CO_3{}^{2-}$ decreases, **Ωara** decreases.
When $CO_3{}^{2-}$ increases, **Ωara** increases.

Q. True or False? when Ωara is low, $CO_3{}^{2-}$ concentrations are also low. Ans. True

When Ωara is <3.3, corals get stressed. When Ωara is <1, the arrow points left and corals dissolve!

Q. What happens to coral when Ωara falls below 3.3? Ans. They become stressed

---

[1] Kleypas, J .A., Buddemeier, R.W., Archer, D., Guttuso, J., Langdon, C. and Opdyke, B.N. (1999). Geochemical Consequences of Increased Atmospheric Carbon Dioxide on Coral Reefs. *Science 284, 118 DOI: 10.1126/science.284.5411.118.*

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Written in Stone – Recall that corals first appeared within the geological record over 250 million years ago but not in Australian waters until approximately 500 000 years ago TO72

Name:

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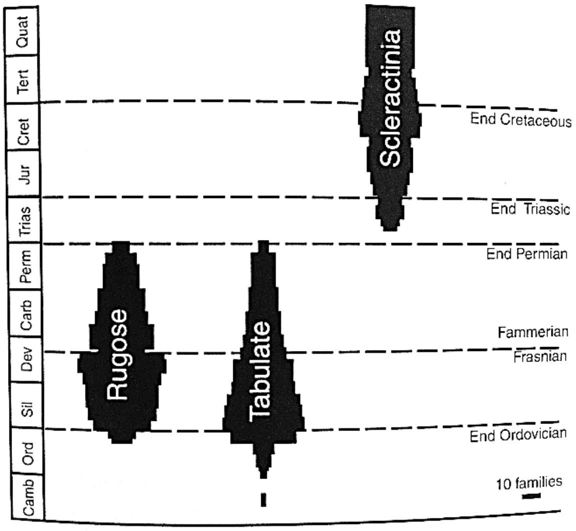


Figure 1: Age ranges of tabulate, rugose and the modern Scleractinia corals. Reprinted with permission from Cambridge University Press[1].

Modern-day reef-building corals from the order **Scleractinia** first appeared *after* the P-T extinction event, over 250 million years ago. *Note:* Prior to the P-T extinction event, Scleractinia corals did *not* exist. Instead there were *Paleozoic* reef-building corals called **Rugose corals** and **Tabulate corals** (Figure 1).

Q. When did Scleractinia corals appear? Ans. After the P-T event, over 250mya

Q. Did Scleractinia corals survive the K-T extinction event 65mya that killed the dinosaurs? Ans. [✓ Yes] [No]

Circle correct answer

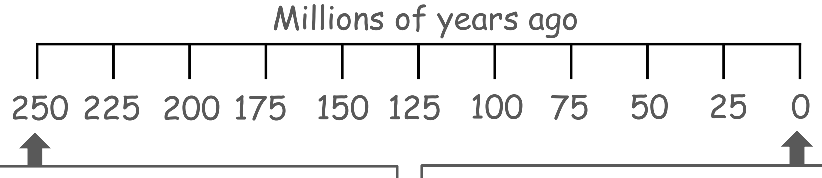
A very confused Santa Clause

Most spectacularly, the location of magnetic north and magnetic south swapped places in the geological past. Yes, that's right. The north pole was at the south pole and vice versa. This reversal has happened quite a few times actually! Every reversal is captured in the orientation of magnetic mineral crystals in rocks (which point to where magnetic north was located at the time the rock was made). The last pole reversal was ~780,000 years ago. No rock samples from the Great Barrier Reef contain evidence of a flip in Earth's magnetic field. Therefore, paleo-ecologists are confident corals did not exist in Australian waters until *after* the last pole reversal ~790,000 years ago. Scleractinian coral fossils start to appear in *Australia's* geological record in (as recent as) ~500,000 years ago (give or take 200,000 years)[2][3].

Q. When was the last reversal of Earth's magnetic field? Ans. ~780,000 years ago

Q. When did corals first appear in Australia's geological record? Ans. ~500,000 years ago

Activity: In the space below, draw a timeline with a scale of 1cm = 25 million years. Indicate when Scleractinian corals first appeared in the fossil record: (1) Globally and (2) in Australia.



1. When Scleractinian corals first appeared in the *Global* fossil record

2. When Scleractinian corals first appeared in *Australia's* fossil record

---

[1] Johnson, D. 2004. *The Geology of Australia.* Cambridge University Press, Cambridge, UK. Page 83. Figure 4.4: Age ranges of tabulate, rugose and the modern scleractinian corals. ISBN: 0521841216

[2] Blewett, R.S. (ed) 2012. *Shaping a Nation: A Geology of Australia.* Geoscience Australia and ANU E Press, Canberra.

[3] Webster, J. M. and Davies, P. J. 2003. Coral variation in two deep drill cores: significance for the Pleistocene development of the Great Barrier Reef. *Sedimentary Geology 159. 61-80.* *DOI: 10.1016/S0037-0738(03)00095-2*

20,000 years ago – Recognise that the Great Barrier Reef of today has been shaped by changes in sea levels that began over 20 000 years before present (BP) and only stabilised 6500 years BP

TO73

Name:

Date:

The Great Flood Event

Imagine it is very cold. It is an ice age. It is 20,000 years ago. Indigenous Australians are braving the cold. The sea level is ~120 metres below its present level. There is a land bridge between Tasmania and Victoria. Rivers flow all the way to the continental shelf. But the cold snap does not last forever. The Earth eventually warms. And a great flood event begins. The flood lasts more than 10,000 years! Ice sheets melt and sea levels rise. Sometimes very quickly. At one point, global sea levels rise 20m in less than 500 years (~14,600 BP during Meltwater Pulse 1A)[2]. Tasmania and PNG separate from mainland Australia, and the Gulf of Carpentaria turns from a lake into a Gulf. Coastal mountains become islands. The Aborigines have no choice but to retreat. It is not until 6,500 BP that sea levels finally stabilise.

> ***In the beginning, as far back as we remember, our home islands were not islands at all as they are today. They were part of a peninsula that jutted out from the mainland and we roamed freely throughout the land without having to get in a boat like we do today. Then Garnguur, the seagull woman, took her raft and dragged it back and forth across the rock of the peninsula letting the sea pour in and making our homes into islands.***
>
> Paraphrased Aboriginal story from the Wellesley Islands, Southern Gulf of Carpentaria[1].

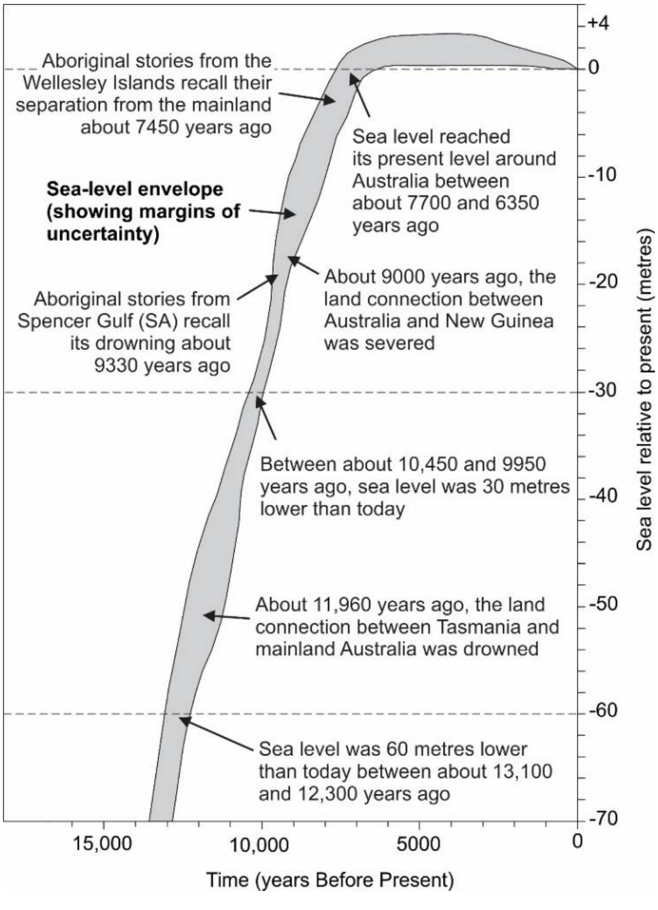


Figure 1: Sea level rise in Australia. Courtesy of Patrick Nunn.

The story above and the graph pictured left are from research by Patrick Nunn and Nick Reid (2016)[1] who travelled Australia and listened to many Aboriginal stories. All of which indicated post-glacial sea level rise and coastal inundation. Patrick Nunn and Nick Reid felt confident the stories survived **unchanged** for *thousands* of years!!!

Activity: Choose an island off the coast of Australia. Describe the appearance of the island 20,000 years ago compared to 6,500 years ago.

Hint: was it joined to the mainland?

E.g. 20,000 years ago, Island X was joined to the mainland. 6,000 years ago it appeared similar to today.

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[1] Nunn, P.D. and Reid, N. 2015. Ancient Aboriginal stories preserve history of a rise in sea level. *The Conversation,* published online 13 January 2015. http://tinyurl.com/k63anzm

[2] Weaver A.J., Saenko, O.A., Clark, P.U. and Mitrovica, J.X. 2003. Meltwater Pulse 1A from Antarctica as a Trigger of the Bolling-Allerod Warm Interval. *Science Vol 299. Pages 1709-1713. DOI: 10.1126/science.1081002*

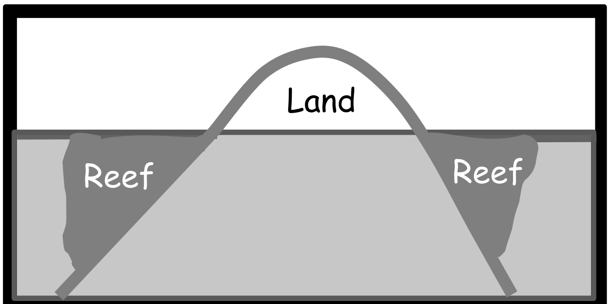
Coral Necklaces and Ribbons – Recall the different types of reef structure (e.g. fringing, platform, ribbon, atolls, coral cays) TO74

Name:

Date:

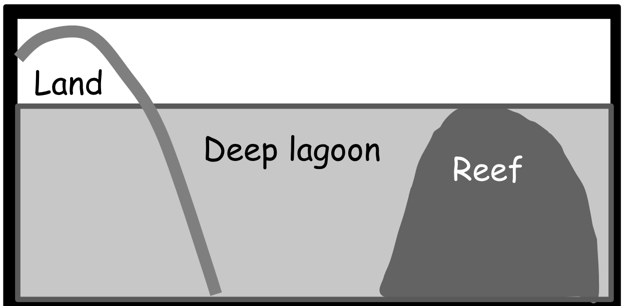
Activity: Complete the sentence below each diagram. Select from the following words below:

Coral Cay, Barrier Reef, Platform Reef, Fringing Reef, Atoll, Ribbon Reef



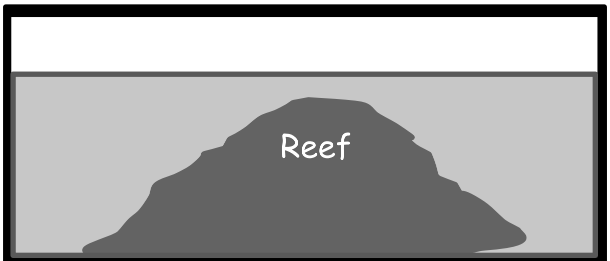
This type of reef is directly attached to land (e.g. mainland or continental island). You can snorkel this type of reef by simply stepping off the beach!

It is called a.... Fringing Reef



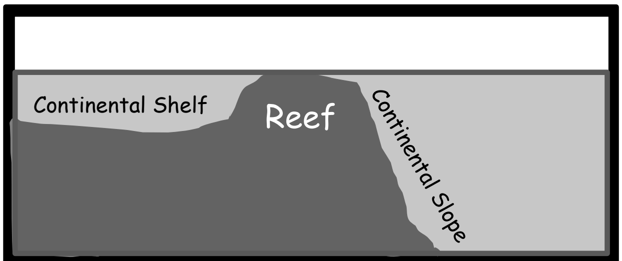
You have to catch a boat to snorkel this type of reef because of the *deep* lagoon (or channel) that separates the reef and the land.

It is called a.... Barrier Reef



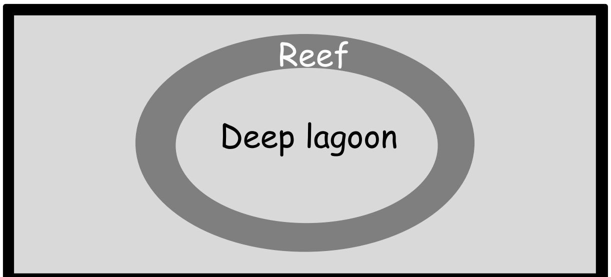
A nice *patch* of reef that rises up from the bottom as a small isolated platform of coral. They vary in size and rarely reach the surface of the water.

It is called a.... Platform Reef



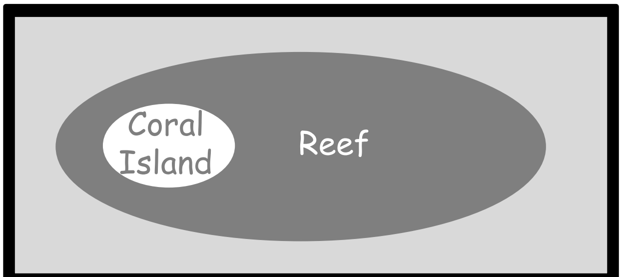
A narrow ribbon-shaped reef tracking alongside the edge of the continental shelf in Nth Qld. Thus, you need to travel a very long way to get there!

It is called a.... Ribbon Reef



Imagine a fringing reef with*out* the island in the middle. This reef is shaped like a ring. The middle of the ring is lagoon (where the island *used to be*)

It is called an.... Atoll



A small low-lying sand island where the sand is made from bits and pieces of coral debris. Reef surrounds the island. Many have a lagoon.

It is called a.... Coral Cay

Zone it – Recognise the zonation within a reef cross-section (e.g. reef slope, reef crest/rim, lagoon/back reef) TO75

Name:

Date:

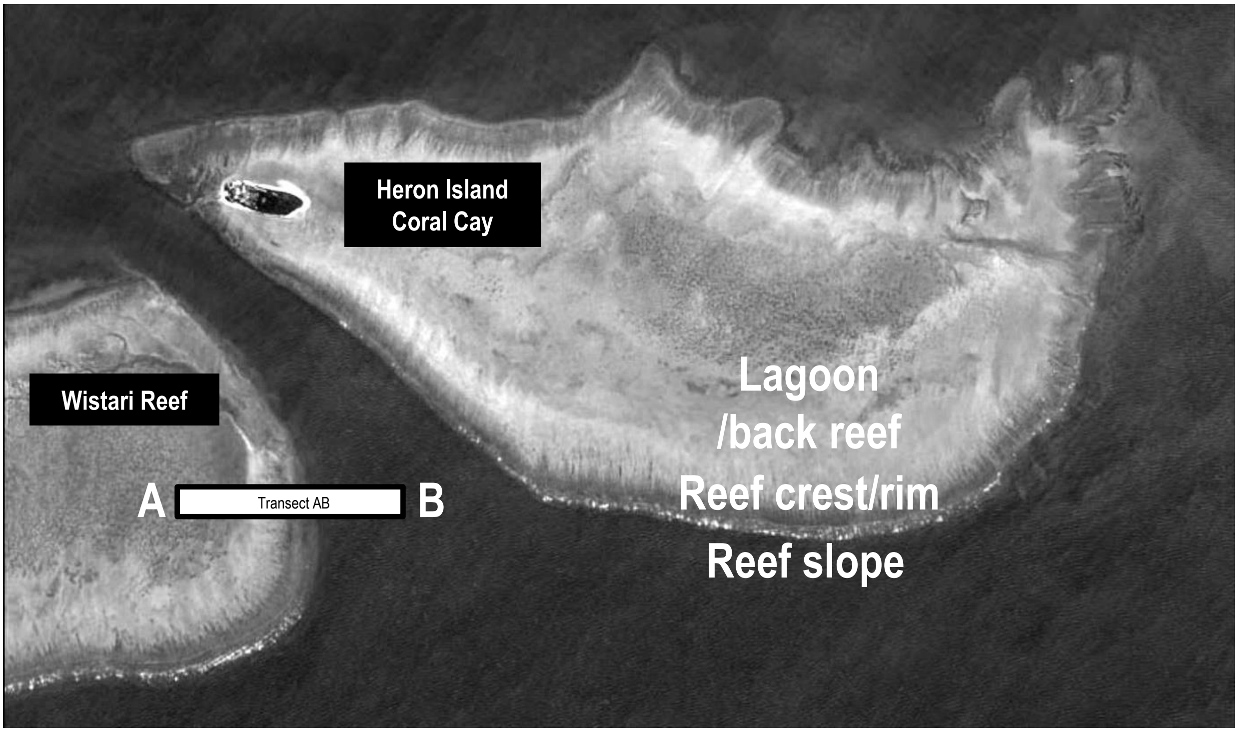
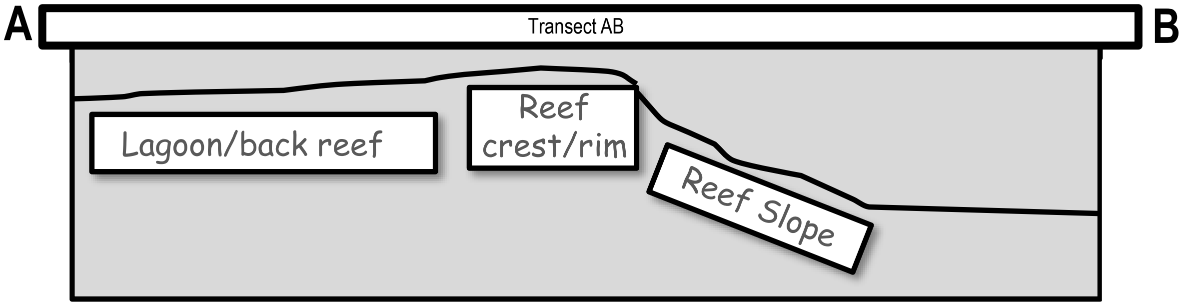


Figure 1: Heron and Wistari Reefs from the PlanetDove Satellite taken 12th January 2018 as a surface reflectance map, created by the Remote Sensing Research Centre, University of Qld[1]. Satellite image data provided by Planet Inc. and the Allen Coral Atlas (https://allencoralatlas.org).

Activity: Write the names of the zones in the boxes below Transect AB (as pictured in Figure 1).



Activity: Complete the table below

Zonation	Description
Lagoon/back reef	The back reef hugs the inner margin of the reef crest/rim and slopes down into a lagoon (towards land or reef centre).
Reef crest/rim	A formidable barrier that absorbs and dissipates the energy of incoming waves. The shallowest part of the reef.
Reef slope	Where the reef descends into deeper water down a 'slope'.

---

[1] Adapted with permission from Professor Stuart Phinn. Director of the Remote Sensing Research Centre located at the School of Environmental Sciences at the University of Qld.

Marine Education
marineeducation.com.au

Coral Classification – Recall the following groups of coral: Alcyonacea 'soft corals' and the two morphological groups within Scleractinia 'hard corals' — reef-forming/hermatypic and non-reef forming/ahermatypic

TO76

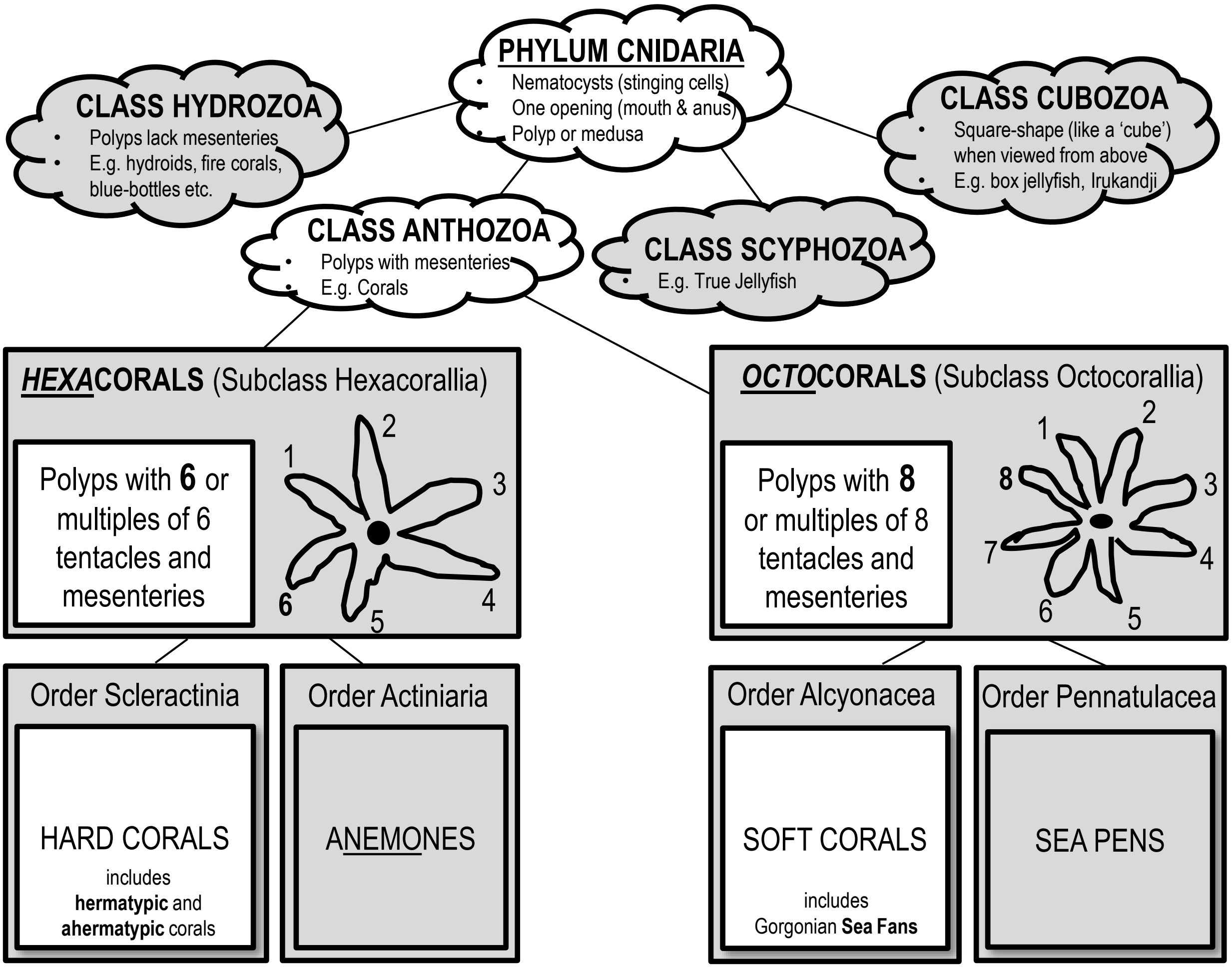
Name:

Date:

Domain → Kingdom → Phylum → Class → Order → Family → Genus → Species

Activity: Create a quirky mnemonic to help remember the correct order for the above

Did	King	Philip	Come	Over	For	Great	Spagetti?



PHYLUM CNIDARIA
- Nematocysts (stinging cells)
- One opening (mouth & anus)
- Polyp or medusa

CLASS HYDROZOA
- Polyps lack mesenteries
- E.g. hydroids, fire corals, blue-bottles etc.

CLASS CUBOZOA
- Square-shape (like a 'cube') when viewed from above
- E.g. box jellyfish, Irukandji

CLASS ANTHOZOA
- Polyps with mesenteries
- E.g. Corals

CLASS SCYPHOZOA
- E.g. True Jellyfish

***HEXA*CORALS** (Subclass Hexacorallia)

Polyps with **6** or multiples of 6 tentacles and mesenteries

***OCTO*CORALS** (Subclass Octocorallia)

Polyps with **8** or multiples of 8 tentacles and mesenteries

Order Scleractinia

HARD CORALS

includes **hermatypic** and **ahermatypic** corals

Order Actiniaria

ANEMONES

Order Alcyonacea

SOFT CORALS

includes Gorgonian **Sea Fans**

Order Pennatulacea

SEA PENS

Activity: Complete the table below

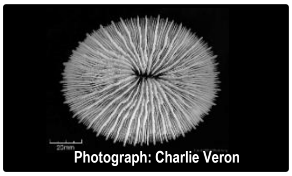
	Hard Corals	Soft Corals
Phylum	Cnidaria	Cnidaria
Class	Anthozoa	Anthozoa
Sub-class	Hexacorallia	Octocorallia
Order	Scleractinia	Alcyonacea

Dichotomous Decisions – Classify a specific coral to genus level only, using a relevant identification key TO77

Name:

Date:

Coral Sample 1



Photograph: Charlie Veron

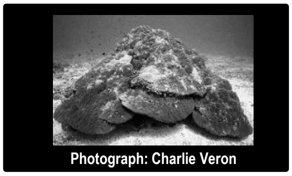
Genus: *Fungia*

Coral Sample 2

Photograph: Charlie Veron

Genus: *Platygyra*

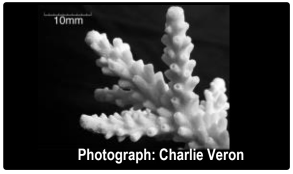
Coral Sample 3



Photograph: Charlie Veron

Genus: *Porites*

Coral Sample 4



Photograph: Charlie Veron

Genus: *Acropora*

Activity: Write the *Genus* for Coral Samples 1-4 above[1] using the dichotomous key below

Dichotomous Key

1a) Solitary ……………………………*Fungia*
b) Colonial ……………………………Go to 2

2a) Brain-like appearance present……*Platygyra*
b) Brain-like appearance absent........Go to 3

3a) Helmet shaped……......................*Porites*
b) Branching shaped…..……………...*Acropora*

'Mushroom Corals' are solitary corals that do not cement themselves to the reef but rather live as one giant individual coral polyp, unattached to the bottom.

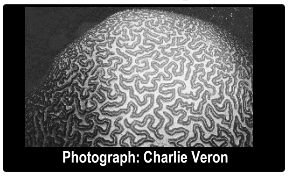
'Brain Corals' have sinuous valleys and ridges that look similar in appearance to the human brain, hence the name.

Porites have many shapes. However, this 'helmet shape' is perhaps its 'signature' shape.

'Branching corals' provide shelter for small fish that can retreat into the branches when danger approaches. *Note: Acropora* also have many shapes, but are best known as branching coral.

Activity: Create your own dichotomous key using Coral Samples 5-8 below[1]

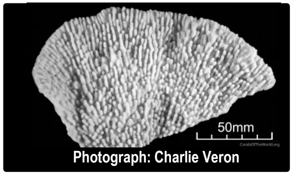
Coral Sample 5



Photograph: Charlie Veron

Genus: *Platygyra*

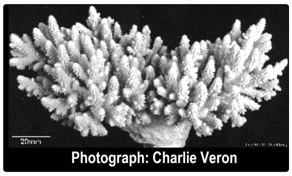
Coral Sample 6



Photograph: Charlie Veron

Genus: *Montipora*

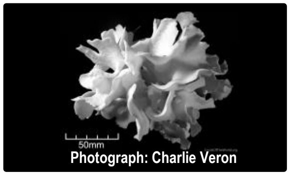
Coral Sample 7



Photograph: Charlie Veron

Genus: *Acropora*

Coral Sample 8



Photograph: Charlie Veron

Genus: *Pavona*

Dichotomous Key (fill in the blanks)

1a) Brain-like appearance present ......*Platygyra*
b) Brain-like appearance absent ....Go to 2

2a) Plate-like appearance present ....…*Montipora*
b) Plate-like appearance absent ……Go to 3

3a) Branching shaped …...*Acropora*
b) Leaf-like shaped …...*Pavona*

How is *Platygyra* different to coral samples 6, 7 and 8?

How is *Montipora* different to coral samples 7 and 8?

How is *Acropora* different to coral sample 8?

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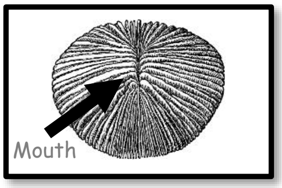
[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 10 May 2019. http://www.coralsoftheworld.org/species_factsheets/

An Octopus's Garden of Stone Flowers –

Identify the anatomy of a typical reef-forming hard coral including skeleton, corallite, coelenteron, coral polyp, tentacles, nematocysts, mouth and zooxanthellae TO78

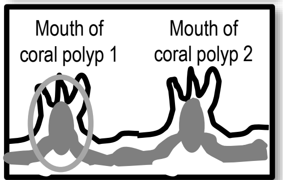
Name:

Date:



The mushroom coral (*Fungia sp.)* is a 'solitary' coral – one single coral polyp. And a very big one! Its large size makes it easy to see its component parts.

Activity: Label the mouth (which is also the anus) in the picture (left).



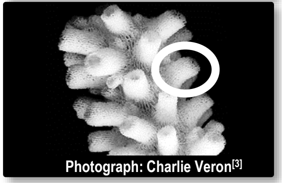
Upon entering the mouth is a cavity called the **coelenteron** (basically its *gut*). *Note:* In a colony, the contents of this cavity are shared with neighbouring polyps.

Activity: Circle the coelenteron of *one* of the polyps in the picture (left).

~95%

Zooxanthellae are symbiotic microscopic algae which live inside the tissues of reef-building corals. ~95% of coral nutrition is provided by zooxanthellae[1].

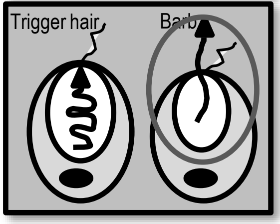
Activity: Write the % of coral nutrition provided by zooxanthellae (left).



Photograph: Charlie Veron[3]

The skeleton that encases each individual coral polyp is called a **corallite**. Each corallite is shaped like a cup (or tube).

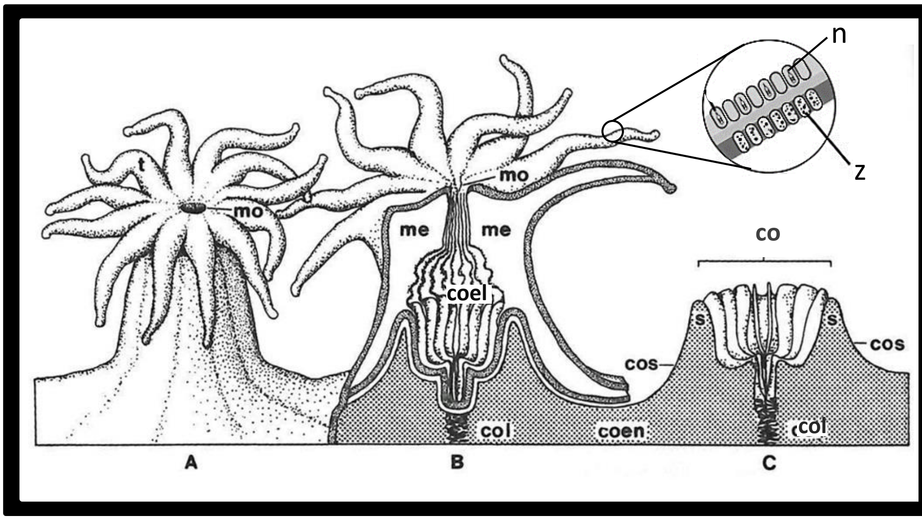
Activity: Circle ONE of the corallites on the branching coral pictured left.



All cnidarians have **nematocysts** – stinging cell capsules that fire poisonous barbs when trigger hairs on the tentacles are touched.
Some barb poisons can be fatal (box jelly). Others are just sticky (anemone).

Activity: Circle the nematocyst that has just been fired (pictured left).

Activity: Use words from the title of this worksheet to complete the Legend below right



Legend	
A	Coral Polyp
t	Tentacles
mo	Mouth
n	Nematocysts
z	Zooxanthellae
coel	Coelenteron
co	Corallite
C	Skeleton
me	mesentery
col	columella
coen	coenosteum
cos	costa
s	septa

Fig. 1. A: entire polyp; B: Section through polyp and skeleton; C: tissues removed to show polyp skeleton (corallite)[2].

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[1] Allemand, D. and Furla, P. (2018). How does an animal behave like a plant? Physiological and Molecular adaptations of zooxanthellae and their hosts to symbiosis. *Comptes Rendus Biologies. Vol 341. Issue 5. Pages 276-280. DOI:10.1016/j.crvi.2018.03.007*

[2] Adapted from: Mather, P. and Bennett, I. (2003). *A Coral Reef Handbook: Australian Coral Reef Society.* Surrey Beatty & Sons Pty Ltd. NSW. Pg. 60

[3] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 10 May 2019. http://www.coralsoftheworld.org/species_factsheets/

Marine Education

Carbonate Count Down – Recall that the limestone skeleton of a coral is built when calcium ions [Ca^{2+}] combine with carbonate ions [CO_3^{2-}] TO79

Name:

Date:

Note: *Limestone* is the well-known name given to *rocks* that are made out of coral.

BEFORE GOING ANY FURTHER, REVISE CONCEPTS INTRODUCED ON PAGE 19 TITLED, 'WHAT IS ARAGONITE?'

Corals turn calcium ions and carbonate ions, that are *dissolved* in seawater, in to *solid* calcium carbonate skeleton ($CaCO_3$). Where? In the *calcifying fluid* directly above the skeleton!

Q. Where do corals turn calcium ions and carbonate ions in to solid coral skeleton?

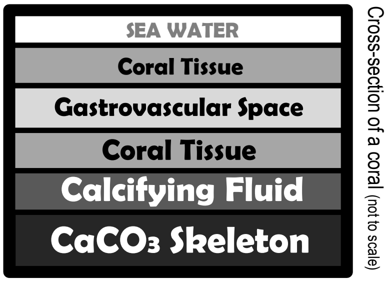
Ans. in the Calcifying fluid (above the skeleton)

Activity: Write the equation for this reaction

$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$

Calcium ions and carbonate ions are transferred *from* the seawater *to* the calcifying fluid…..

where the magic happens!



Cross-section of a coral (not to scale)

Corals NEED carbonate

Unfortunately, the way we are going, in *your* lifetime, there will not be enough carbonate ions in seawater for corals to make their skeletons strong enough or fast enough to build *coral* reefs.

> *"Field studies confirm that carbonate accretion on coral reefs approaches zero or becomes negative at aragonite saturation (Ω_{ara}) values of 3.3 in today's oceans, which occurs when atmospheric CO_2 content approaches 480 ppm and carbonate-ion concentrations drop below 200 µmol kg^{-1} in most of the global ocean"*[1].

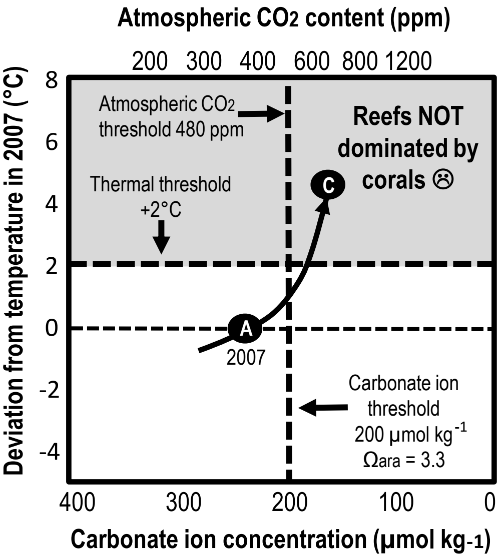


Figure 1: **Thresholds indicate a point in time when corals will not have enough carbonate ions to make their skeletons strong enough, or be able to calcify at a rate fast enough, to build coral reefs. Scenario Ⓐ : ~380ppm (2007). Scenario Ⓒ : Coral reefs will be reduced to crumbling frameworks of few calcareous corals. Reefs will become rubble banks[1].**

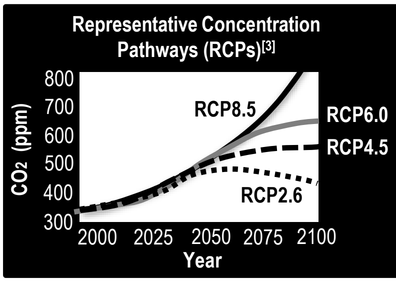


Figure 2: Carbon dioxide (CO_2) concentrations predicted for the future, based on changes we make now to reduce CO_2 emissions[2][3]:

RCP8.5: Small changes ☹

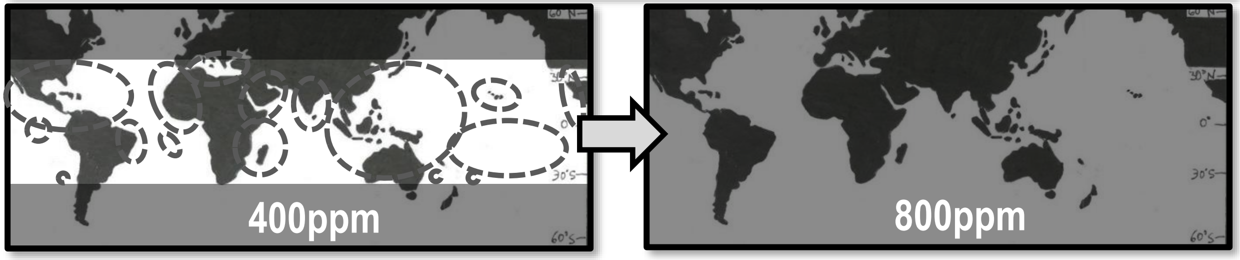
RCP6.0: Medium changes

RCP4.5: Large changes

RCP2.6: Very large changes now

Q. If we do NOT drastically reduce CO_2 emissions NOW, in how many years will coral reefs become rubble banks? Ans. 30-55 yrs

Activity: Mark the distribution of *coral* reefs on the maps below. Shaded areas have Ω_{ara} value <3.3



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[1] Adapted with permission from: Hoegh-Guldberg, O., Mumby, P.J., Hooten, J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Trieto, R., Muthiga, N., Bradbury, R.H., Dubi, A. and Hatziolos, M.E. (2007). Coral Reefs Under Rapid Climate Change and Ocean Acidification. *Science 318, 1737. DOI: 10.1126/science.1152509*

[2] Coast Adapt (2018). What are the RCP's? Coastal Climate Change Infographics Series. *Accessed 06.09.18 from: www.coastadapt.com.au (infographics tab)*

[3] See page 89

Midnight Munchies – Describe the process of coral feeding (including night-feeding patterns and the function of nematocysts) TO80

Name:

Date:

What does a coral eat?
Zooplankton and very small biota

How do they catch it?
With harpoons or mucous!

When?
Usually at night time

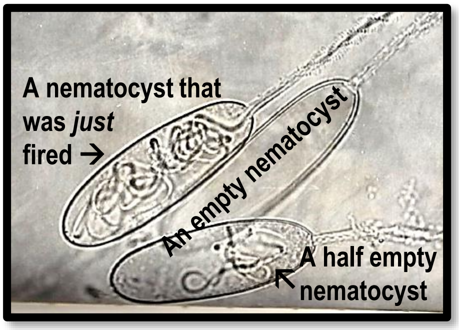


Figure 1: Nematocysts under the microscope (x1000)[1]

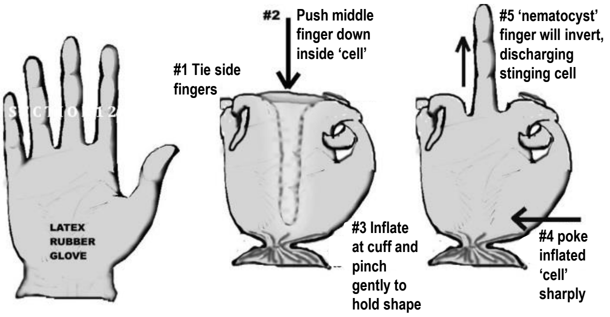
Cnido-BLAST off!

Coral tentacles possess batteries of stinging cells, called *cnidoblasts* [a]. Each cnidoblast contains a cylindrical capsule called a ***nematocyst*** [b]. Inside each nematocyst is a tightly coiled up thread, that ends in a barb filled with poison. Outside the nematocyst is a *trigger hair* [c]. When the trigger hair is touched by a passer-by, the thread and barb come shooting out of the nematocyst in a harpoon-like fashion to immobilise the passer-by[1].

[a] Also called a cnidocyte or nematocyte[3].
[b] They are large organelles produced from the golgi apparatus as a secretory product within the cnidoblast[3].
[c] A concentric hair bundle, also called the cnidocil or cnidocil apparatus.

Q. What is the stinging capsule called? Ans. **N**ematocyst

Activity: Get a latex glove. Tie digits 1 and 2 together and 4 and 5 together, leaving the middle finger free. Push the middle finger inward inside the glove. Cup the bottom of the glove and gently blow to inflate WITHOUT disturbing the middle finger. Now your cell (glove) and nematocyst (middle finger) is armed ready. Ask someone to be a prey item that unknowingly bumps into the stinging cell. Have them sharply poke the side of the air-filled glove. The 'nematocyst' finger will invert discharging the stinging cell![2]



Activity: Cut holes in an old bed sheet, with each hole big enough for a student's hands to fit through. Students put on a glove each (use a marker pen to draw dots on the glove to represent the zooxanthellae). Students crouch beneath the sheet and poke their gloves through the holes in the sheet to try and catch any food held above the sheet by the teacher. When a student 'catches' a food item with their glove, they must pull it back down through the hole to eat and SHARE with the other 'coral polyp coelenterons'.

Activity: Below, create a cartoon that best describes a coral catching an unsuspecting prey.

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[1] Bennett, I. (1971). *The Great Barrier Reef.* Lansdowne Press. Victoria. Australia. Page 79. ISBN: 7018 0403 3
[2] Adapted from: Panos, S. (n.d.). *Lab Demo: How does a Cnidarian catch its prey?* Earth Watch. Accessed 4/10/2018 from https://au.earthwatch.org/Portals/0/Downloads/Education/Lesson-Plans/Coral_Reefs.pdf
[3] Beckman, A. and Ozbek, S. (2012). The Nematocyst: a molecular map of the Cnidarian stinging organelle. *The International Journal of Developmental Biology. 56(6-8): 577-82. DOI: DOI: 10.1387/ijdb.113472ab*

Plant or Animal? – Identify and describe the symbiotic relationships in a coral colony (including polyp interconnections and zooxanthellae) TO81

Name:

Date:

Symbiosis is a host-guest relationship whereby two different species live together, in direct contact, for an extended period of time. Examples include: mutualism (+,+), commensalism (+,o), & parasitism (+, -).

The Coral Farmer

Reef-building corals obtain ~95% of their nutritional needs from zooxanthellae – an algae (dinoflagellate) from the Family *Symbiodiniaceae* that lives as a guest inside the tissues of its coral host in a mutualistic symbiotic relationship. The zooxanthellae guest carries out photosynthesis, providing its coral host with oxygen (for respiration) and energy (for building reefs). A zooxanthellae guest also provides its coral host with its **colour**. In return, the coral host provides its zooxanthellae guest with carbon dioxide (for photosynthesis) and an environment safe from predators[1].

Activity: Below, LIST the benefits that corals and zooxanthellae gain by living together

Coral (host)	Zooxanthellae (guest)
• Oxygen (for respiration) • Energy (e.g. glucose, glycerol, amino acids, etc., which are the products of photosynthesis) • Colour	• Carbon dioxide (for photosynthesis) • An environment safe from predators

Coral Bleaching

When the water gets too warm, some zooxanthellae get stressed and start to produce toxic levels of oxygen (*reactive oxygen species* or ROS). The coral does not like this and, as a result, expels the zooxanthellae, kicking it out of its home. Without its colourful zooxanthellae, the transparent tissue of the coral reveals its white coral skeleton. Hence, the name 'coral bleaching'. And, without its regular food supply, the coral begins to starve[2].

Q. Why do corals bleach? Ans. Water is too warm and zooxanthellae are expelled

Zooxanthellae Variability

Zooxanthellae are *not* all the same. Some zooxanthellae are more tolerant to thermal stress than others. Zooxanthellae variability had geneticists group them into ***clades*** (A-I). For example, clade **D** are more tolerant to thermal stress than Clade C. Hence, Clade **D** are less likely to be expelled by their host coral during a heat wave[1].

Q. Which clade of zooxanthellae are more tolerant to thermal stress? Ans. Clade D

The Coral Holobiont

The coral holobiont is made up of the host organism and all its associated symbiotic microorganisms[2].
A consortium of bacteria, archaea, viruses, and fungi all form close associations with corals and contribute collectively to the overall function and environmental thresholds of corals (e.g. coral probiotic hypothesis).

Q. What is the coral holobiont? Ans. The community of microbes that live in a coral

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[1] Stat, M. & Gates, R. D. (2011). Clade D *Symbiodinium* in Scleractinian Corals: A 'Nugget' of Hope, a Selfish Opportunist, an Ominous Sign, or All of the Above? *Journal of Marine Biology.* Vol. 2011, Review Article ID 730715. DOI: 10.1155/2011/730715 (*Note*: the nomenclature of zooxanthellae is currently under review; i.e. clades → *Genus sp.*)

[2] Thompson, J.R., Rivera, H.E., Closek, C.J. and Medina, M. (2015). Microbes in the coral holobiont: partners through evolution, development, and ecological interactions. *Front Cell Infect Microbiol Vol.4 Article 176. DOI: 10.3389/fcimb.2014.00176*

Coral Babies – Recall the life cycle stages of a typical reef-forming hard coral (sexual: gametes, zygotes, planulae, polyp/asexual budding; asexual: fragmentation, polyp detachment) TO82

Name:

Date:

> ***"Bundles of eggs and sperm which look like small polystyrene balls used in bean bags, float up to the surface like an up-side-down snowstorm"*** David Attenborough[1]

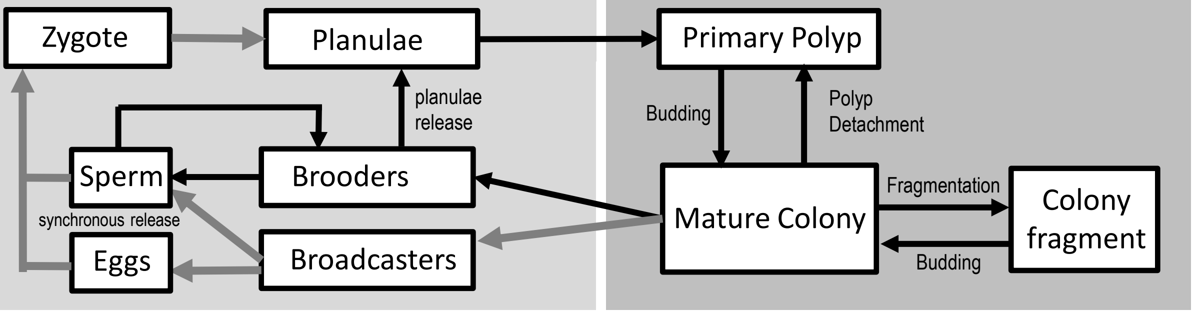
Q. What event is this quote describing? Ans. Annual Coral Spawn Event Full moon of Oct/Nov on GBR

Sexual Reproduction

Broadcasters: External fertilisation (eggs and sperm fertilise in the water)
Brooders: Internal fertilisation (released sperm enters egg-carrying coral)
Gametes: Eggs & Sperm
Zygote: Fertilised Egg
Planulae: Coral Larvae

Asexual Reproduction

Budding: Polyps multiply (within a colony) by budding new polyps. E.g. 1 polyp divides into 2 (intratentacular budding), or; a new mouth with tentacles forms *between* 2 polyps (extratentacular budding).
Polyp Detachment: A single polyp detaches itself from the colony.
Fragmentation: section breaks off; grows into new colony elsewhere.

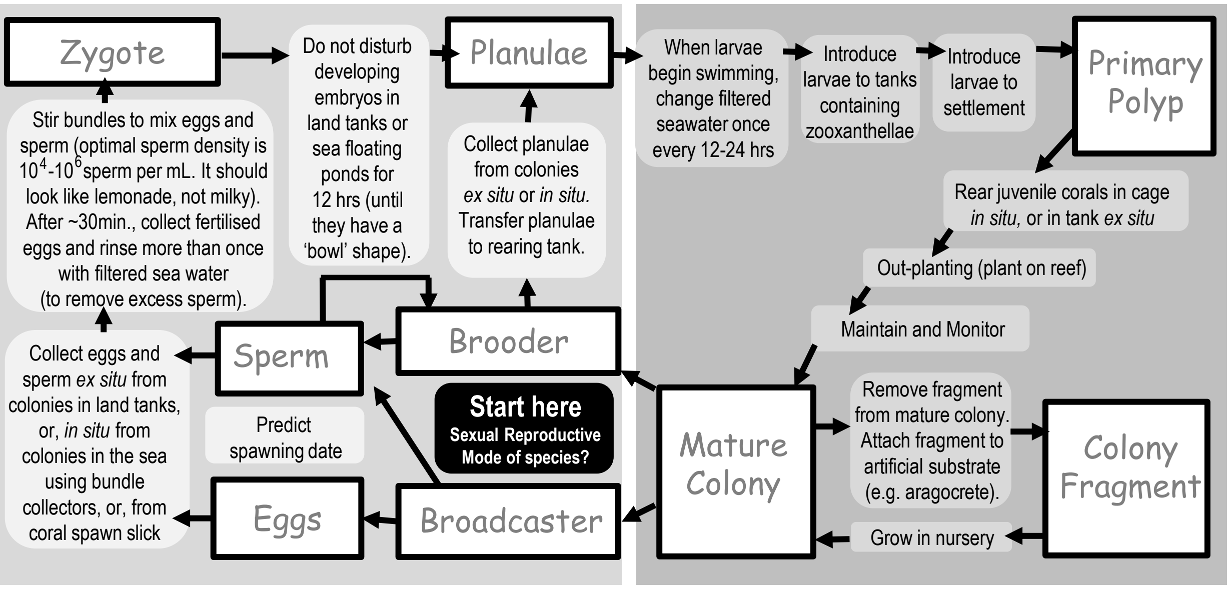


Q. What are the 2 modes of coral *sexual* reproduction? Ans. Brooders and Broadcasters

Coral Restoration

Pictured below is a flowchart of some of the techniques used for coral reef restoration[2][3] (e.g. how to collect coral gametes, grow them and plant them, or; re-plant colony fragments in nurseries).

Activity: Fill in the blanks using words from the diagram above to recall each life cycle stage



Stir bundles to mix eggs and sperm (optimal sperm density is 10^4-10^6 sperm per mL. It should look like lemonade, not milky). After ~30min., collect fertilised eggs and rinse more than once with filtered sea water (to remove excess sperm).

Do not disturb developing embryos in land tanks or sea floating ponds for 12 hrs (until they have a 'bowl' shape).

Collect planulae from colonies *ex situ* or *in situ*. Transfer planulae to rearing tank.

When larvae begin swimming, change filtered seawater once every 12-24 hrs

Introduce larvae to tanks containing zooxanthellae

Introduce larvae to settlement

Rear juvenile corals in cage *in situ*, or in tank *ex situ*

Collect eggs and sperm *ex situ* from colonies in land tanks, or, *in situ* from colonies in the sea using bundle collectors, or, from coral spawn slick

Remove fragment from mature colony. Attach fragment to artificial substrate (e.g. aragocrete).

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[1] Byatt, A., Fothergill, A. and Holmes, M. (2001). *The Blue Planet: A Natural History of the Oceans*. BBC Worldwide Limited. London. UK.
[2] Adapted from: Barton, J.A., Willis, B.L. and Hutson, K.S. (2015). Coral propagation: a review of techniques for ornamental trade and reef restoration. *Reviews in Aquaculture 0, 1-19. DOI: 10.1111/raq.12135*
[3] Adapted from: Omori, M. and Iwao, K. (2014). *Methods of farming sexually propagated corals and outplanting for rehabilitation.* Akajima Marine Science Laboratory, Okinawa, Japan. p1-63

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Marine Education

Finding Home – Explain the process of larval dispersal, site selection, settlement and recruitment TO83

Name:

Date:

Larval dispersal: the *spread* of coral larvae (planulae) from a spawning source to a settlement site.
Site Selection: when coral larvae (planulae) respond to environment cues (e.g. pressure, chemicals) to select a suitable site in which to settle, forever!
Settlement: when coral larvae (planulae) find a suitable substrate for attachment and complete metamorphosis (to become a polyp)[1].
Recruitment: the number of young individuals that undergo larval settlement and become part of the adult population[2].

1. Larval Dispersal

The arrival of new recruits

When the recovery of a disturbed reef relies on the arrival of new recruits, **larval dispersal** (and **connectivity** - to get them there) become critical. Dispersal rescues declining populations, re-establishes extirpated (locally extinct) populations and maintains genetic diversity[3].

What if they don't make it?!

A species may be absent from a reef because it has *not* been able to disperse there. Particularly if it was born a long distance away (see 1st box in Figure 1).

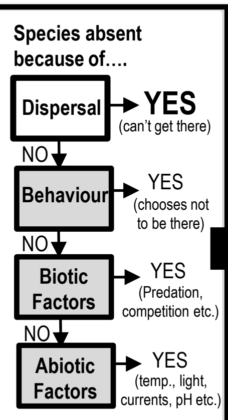

Figure 1: To explain a problem of distribution, proceed down the chain by process of elimination[3].

2. Site Selection

During dispersal, planulae can swim up, down and sideways. Swimming rates average 1 to 5 mm/sec. Not as fast as the currents they are swimming in a lot of the time, but still fast enough to be able to control, to some degree, their *vertical* distribution in the water column. Whereby, any increase in pressure (i.e. depth) is the cue for planulae to swim UP, to avoid water that is too deep and too dark for coral reefs to be found[4]. If they do happen to be at the right depth to encounter a reef (hopefully before their energy supply of lipids run out) they will actively and repeatedly test, probe and explore the substrate (usually guided by chemical cues) searching for some characteristic properties to indicate a favourable settlement location. In the absence of cues to stimulate settlement (or in the presence of inhibitors that deter settlement), planulae may either continue to seek a more suitable substrate, or re-enter the plankton to seek a more suitable reef[5].

3. Settlement

Planulae will *not* settle on live coral, loose sediment (i.e. sand), macro-algae or encrusting sponges. However, *dead* coral they are ok with (so long as it is not covered in macro-algae of course). What they really like to settle on is crustose coralline algae (CCA) and bacterial biofilms. If you want to get a planula to settle, leave your settlement panels in seawater for ~3 months to develop a thick assemblage of crustose coralline algae before introducing the planulae to settlement[5]. The chemical cues from the CCA induce settlement. Planulae love the stuff! Then, upon settlement, planula undergo metamorphosis to become a coral polyp. During metamorphosis, the planula flatten out into a disc-shaped structure with septal mesenteries radiating from the central mouth region[5].

4. Recruitment

Counting the number of young individuals that become part of the adult population is termed recruitment (originally a fisheries term). Notably, it is tough going as a recruit. Early recruits are small (<1mm). Juveniles are not much bigger (1-5 cm) and still vulnerable to grazing, overgrowth and smothering from sediment[5]. Then, competition for space on a coral reef can be quite the battlefield. For example, some hard corals attack their neighbours by extending out extra long sweeper tentacles at their margins. Soft corals resort to chemical weaponry releasing toxic allelopathic chemicals into the water column. All corals are competing for space. If new recruits happen to survive and make it to spawning age, their gametes become the next source of larvae. And so the cycle continues. That is, IF they make it. If not, the reef might have to rely on the arrival of larvae from elsewhere!

Activity: Explain the process of larval dispersal, site selection, settlement and recruitment

1. **Dispersal:** the spread of larvae (e.g. by ocean currents) from a spawning source to a settlement site.
2. **Site Selection:** when larvae respond to environmental cues to select a suitable site in which to settle.
3. **Settlement:** when larvae find a suitable substrate for attachment and complete metamorphosis → polyp
4. **Recruitment:** the number of young individuals that undergo larval settlement and become part of the adult population

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[1] Barton, J.A, Willis, G.L. & Hutson, K.S. (2015). Coral propagation: a review of techniques for ornamental trade and reef restoration. *Reviews in Aquaculture 0, 1-19. DOI:10.1111/raq.12135*
[2] Reef Resilience Network (2018). *Coral Reefs; Coral Reef Module; Reefs and Resilience; Understanding Coral Reef Resilience; Recruitment.* The Nature Conservancy. Accessed 08/10/2018 from reefresilience.org/
[3] Adapted from: Krebs, C. J. (1972). *Ecology: The experimental analysis of distribution and abundance.* Harper & Row, Publishers, Inc., New York. Library of Congress Catalog Card Number: 70-184931. p.16.
[4] Stake, J.L. and Sammarco, P.W. (2002). Effects of pressure on swimming behaviour in planula larvae of the coral *Porites astreoides* (Cnidaria, Scleractinia). *Journal of Experimental Biology and Ecology. 288 p.181-201. DOI:10.1016/S0022-0981(03)00018-2*
[5] Ricardo, G. F. and Negri, A.P. (2017). Settlement patterns of the coral Acropora millepora on sediment-laden surfaces. *Science of the Total Environment. Vol. 609 pages 277-288. DOI:10.1016/j.scitotenv.2017.07.153*

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Construction and Destruction – Explain that growth of reefs is dependent on accretion processes being greater than destructive processes TO84

Note: accretion refers to the growth of coral substrate due to calcification rate[1]

Name:

Date:

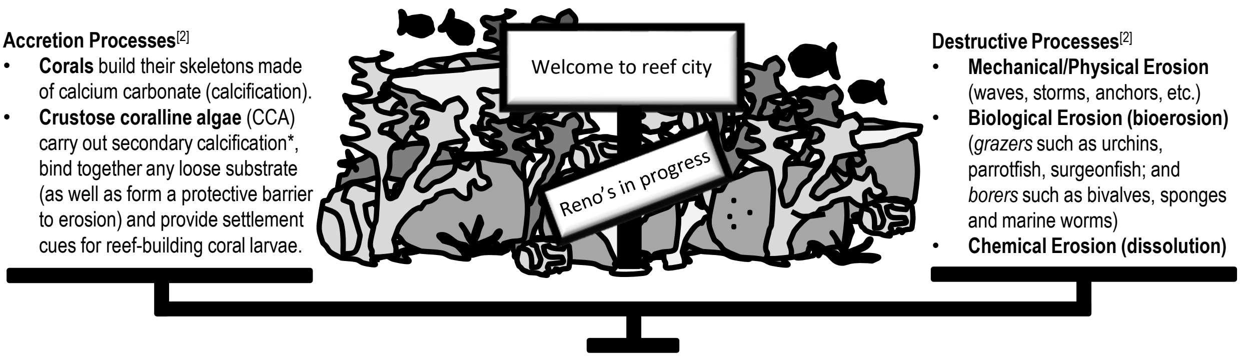
Reef CITY Reno's

Imagine the reef is a city, with buildings made of **coral** bricks (and mortar made of crustose coralline algae). The reef city is in a constant state of renovation. Old buildings are continuously being destroyed to make way for new buildings. The *demolition crew* comprise a workforce of grazers and borers (called bioeroders). One of the grazers is a parrotfish that uses a parrot-like beak as a scraping tool. One of the borers is a worm that uses hooks to mechanically grind its burrows. Some of the demolition crew cleverly manipulate the chemistry of their immediate environment to dissolve the coral. And if that isn't enough, the mechanical erosion of the reef (waves, storms) will either get the job done, breaking them into pieces and carting them away, or, in the very least, weaken city structures. The *demolition* crew are so efficient at their jobs, that the *construction* crew (corals) need to work fast. The reef city will only grow in size if the rate of construction is greater than the rate of destruction[2].

Reef growth = construction > destruction

Accretion Processes[2]

- **Corals** build their skeletons made of calcium carbonate (calcification).
- **Crustose coralline algae** (CCA) carry out secondary calcification*, bind together any loose substrate (as well as form a protective barrier to erosion) and provide settlement cues for reef-building coral larvae.



Destructive Processes[2]

- **Mechanical/Physical Erosion** (waves, storms, anchors, etc.)
- **Biological Erosion (bioerosion)** (*grazers* such as urchins, parrotfish, surgeonfish; and *borers* such as bivalves, sponges and marine worms)
- **Chemical Erosion (dissolution)**

* Secondary calcification is calcification by non-coral invertebrates and calcareous algae (often in the form of calcite, not aragonite)[2]

Activity: Complete the sentence by circling the correct answer. The growth of reefs is dependent on accretion processes being [✓ [greater than]] [less than] **destructive processes.**

A Ticking Time Bomb

Reef growth only occurs when reef-building corals and CCA carry out calcification *faster* than destructive processes carry out erosion. How fast is that exactly? Well, it is a little hard to say, because corals grow at different rates. For example, *Acropora* is much faster at growing than *Porites*! Rates of erosion also vary. But, when you add them altogether, the *net* rate of calcification and the *net* rate of erosion are very close[3]. Thus, any decline in the rate of calcification will easily tip the balance to net erosion. Which may actually happen….in your lifetime. If corals do not have enough carbonate ions to make their skeletons fast enough or strong enough, coral reefs will erode faster than they calcify. Eyre *et al.,* (2018)[3] believe this will occur before the end of this century ☹.

Q. What is causing the rate of calcification to decline? Ans. Rising atmospheric CO_2

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[1] Queensland Curriculum and Assessment Authority (2018). *Marine Science 2019 v1.2: General Senior Syllabus*. QCAA. Queensland. Australia. Accessed 10.11.2018 from: https://www.qcaa.qld.edu.au/

[2] Glynn, P. W. and Manzello, D.P. (2007). Bioerosion and Coral Reef Growth: A Dynamic Balance. *Coral Reefs in the Anthropocene. Springer, Dordrecht. DOI: 10.1007/978-94-017-7249-5_4. ISBN: 978-94-017-7249-5*

[3] Eyre, D.E., Cyronak, T., Drupp, P., De Carlo, E.H., Sachs, J.P. and Andersson, A.J. (2018). Coral reefs will transition to net dissolving before end of century. *Science. 359(6378):908-911. DOI: 10.1126/science.aao1118*

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Marine Education

Abiotic Borders – Assess data of abiotic factors (e.g. dissolved oxygen, salinity, substrate) that affect the distribution of coral reefs TO85

Name:

Date:

Shallow-water coral reefs

Activity: Complete the empty boxes in Table 1 by referring to the data (in brackets) in Table 2

Table 1: Statistically derived environmental averages and extremes among reef sites[1]
Note: does not include non-reef coral communities

	Min	Max	Avg	SD
Temperature (°C)				
Avg	21.0	29.5	27.6	1.1
Min	16.0	28.2	24.8	1.8
Max	24.7	34.4	30.2	0.6
Salinity (PSU)				
Min	23.3	40.0	34.3	1.2
Max	31.2	41.8	35.3	0.9
Nutrients (µmol per Litre)				
NO_3	0.00	5.61	0.25	0.28
PO_4	0.00	0.54	0.13	0.08

Table 2: **Examples of shallow-water reefs that exist within 'marginal' environmental conditions[1].**
Note: 'marginal' means in close proximity to the minimum and maximum value/s for an environmental variable.

Low temperature reefs (minimum weekly SST <18°C). Minimum temperature °C in brackets. Northern Persian Gulf (16.0-17.8); Florida (16.5); SW Pacific: Elizabeth and Middle Reefs, Acacia Place, Lord Howe Island (17.3-17.7); Taiwan (17.9); Hawaiian Islands: Kure and Midway Atolls (17.9)
High temperature reefs (maximum weekly SST >31.5°C). Maximum temperature °C in brackets. Persian Gulf (33.6-34.4); Strait of Hormuz (34.2); Gulf of Oman (31.6-33.9); Southern Red Sea (31.7-32.9); Gulf of California (32.1); Gulf of Aden (31.8); Ctrl Red Sea (31.5-31.8); Andaman Is (31.6-31.7)
Low salinity reefs (monthly minimum <30PSU). Minimum salinity (PSU) in brackets. Burma (23.3); Bay of Bengal: St Martins I (27.0); Eastern Pacific: Ensenada de Utria, Isla de Gorgona (27.0-29.9); Central GBR: Cairns, Murray, Low Wooded I, Fitzroy I (28.9-29.3). Gulf on Thailand: Sichang I, Ko Lan, Ko Sak, Khao Sam Roi Yo (29.7).
High salinity reefs (monthly maximum >40PSU). Maximum salinity (PSU) in brackets. Gulf of Aqaba (41.8); Gulf of Suez (41.8); Northern Red Sea (41.2-41.8); Central Red Sea (40.0-41.2); Persian Gulf (40.3-40.9)
High nitrate reefs (average >2µmol per litre). NO_3 values in brackets. Galapagos I (3.24-5.61); Strait of Hormuz (3.34); N Honduras: Guanaja, Laguna de Guaymoreto (2.50-2.76); Gulf of Oman (2.69); Mid Pacific: Marquises, Phoenix, Baker, Starbuck, Kiritimati, Malden (2.15-2.23); Micronesia: Gilbert I (2.00-2.23).
High Phosphate reefs (average 0.4µmol per litre). PO_4 values in brackets. Galapagos I (0.41-0.54); Arabian Sea (0.40-0.54); Mid Pacific (as above) (0.40-0.49); Strait of Hormuz (0.43); Gulf of Oman (0.40); Gulf of California (0.40); French Polynesia (0.40).

(very old) Deep-sea coral populations

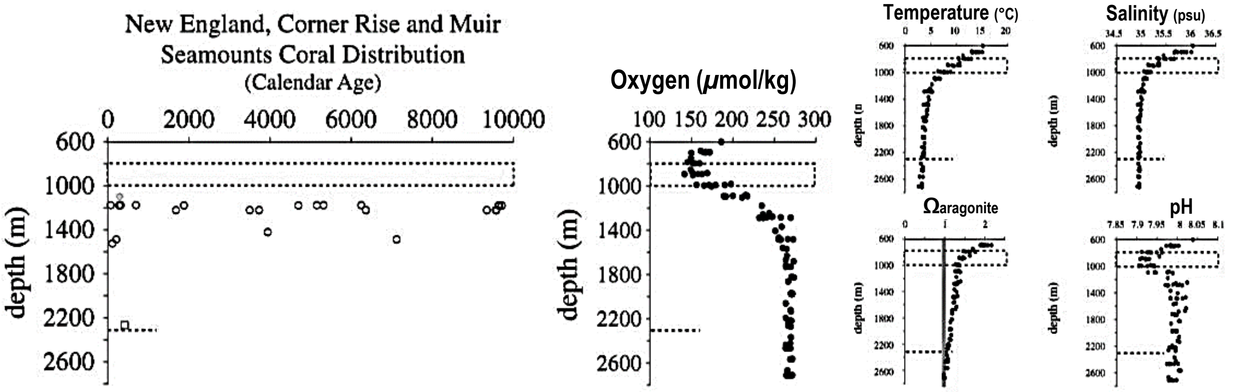

Figure 1: The calendar age and depth of Holocene deep-sea coral *Desmophyllum dianthus* on North Atlantic Seamounts. The dashed boxes represent gaps in coral distribution (i.e. corals do not grow there) which also correspond to the oxygen minimum zones or OMZs (n=>5000)[2]. Water column profiles for temperature, salinity and pH are from World Atlas 2009 (34°N–40°N, 60°W–68°W) and Ωaragonite and CO_2 were calculated using CO2SYS[2].

Q. What abiotic factors are affecting the distribution of deep sea corals in Figure 1? Ans.

E.g. oxygen (no corals in OMZ), aragonite (no corals below Ωara = 1)

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[1] Adapted with permission from: Kleypas, J.A, McManus, J.W. and Menez, L.A.B. (1999). Environmental Limits to Coral Reef Development: Where Do We Draw the Line? *Amer. Zool., 39: 146-159. DOI: 10.1093/icb/39.1.146*

[2] Adapted with permission from: Thiagarajan, N., Gerlach, D. Roberts, M.L., Burke, A., McNichol, A., Jenkins, W.J., Subhas, A.,V., Thresher, E.E., and Adkins, J.F. (2013). Movement of deep-sea coral populations on climatic timescales. *Paleoceanography. Vol. 28. 227-236 DOI: 10.1002/palo.20023*

TESTING TIMES

Data Test Preparation

Name:

Date:

What to expect

You will be assessed on your ability to:

(1) **apply understanding** of the reef and beyond and changes on the reef to given algebraic, visual or graphical representations of scientific relationships and data **to determine unknown scientific quantities** (30% of marks);

(2) **analyse evidence** about the reef and beyond and changes on the reef **to identify trends, patterns, relationships, limitations or measures of uncertainty** in datasets (30% of marks); and

(3) **interpret evidence** about the reef and beyond and changes on the reef **to draw conclusions** based on analysis of datasets (40% of marks).

- Length: **60min** long (+10min perusal). Maximum word length: 400-500 words. The data test is worth **10%.**
- Answers will range from short response to written paragraphs.
- You will be responding to questions using quantitative data and/or qualitative data derived from the mandatory or suggested practicals, activities or case studies from the unit being studied. Stimulus is unseen.

Q. What might the stimulus be comprised of (i.e. what will you see on the test)**? Ans.** (*hint:* see underlined)

Algebraic, visual or graphical representations. Quantitative data and/or qualitative data derived from mandatory or suggested practicals, activities or case studies.

Q. What will the questions ask you to do? Ans. (*hint*: see words in bold)

(1) Apply understanding to determine unknown scientific quantities.
(2) Analyse evidence to identify trends, patterns, relationships, limitations or measures of uncertainty.
(3) Interpret evidence to draw conclusions.

Activity: Complete the table below by providing definitions for the following words.

Word	Definition
Identify	Locate, recognise, name, provide an answer from a number of possibilities.
Analyse	Break down or examine in order to identify the essential elements, features, components or structure.
Trend	When the data overall is moving in one particular direction over time, usually represented by a line or curve on a graph.
Pattern	Consistent and recurring characteristic or trait that helps in the identification of a phenomenon or problem, and serves as an indicator or model for predicting its future behaviour.
Relationship	The strength of the connection or correlation between two or more variables (e.g. variables on the x and y axis).

DATA TEST PRACTICE

Name:

Date:

Dataset 1

The graphs below illustrate the habitat selection, facilitation, and biotic settlement cues affecting the distribution and performance of coral recruits.

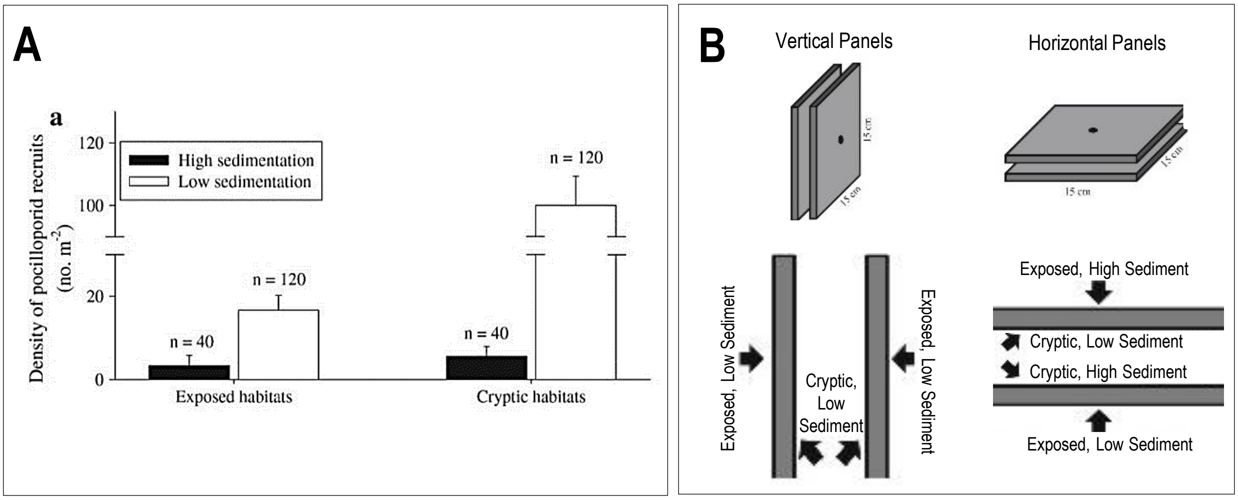

Figure 1: A: Density (no. m^{-2}) of pocilloporid coral recruits (mean + SE) in exposed or cryptic habitats with high (14.67 ± 1.33 g m^{-2} year $^{-1}$) or low (7.56 ± 0.44 g m^{-2} year $^{-1}$) sedimentation after 6 months. Cryptic habitats were shaded and protected from predation and grazing. Sample sizes (n) reported above each bar. B: Experimental set-up showing parts of the panels that were exposed (facing outwards), cryptic (facing inwards), with high sedimentation (facing upwards) and low sedimentation (facing downwards or sideways)[1].

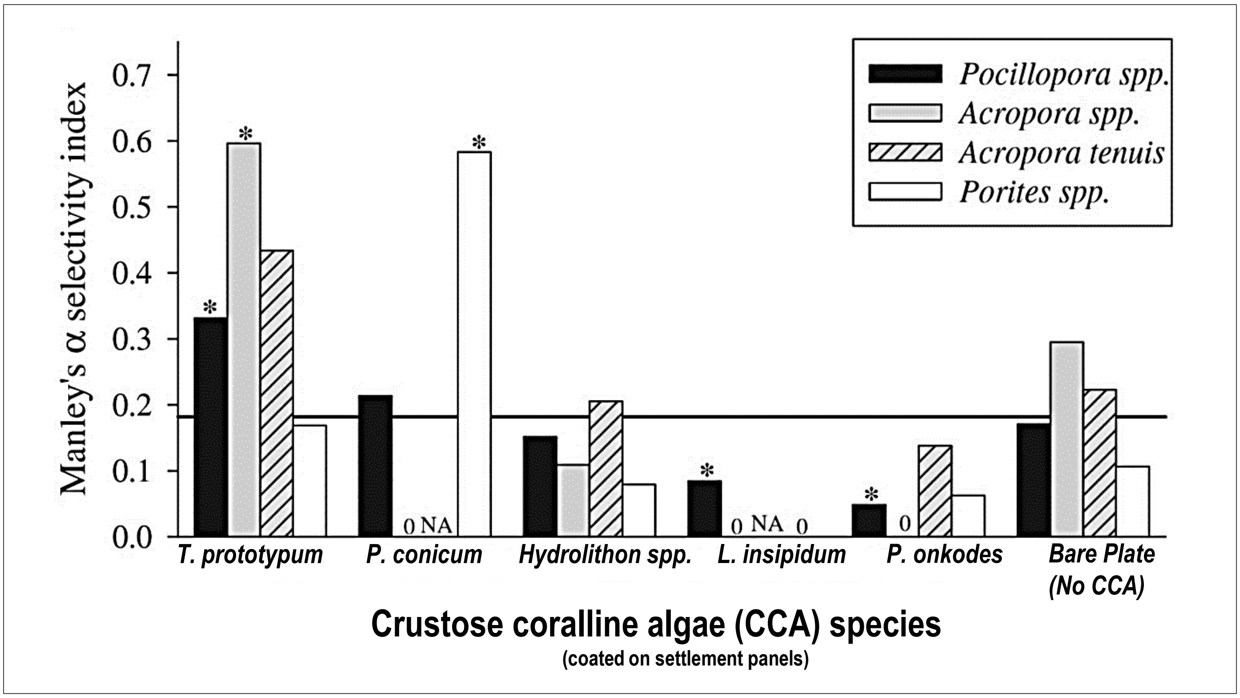

Figure 2: Selectivity indices (Manley's α) calculated for each of the possible CCA substrate choices for coral recruits (whereby 1.0 is 100% preference for that substrate). The solid line represents random or passive settlement (α=0.1667)[1].

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[1] Adapted with permission from: Price N. (2010). Habitat selection, facilitation, and biotic settlement cues affect distribution and performance of coral recruits in French Polynesia. *Oecologia Vol. 163 (3) pp 747-758. DOI: 10.1007/s00442-010-1578-4.*

DATA TEST PRACTICE

Name:

Date:

Dataset 1

Item 1 (apply understanding) 2 marks

Determine the:

a. density of *Pocilloporid* recruits in exposed habitats with high sedimentation (refer to Fig. 1A).

Answer: 2-3 m^{-2}

b. CCA species with the highest selectivity index for the majority of coral recruits (refer to Fig. 2).

Answer: *T. prototypum*

Item 2 (analyse evidence) 1 mark

Contrast the density of *Pocilloporid* recruits between cryptic habitats with high sedimentation and cryptic habitats with low sedimentation (refer to Fig. 1A).

The density of recruits in cryptic habitats with high sedimentation (~8) is significantly lower than the density of recruits in cryptic habitats with low sedimentation (~100).

Item 3 (interpret evidence) 3 marks

Justify how to best prepare settlement panels to attract the most coral recruits.

Utilise the chemical cues of CCA that induce settlement by coating the panels in a thick assemblage of *T. prototypum* to attract *Pocillopora* and *Acropora* larvae and *P. conicum* to attract *Porites* larvae (Fig. 2). In addition, orientate the settlement panels vertically to minimise the surface area subject to sedimentation (Fig. 1). Lastly, align the plates in stacks of pairs to create more 'cryptic' habitat environments, shaded and protected from predation and grazing (Fig. 1).

Dataset 2

Figure 1 and Table 2 below illustrate the effect of aragonite saturation state (Ωarag) on settlement and post-settlement growth of *Porites astreoides* larvae.

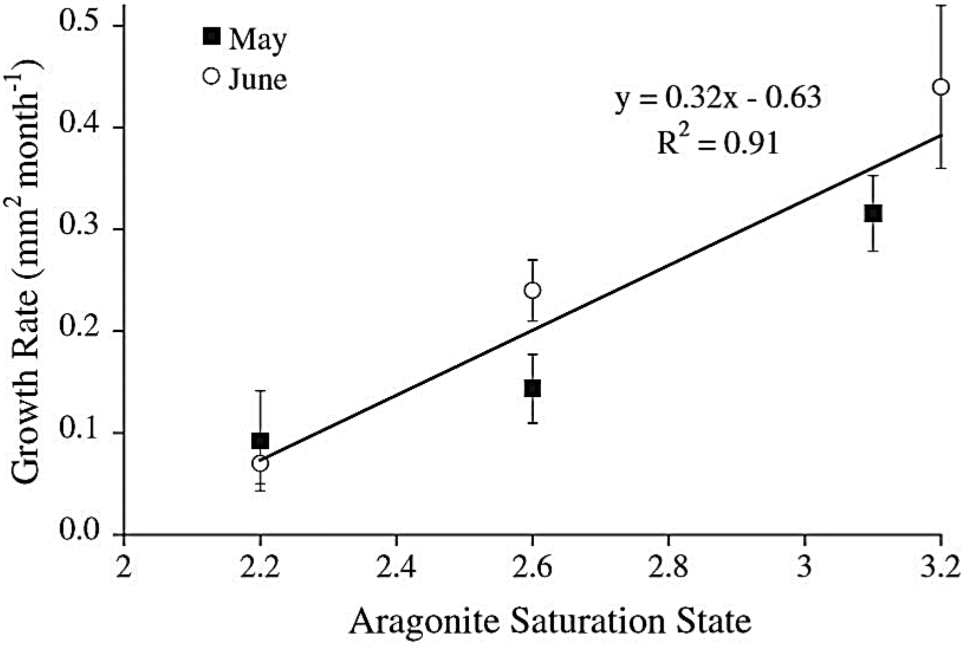

Fig. 1 Effect of saturation state on skeletal growth rate (±SE) of *Porites astreoides* juveniles ($P = 0.003$) [1]

Table 2 Percent larval settlement and juvenile growth rate (mm^2 month^{-1}) of *Porites astreoides*^{a} [1].

	Control $\Omega_{arag} = 3.2$	Mid $\Omega_{arag} = 2.6$	Low $\Omega_{arag} = 2.2$
Percent settlement			
May	34.72 ± 7.29 (12)	41.94 ± 8.82 (12)	26.39 ± 5.83 (12)
June	12.50 ± 4.95 (8)	16.67 ± 4.88 (8)	13.33 ± 3.56 (8)
Growth rate			
May	0.32 ± 0.03 (58)	0.14 ± 0.03 (73)	0.09 ± 0.05 (30)
June	0.44 ± 0.08 (14)	0.24 ± 0.03 (16)	0.07 ± 0.02 (10)

^{a} Mean ± 1 SE (n)

A flow-through seawater system was used to create and maintain three aragonite saturation states:
Ωarag = 3.2 (control),
Ωarag = 2.6 (mid), and
Ωarag = 2.2 (low)
based on *p*CO_2 levels in 2008 (control) and projected *p*CO_2 scenarios for the years 2065 (mid) and 2100 (low), respectively, as determined by the IPCC 3rd Assessment Report (2001). Treated water was then introduced to experimental aquaria at a constant rate.

Fig. 2: Part of the experimental set-up[1]

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[1] Adapted with permission from: Albright, R., Langdon, C., and Mason, B. (2008). Effect of aragonite saturation state on settlement and post-settlement growth of *Porites astreoides* larvae. *Coral Reefs. 27:485-490*

DATA TEST PRACTICE

Name:

Date:

Dataset 2

Item 4 (apply understanding) 2 marks

Calculate the growth rate of *Porites astreoides* when the aragonite saturation state (x) is 2.6 using the formula y=mx+c (refer to Fig. 1). Show working.

$y=mx+c$
$y=0.32(2.6)-0.63$
$y=0.202$

Answer: 0.202 **mm^2 month^{-1}**

Item 5 (analyse evidence) 2 marks

Identify the direction and strength of the relationship between the aragonite saturation state and the growth rate of *P. astreoides.*

The aragonite saturation state is ***positively*** correlated with the growth rate of *P. astreoides*. As one increases, the other increases. The relationship is **linear**. The relationship is relatively **strong** because the data points are close to the line of best fit and Pearson's correlation squared (R^2) is close to 1.0 (0.91).

Item 6 (interpret evidence) 3 marks

Predict the likelihood of the rate of erosion exceeding the rate of accretion in the year 2065.

In 2065, it is more likely than unlikely the rate of erosion will exceed the rate of accretion. Ωara in 2065 is projected to be 2.6 (Fig. 2) whereby the growth rate of *P. asteroides* is predicted to be 0.202 mm^2/month (Item 4 above). This is almost half (48.73%) the growth rate of *P. asteroides* in 2008 (0.394mm^2/month). The net rate of calcification is currently faster than the net rate of erosion, however, not by much. Thus, any decline in the rate of calcification, due to a decline in the aragonite saturation state, could easily tip the balance to net erosion (pg. 32).

DATA TEST PRACTICE

Name:

Date:

Dataset 3

The graphs below illustrate the spatial, temporal and taxonomic variation in coral growth.

SPATIAL, TEMPORAL AND TAXONOMIC VARIATION IN CORAL GROWTH

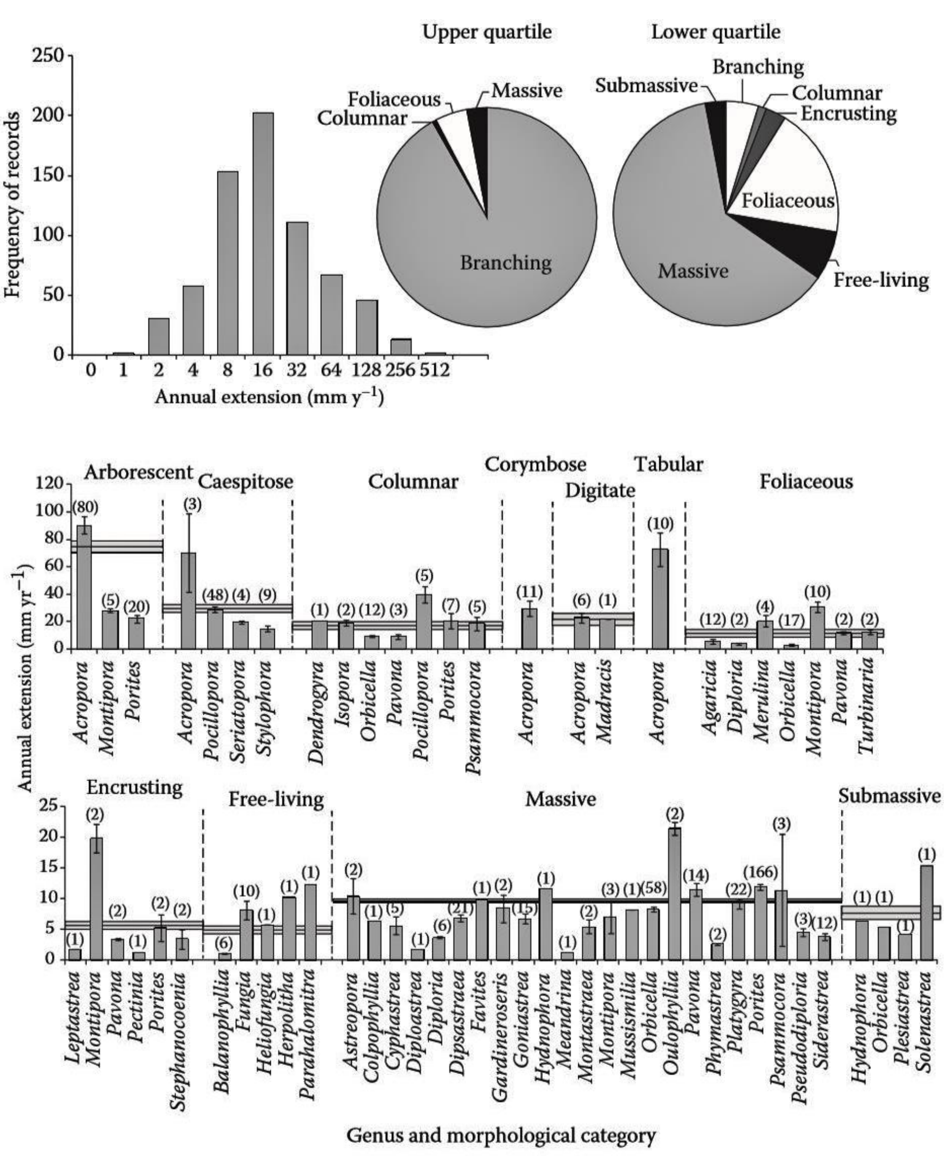

Figure 1: Variation in annual extension rates (mm) of corals with different gross morphology (shapes). Top panel shows the distribution of reported extension rates across all coral taxa (note the geometric scale showing the lower limit of each extension rate class), with pie charts showing the representation of corals with different growth forms in the upper (faster-growing taxa) and lower quartile (slower-growing taxa). Lower panel shows mean (± standard error [SE]) extension rates recorded for reef-building corals by genus and growth form. Numbers in brackets indicate the number of records for each genus. Grey horizontal bars indicate mean (±SE) extension rates for distinct growth forms (averaged across relevant taxa). No distinction is made between branch extension, radial extension, or AMR[1].

MAJOR GROWTH FORMS

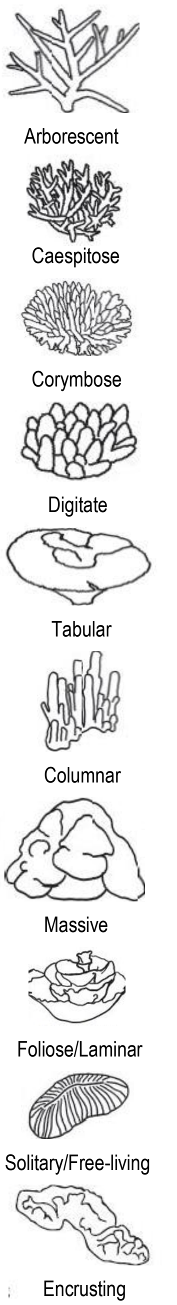

Figure 2: Scleractinian morphologies (shapes)[1].

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[1] Adapted with permission from: Pratchett, M., Anderson, K.D., Hoogenboom, M.O., Windman, E., Baird, A.H., Pandolfi, J.M., Edmunds, P.J. and Lough, J.M. (2015). Spatial, Temporal and Taxonomic Variation in Coral Growth – Implications for the Structure and Function of Coral Reef Ecosystems. *Oceanography and Marine Biology: An Annual Review. 53. pp. 215-295.*

Dataset 3

Item 7 (apply understanding) 2 marks

Determine the:

a. **morphology most represented as fast growing (refer to Figure 1 top panel).**

Answer: Branching

b. **morphology most represented as slow growing (refer to Figure 1 top panel).**

Answer: Massive

Item 8 (analyse evidence) 1 mark

Organise *Porites* coral morphologies from fastest growing to slowest growing.

Arborescent, Columnar, Massive, Encrusting (Figure 1 Lower panel)

Item 9 (analyse evidence) 2 marks

Contrast the growth rate of the two corals with the highest and second highest number of records.

The growth rate of *Acropora* arborescent coral (~90mm/year) is more than seven times faster than the growth rate of *Porites* massive coral (~12mm/year)

Item 10 (interpret evidence) 2 marks

Predict how long it takes for a *Porites* massive coral to grow from a micro-atoll that is 20cm (200mm) wide to a micro-atoll that is 2m (2000mm) wide in a healthy shallow reef lagoon (assuming there are no destructive processes eroding the coral).

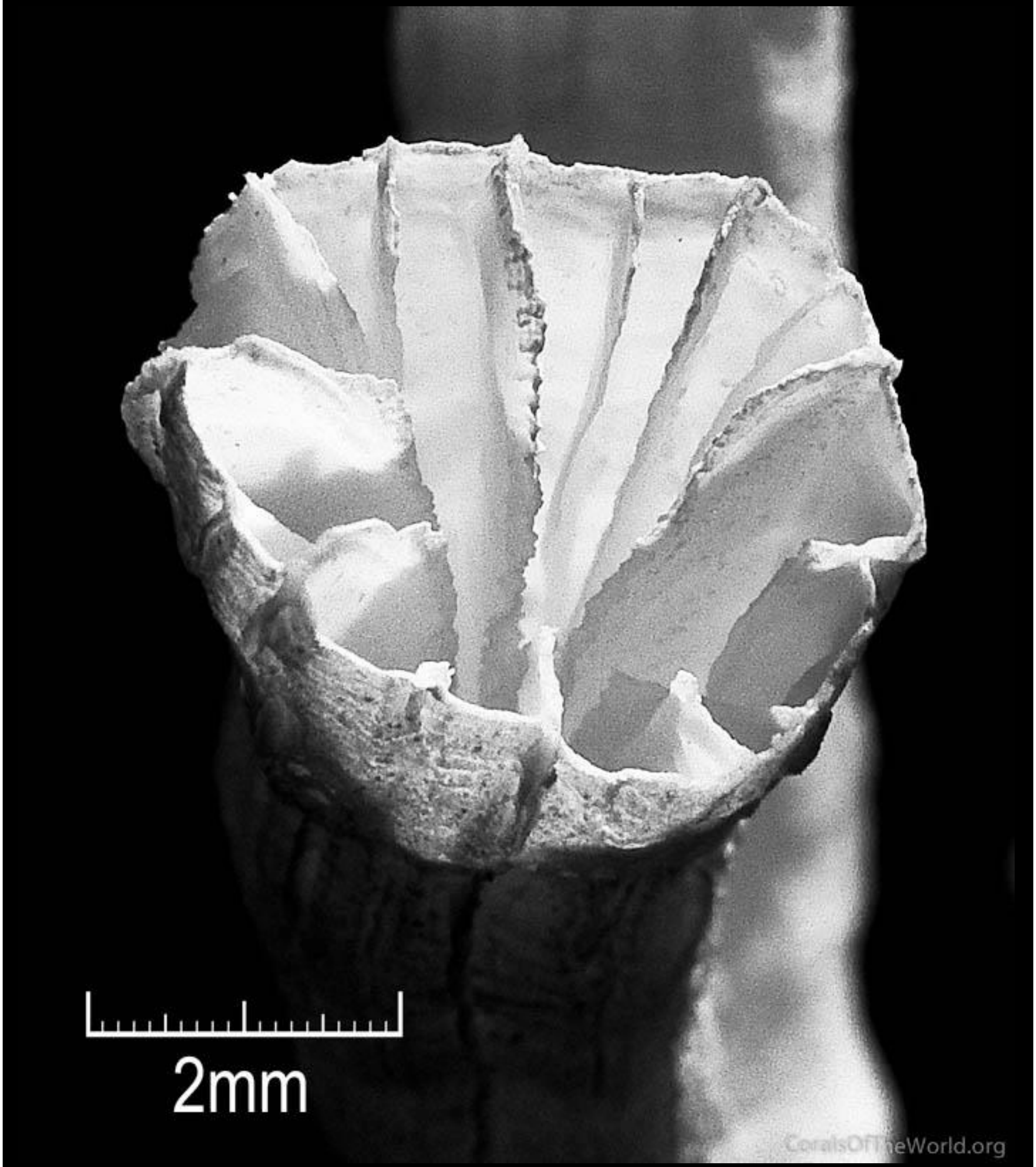
If the growth rate is ~12mm/year, and the coral grows from a micro-atoll that is 20cm (200mm) wide to a micro-atoll that is 2m (2000mm) wide, which is a difference of (2000-200) 1800mm, then it will take (1800/12) ~150 years.

END OF PAPER

Name:

Date:

An Introductory Guide to Coral Taxonomy



Euphyllia baliensis showing calice opening. INDONESIA. Photograph: Emre Turak. Reprinted with permission[1].

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[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/euphyllia-baliensis/

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Marine
Education

Game of Coral BINGO

Name:

Date:

Activity: Choose 9 different words from the word box below (*note:* they are all coral *Genus*). Write them in the boxes below. This is your BINGO card. You are now ready to play BINGO!

Acropora ***Montipora***
Galaxea ***Pocillopora*** ***Stylophora***
Favites ***Platygyra*** ***Caulastrea*** ***Lobophyllia***
Euphyllia ***Tubastrea*** ***Turbinaria***
Favia ***Porites*** ***Goniopora***
Fungia ***Isopora*** ***Merulina***
Pavona ***Leptoseris*** ***Diploria*** ***Heliofungia***

Instructions: When you hear the teacher call out one of the words on your BINGO card, mark it with a cross. When all 9 boxes are crossed, shout ‘BINGO!’. First person to shout BINGO wins.

Hard Coral SHAPES

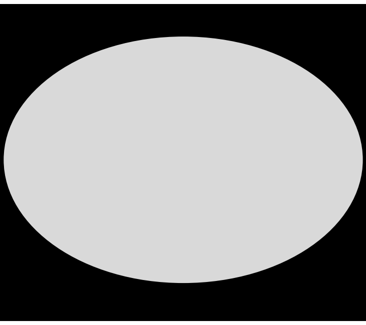
Scleractinian Growth Forms

Name:

Date:

Activity: Fill in the blanks with the following descriptive words....
Laminar Columnar Massive Encrusting Branching Foliaceous Free-living

BRANCHING coral is Branching which means it forms branches



BOULDER coral is Massive which means it is solid-like and mound-shaped

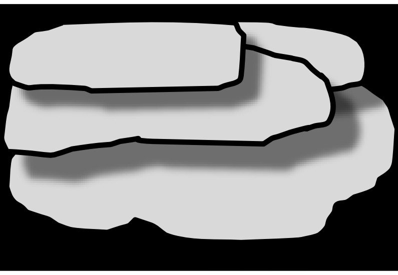
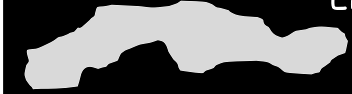
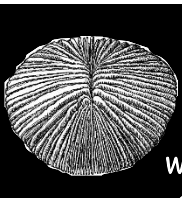


PLATE coral is Laminar which means it is plate-like



Encrusting coral is Encrusting which means it has a flat crust with the same shape as the underlying reef

Columnar coral is Columnar which means it forms thick columns (with no secondary branches)



Solitary corals are Free-living which means they are NOT attached to the substrate

Foliose coral is Foliaceous which means it forms shapes similar to foliage (i.e. a whorl, scroll, tier or vase)

The prefix 'sub' is sometimes attached to descriptive words. It means 'less than' or 'not quite'. For example, *sub*massive.

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Marine Education

Name Game

Common Hard Corals

Phylum: Cnidaria   Class: Anthozoa   Order: Scleractinia

Name:

Date:

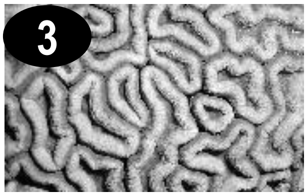
Challenge! Try to match the Common Name to the Number on the picture[1]

When you think you have finished, check your answers using www.coralsoftheworld.org/ (search the Genus on '*Species Factsheets*')

Common Name	*Genus species*	Growth Form	Number
Branching coral	*Acropora parahemprichii*	Branching	**1**
Plate coral	*Montipora foliosa*	Laminar	2
Cauliflower Coral	*Pocillopora meandrina*	Branching	7
Helmet coral	*Porites lutea*	Massive	4
Larger star coral	*Favites abdita*	Massive	5
Lesser valley coral	*Platygyra acuta*	Massive	6
Pineapple coral	*Favia leptophylla*	Massive	12
Lobed brain coral	*Lobophyllia hemprichii*	Massive	3
Galaxy coral	*Galaxea astreata*	Massive	11
Anchor coral	*Euphyllia ancora*	Massive	10
Mushroom coral	*Fungia corona*	Solitary	9
Cactus coral	*Pavona cactus*	Foliaceous	8

1


2


3


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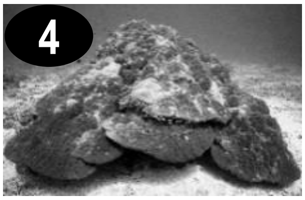

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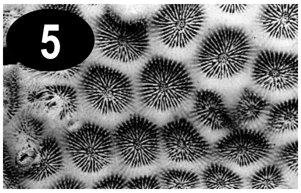

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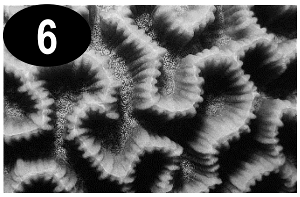

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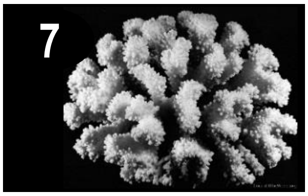

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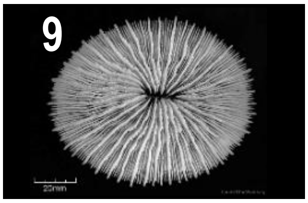

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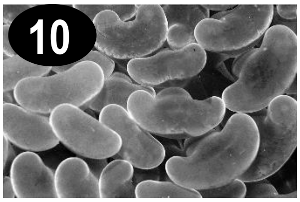

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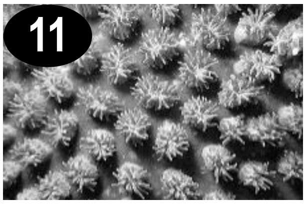

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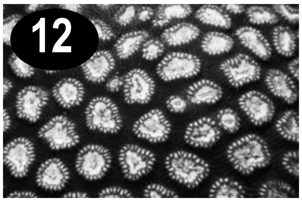

***Note*:** There are now several classifications for Scleractinian corals. Frequently cited, and used in this guide, is Veron *et al.* (2016)[1]. However, keep in mind that Wikapedia and the World Register of Marine Species (WORMS) may cite the names of scleractinian corals a little differently to Veron *et al.* (2016). For example, in Wikapedia, many Indo-Pacific corals in families Pectiniidae, Faviidae and Mussidae have been moved to families Merilinidae and Lobophyllidae. As a result, Pectiniidae was deleted, Mussidae now only has Atlantic species, Lobophyllidae is new (2009), and Merulinidae just got bigger. Thus, well-known species (such as *Goniastrea apsera)* might have a different name[2][3].

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[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World*. Accessed 02 May 2019. http://www.coralsoftheworld.org/species_factsheets/

[2] Huang D., Arrigoni, R., Benzoni, F., Fukami, H., Knowlton, N., Smith, N.D., Stolarski, J., Chou, L.M. and Budd, A.F. (2016). Taxanomic classification of the reef coral family *Lobophylliidae* (Cnidaria: Anthozoa: Scleractinia). *Zoological Journal of the Linnean Society. Vol. 178 (3). p.436-481. DOI: 10.1111/zoj.12391*

[3] Pichon, M. (2014). *Recent changes in Scleractinian coral nomenclature and classification: a practical guide for coral and reef ecologists.* James Cook University. Accessed 10 November 2018. http://www.mideastcrs.org/mcrs/sites/mcrs/files/documents/Scleractinian%20nomenclature%20update%20%28Michel%20Pichon%202014%29.pdf

Genus: *Acropora*

Name:

Date:

AXIAL and RADIAL CORALLITES

Figure 1: *Acropora muricata* showing branching pattern. GREAT BARRIER REEF, AUSTRALIA. Photograph: Veron archives. Reprinted with permission[1]

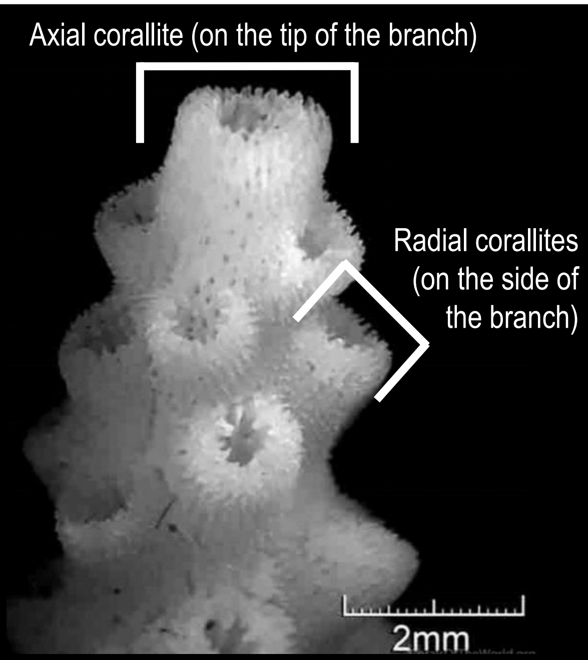

Figure 2: *Acropora muricata* showing axial corallite. GREAT BARRIER REEF, AUSTRALIA. Photograph: Veron archives. Reprinted with permission[1].

Is that BRANCHING coral *ACROPORA*?

If you are looking at a *lot* of branching coral, there is a pretty good chance it comes from the Genus ***Acropora*.** But, if you want to be sure, simply look at the very tip of a branch. If there is a single corallite (the 'cup' that holds the polyp) at the very tip of the branch, then it is *Acropora*!!! This corallite is called the **axial corallite.** It is the starting point of every branch. As it grows, its corallite 'cup' grows into a 'tube' and forms the central *axis* of the branch. All the other *Acropora* corallites are called **radial corallites**. Radial corallites grow around the sides of branches**.** Radial corallites come in a range of shapes that are used to help identify each species (Figure 2).

Q. What are the two types of corallites unique to *Acropora*? Ans. Axial and radial

Q. What shape category is the radial corallite in Figure 2? Ans. Appressed tabular

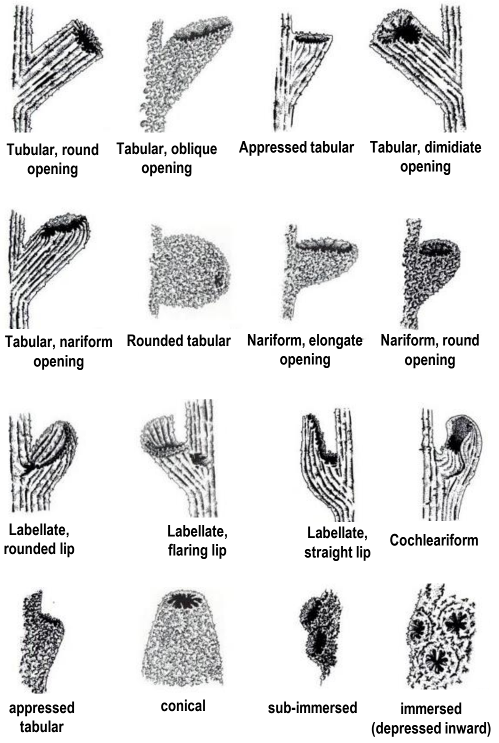

Figure 3: *Acropora* radial corallite shape categories. Adapted from Wallace (1999) with permission from CSIRO Publishing[2]

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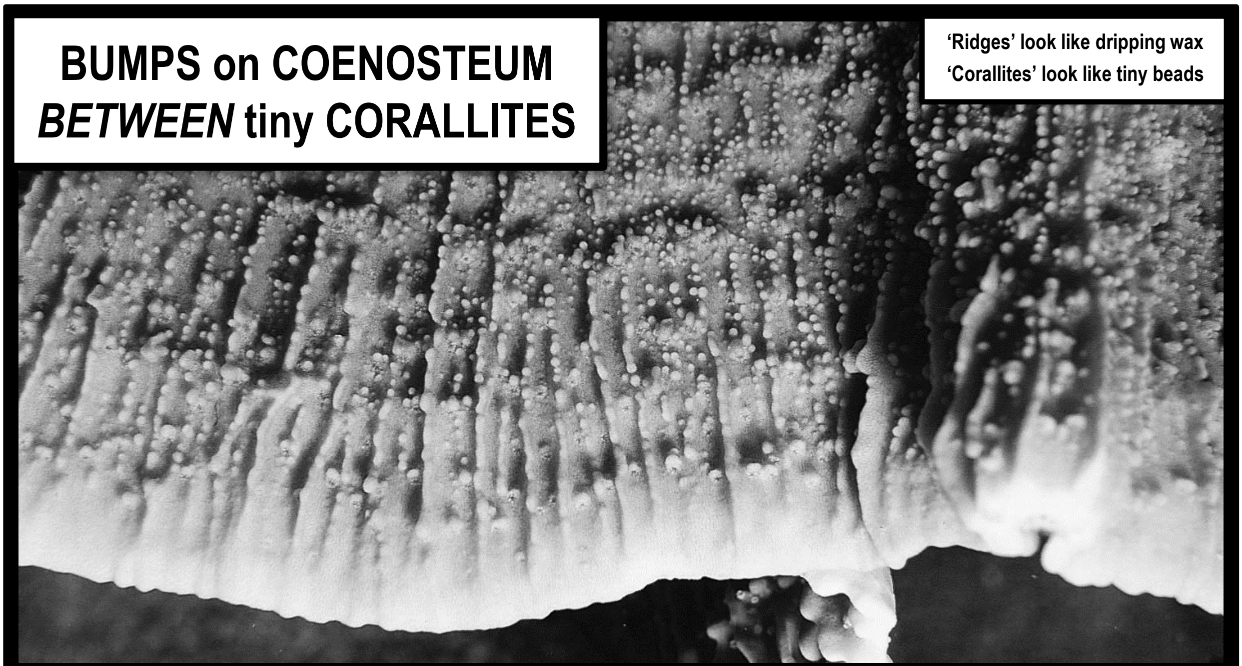
[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 05 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/acropora-muricata/

[2] Wallace, Carden C & CSIRO (1999). *Staghorn corals of the world : a revision of the coral genus Acropora (Scleractinia; Astrocoeniina; Acroporidae) worldwide, with emphasis on morphology, phylogeny and biogeography*. CSIRO Publishing, Clayton, Vic

Genus: *Montipora*

Name:

Date:



BUMPS on COENOSTEUM *BETWEEN* tiny CORALLITES

‘Ridges’ look like dripping wax
‘Corallites’ look like tiny beads

Figure 1: *Montipora foliosa* Broken coenosteum ridges. GREAT BARRIER REEF, AUSTRALIA. Photograph: Charlie Veron. Reprinted with permission[1].

Montipora are perhaps best known as some form of *bumpy* plate coral or *bumpy* encrusting coral (sometimes with random branches jutting upwards). The bumpy appearance is due to the bumps or ridges that grow on its skeleton, *between* the tiny corallites on the **coenosteum** (Figure 2).

- Sometimes the bumps are small (papillae).
- Sometimes the bumps are big (tuberculae).
- Sometimes the bumps are *very* big and dome-like (verrucae).
- Sometimes the bumps fuse to make ridges (Figure 1).
- Sometimes there are no bumps.

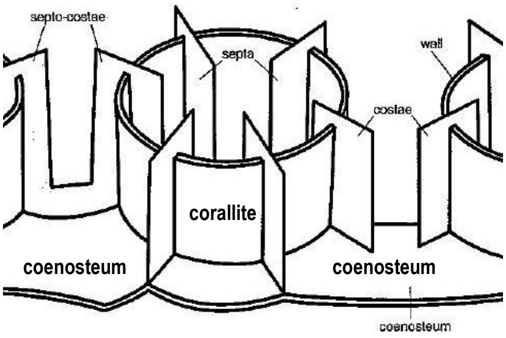


Figure 2: The coenosteum is located *between* the corallites[2].

Activity: Complete the table below using the *Species Factsheets* on www.coralsoftheworld.org

Genus species	**Coenosteum Description**
Montipora informis	The coenosteum is covered with elongate papillae of uniform length
Montipora danae	Large rounded verrucae which are dome-shaped or partly fused into radiating ridges
Montipora digitata	The coenosteum is smooth

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[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 05 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/montipora-foliosa/

[2] Adapted with permission from: Veron, J.E.N. and Stafford-Smith M.G. (2000). *Corals of the World: Volume 1*. Australian Institute of Marine Science and CRR Qld Pty Ltd. Townsville, Australia. Page 49.

Genus: *Pocillopora*

Name:

Date:

VERRUCAE (BIG bumps) *COVERED IN* CORALLITES

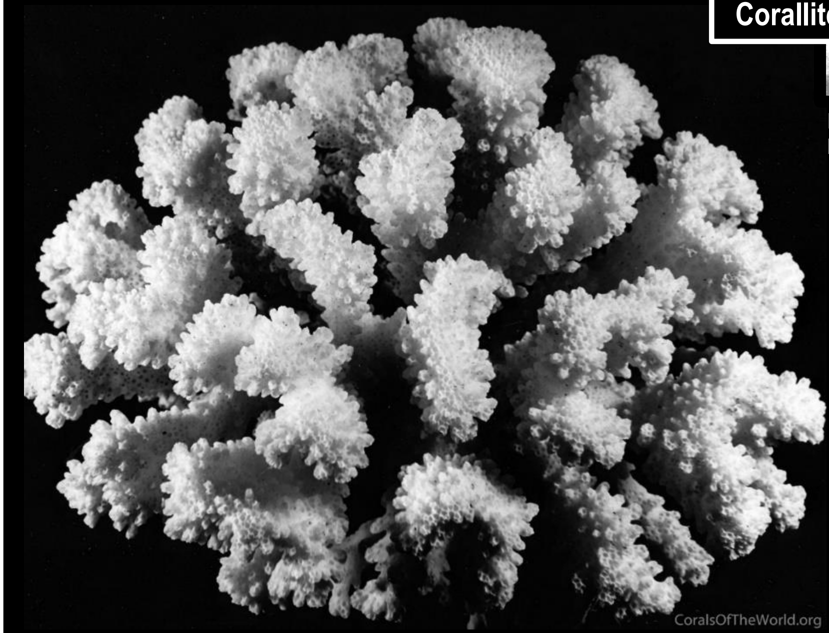

Figure 1: Cauliflower coral *Pocillopora meandrina.* HAWAII Photograph: Veron archives. Reprinted with permission[1].

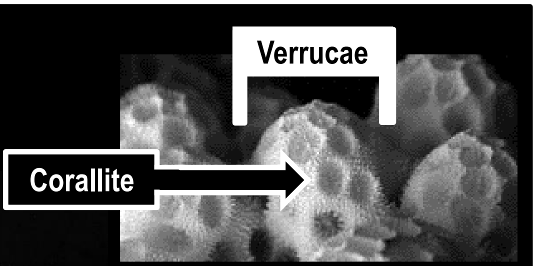

Figure 2: *Pocillopora fungiformis* Showing verrucae. MADAGASCAR. Photograph: Veron archives[2]

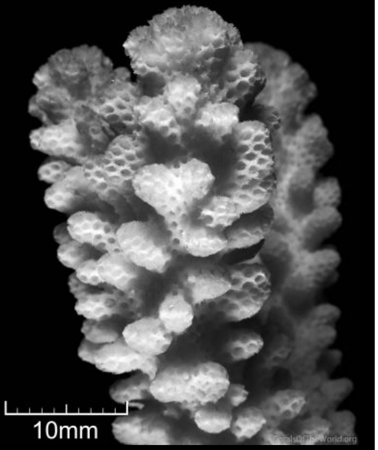

Figure 3: *Pocillopora capitata* Showing branch end. EASTER ISLAND, SOUTH PACIFIC OCEAN. Photograph: Veron archives[3]

Pocillipora are tough, weed-like branching corals (although still very colourful) occurring in habitats ranging from exposed reef-fronts and wave-washed reef flats to protected lagoons and lower reef slopes.
They do *not* have the axial and radial corallites like *Acropora*.
Instead, they have **verrucae** (dome-like bumps).
Can you see tiny holes on the verrucae? These tiny holes are corallites!

Activity: Complete the table below using the *Species Factsheets* on www.coralsoftheworld.org

Genus species	**Verrucae Description**
Pocillopora eydouxi	Verrucae are uniform in shape and spacing
Pocillopora meandrina	Verrucae are neat and uniform
Pocillopora ankeli	Verrucae are small and crowded. Corallites are crowded on verrucae

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[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/pocillopora-meandrina/
[2] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/pocillopora-fungiformis/
[3] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/pocillopora-capitata/

Genus: *Porites*

Name:

Date:

SMALL CORALLITES SMOOTH APPEARANCE

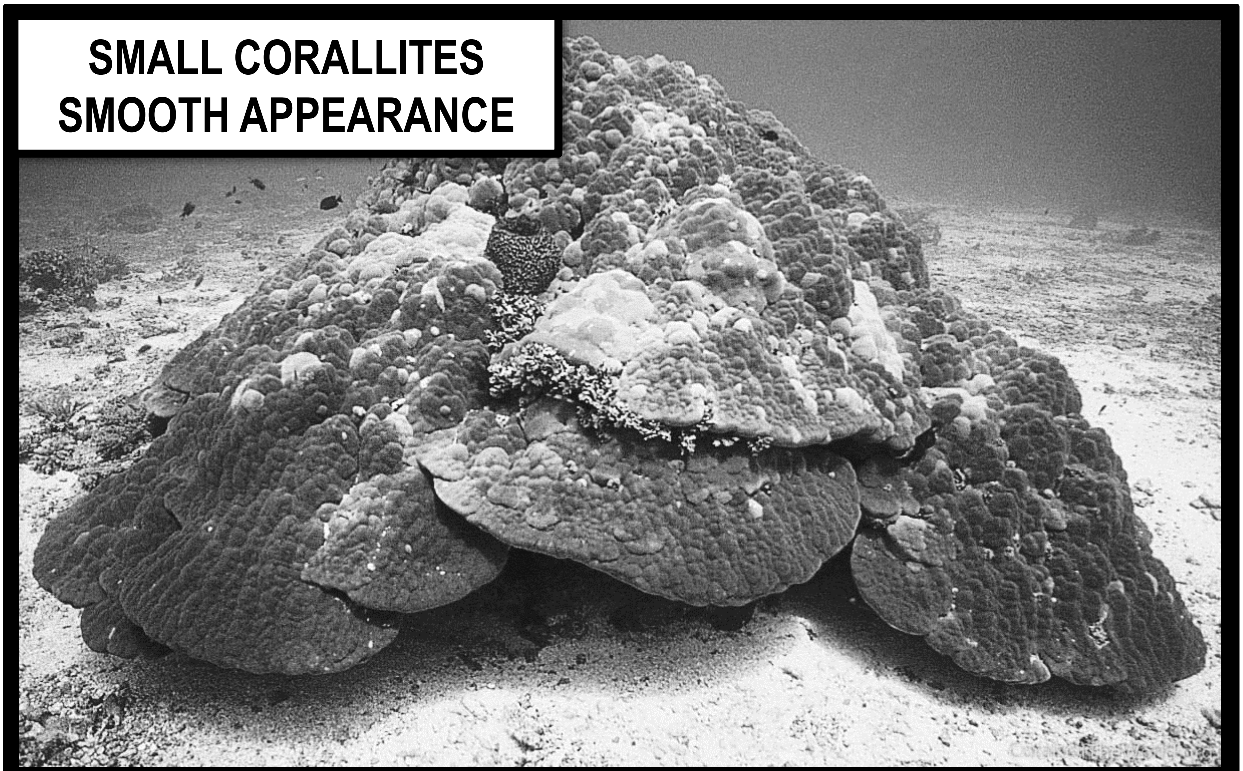

Figure 1: *Porites lutea* A large helmet-shaped colony. GREAT BARRIER REEF, AUSTRALIA. Photograph: Charlie Veron. Reprinted with permission[1].

***Porites* have very small corallites (<2mm) thus the colony often has a smooth appearance**

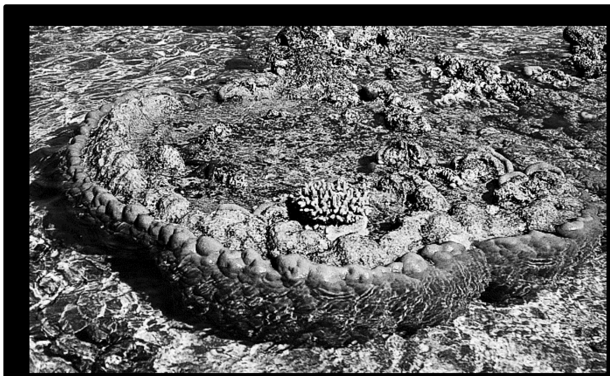

Figure 2: *Porites lutea* An intertidal 'micro-atoll'. GREAT BARRIER REEF, AUSTRALIA. Photograph: Charlie Veron. Reprinted with permission[1].

Figure 3: *Porites profundus* Branches dropping over an overhang. PAPUA NEW GUINEA. Photograph: Charlie Veron. Reprinted with permission[2].

Colonies come in a great variety of shapes - from flat (laminar or encrusting) to massive (Figures 1 & 2) or branching (Figure 3). However, they are perhaps best known as the helmet-shaped colonies in deeper water (Figure 1) or the circular, flat-top structures on reef flats called 'micro-atolls' (Figure 2).

Q. What two shapes are recognisably *Porites* coral? Ans.

Helmet-shape and the micro-atoll

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[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/porites-lutea/

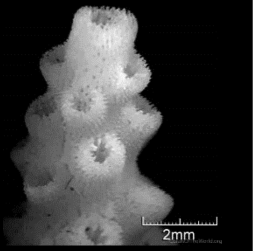
[2] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/porites-profundus/

KNOWLEDGE REVIEW 1

Name:

Date:

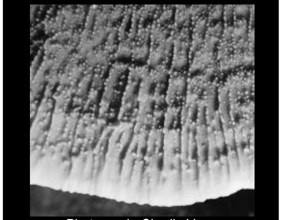
Acropora



Photograph: Charlie Veron

Axial and radial corallites

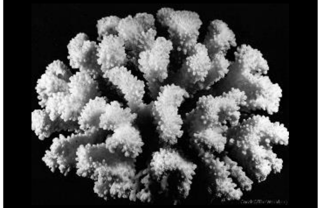
Montipora



Photograph: Charlie Veron

Bumps on coenosteum *between* tiny corallites

Pocillopora



Photograph: Charlie Veron

Verrucae (big bumps) *covered in* corallites

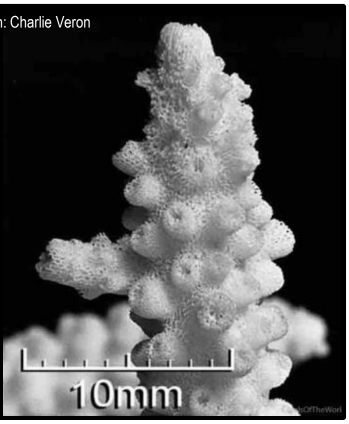
Porites

Photograph: Charlie Veron

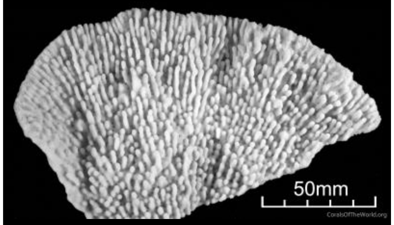
Small corallites Smooth appearance

Activity: Identify the coral samples below[1]. Choose from one of the four Genus pictured above[1].

Photograph: Charlie Veron



Genus: Acropora

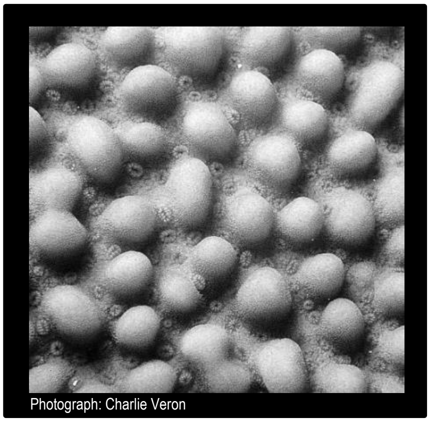


Photograph: Emre Turak and Charlie Veron

Genus: Montipora

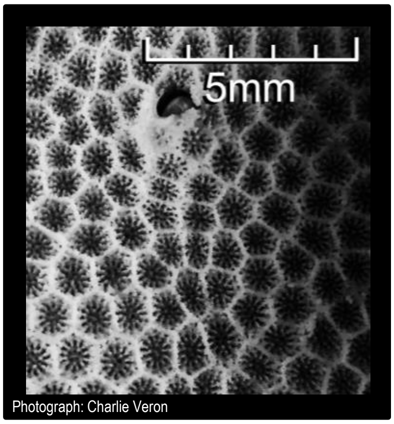
Photograph: Charlie Veron

Genus: Acropora



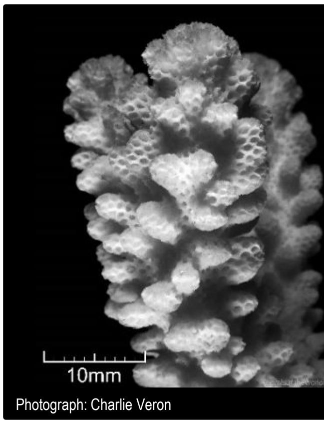
Photograph: Charlie Veron

Genus: Montipora



Photograph: Charlie Veron

Genus: Porites



Photograph: Charlie Veron

Genus: Pocillopora

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[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World*. Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/

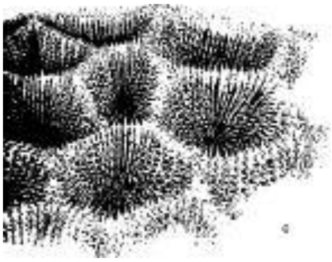
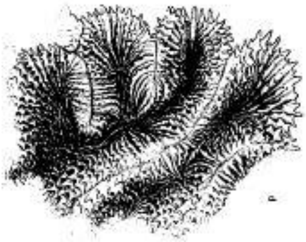
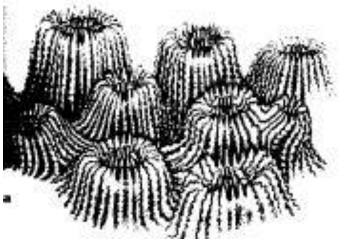
It has a What?

Coral ID Terminology

Name:

Date:

When identifying species, the terminology used to describe the shape of the corallite skeleton include:

Shape of corallites	Diagram[1]	Description
CERIOID		The corallites share a common wall. No valleys.
MEANDROID		The corallites create valleys that share a common **wall.**
PLOCOID		The corallites have their own separate walls – not shared.
PHACELOID		The corallites have their own separate walls – not shared. But, unlike Placoid corallites, the walls are long and tubular (stalk-like).
FLABELLO-MEANDROID		The corallites have formed valleys. But, unlike meandroid corallites, the valleys do NOT share walls.

---

[1] Adapted with permission from: Veron, J.E.N. and Stafford-Smith M.G. (2000). *Corals of the World: Volume 1.* Australian Institute of Marine Science and CRR Qld Pty Ltd. Townsville, Australia. Page 55.

Genus: *Favites*

Name:

Date:

Most Favites **have cerioid corallites, meaning, the corallites share a common wall[1]**

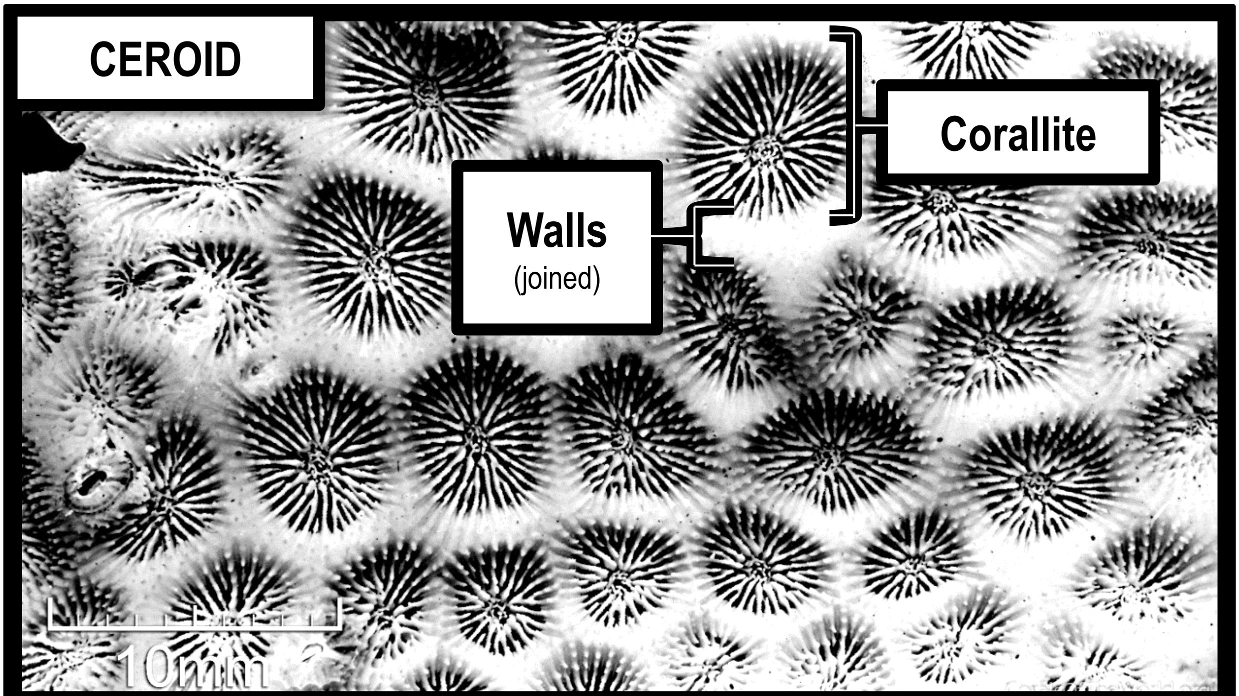


Figure 1: *Favites abdita* Showing corallites. GREAT BARRIER REEF, AUSTRALIA. Photograph: Veron archives. Reprinted with permission[1].

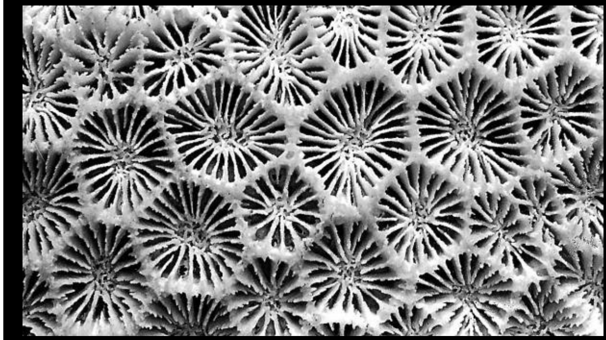


Figure 2: *Favites chinensis* Showing corallites. GREAT BARRIER REEF, AUSTRALIA. Photograph: Veron archives. Reprinted with permission[2]

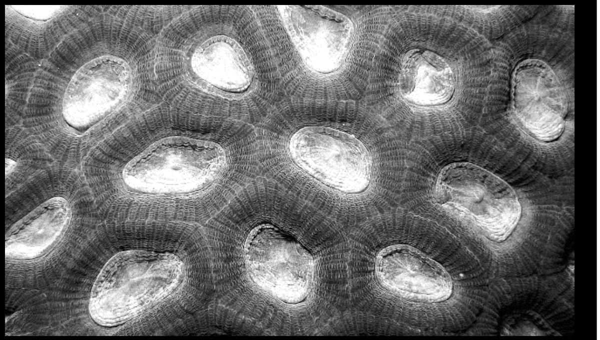


Figure 3: *Favites paraflexuosa* Corallite detail (alive). PHILLIPINES. Photograph: Veron archives. Reprinted with permission[3].

Activity: Complete the table below using the *Species Factsheets* on www.coralsoftheworld.org

Genus species	**Wall Description**
Favites acuticollis	Thin angular walls giving colonies a honeycomb appearance
Favites vasta	Corallites are deep and angular and have very thick walls

---

[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/favites-abdita/

[2] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/favites-chinensis/

[3] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/favites-paraflexuosa/

Genus: *Platygyra*

Name:

Date:

Platygyra have meandroid corallites, meaning, they create valleys that share a common wall

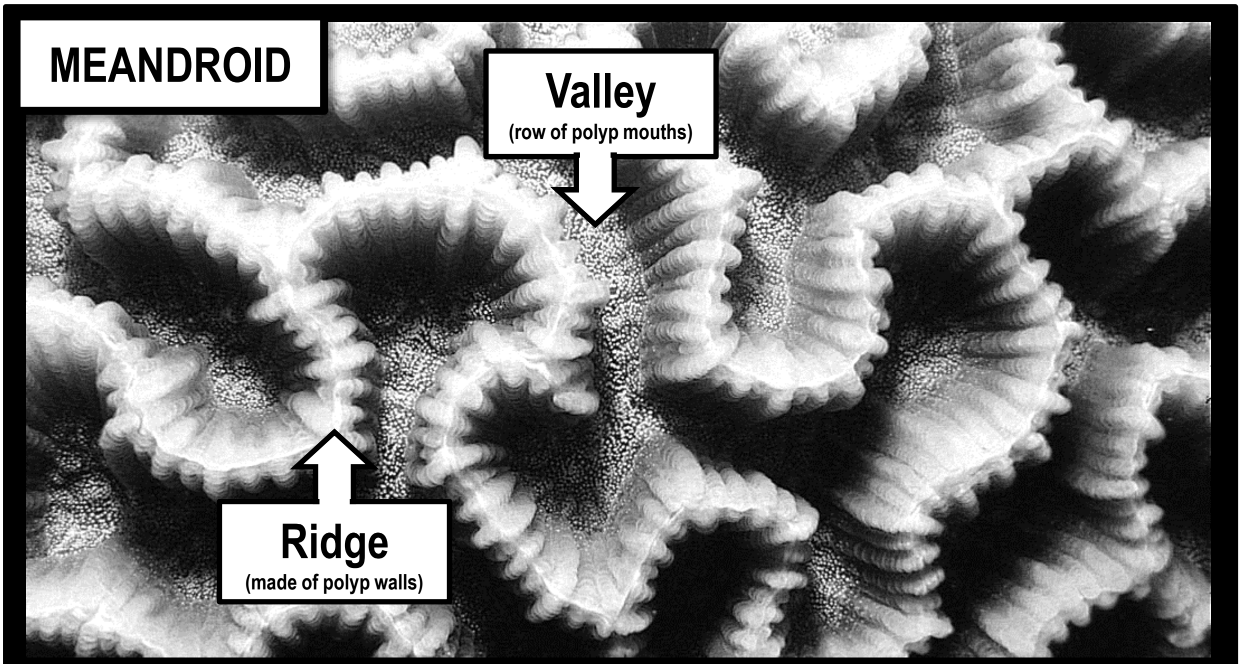


Figure 1: *Platygyra acuta.* SEYCHELLE ISLANDS. Photograph: Charlie Veron. Reprinted with permission[1] .

BRAIN corals

Platygrya (and *Leptoria*) are often called **brain** coral.

- The technical term used to describe their brain-like appearance is ***meandroid***
- Dividing polyps form walls along their sides (forming the ridges) but not between their mouths (forming the valleys).

For example, look at the ridges (high walls) and valleys (deep channels) in Figure 2. If this were alive, it would be covered in a thin layer of soft tissue, and the polyp mouths would be sitting side by side in the valleys.

The average length and width of the valley is a common measurement tool used to ID different species.

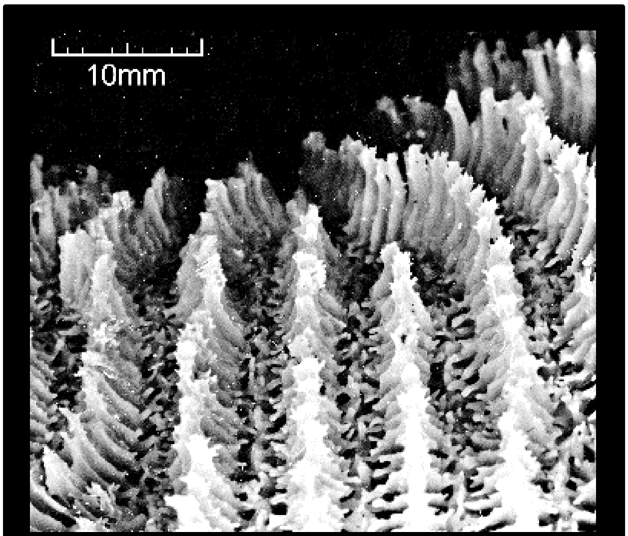


Figure 2: *Platygyra daedalea* Showing valleys. GREAT BARRIER REEF, AUSTRALIA. Photograph: Veron archives. Reprinted with permission[1] .

Q. How wide (in mm) is a valley of *Platygyra daedalea* in Figure 2? Ans. ~4mm

Q. Are the valleys on *Platygrya daedalea* 'long' or 'short'? Ans. long

---

[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/platygyra-acuta/

[2] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 27 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/platygyra-daedalea/

Genus: *Favia (Dipsastraea)*

Note: Favia corals in the Indo-Pacific may instead have the Genus name *Dipsastraea*[2]

Name:

Date:

***Favia* have plocoid corallites, meaning, they have their own separate walls – not shared**

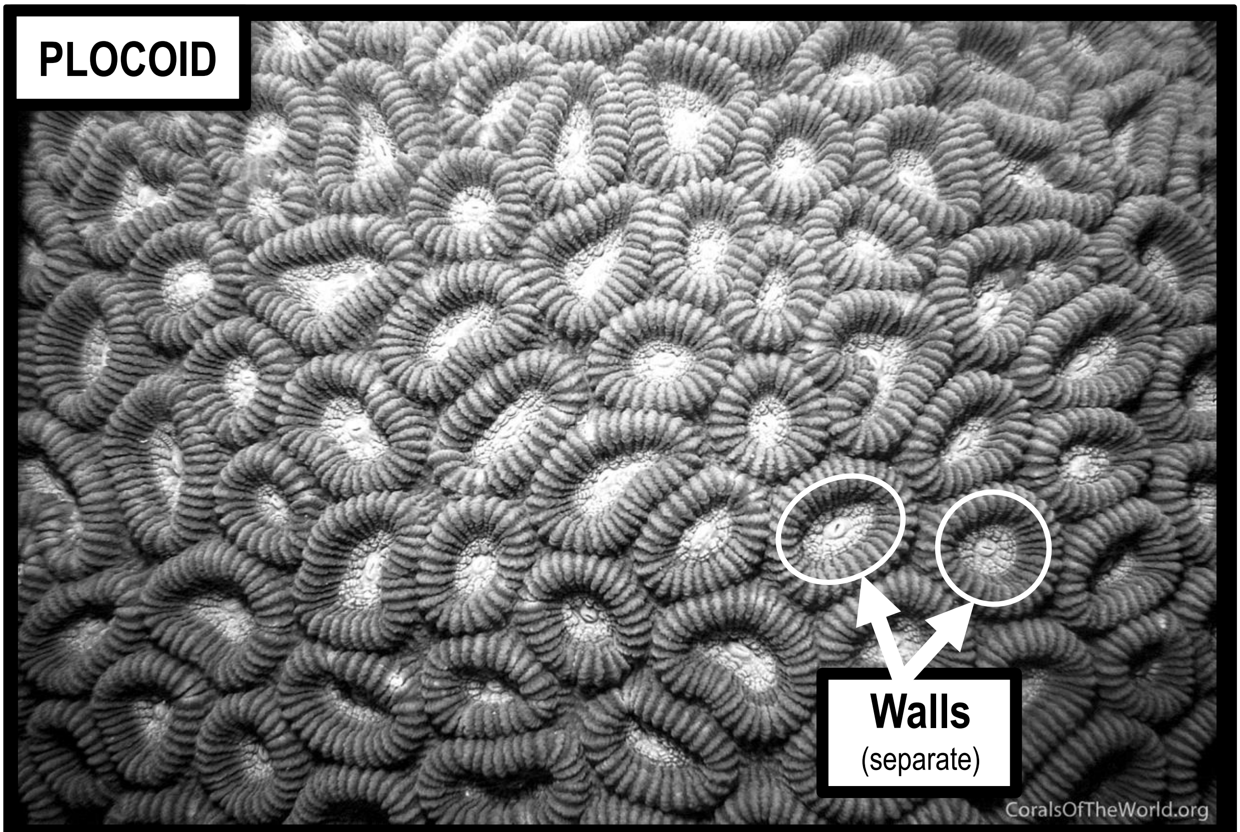


Figure 1: *Favia lizardensis* The characteristic shape and common colour of corallites SEYCHELLES ISLANDS. Photograph: Charlie Veron. Reprinted with permission[1].

In *Favia* corals, the colour *inside* a corallite wall is usually very different to the colour *outside* a corallite wall.
Note: different colonies (same species) can also be different colours

Activity: Complete the table below using the *Species Factsheets* on www.coralsoftheworld.org

Genus species	**Colour inside corallite wall**	**Colour outside corallite wall**
Favia speciosa	cream	green
Favia speciosa **(different colony)**	orange/brown	green
Favia pallida	pale yellow	dark brown
Favia pallida **(different colony)**	cream	dark brown

---

[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). Corals of the World. Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/favia-lizardensis/

[2] Pichon, M. (2014). *Recent changes in Scleractinian coral nomenclature and classification: a practical guide for coral and reef ecologists.* James Cook University. Accessed 10 November 2018. http://www.mideastcrs.org/mcrs/sites/mcrs/files/documents/Scleractinian%20nomenclature%20update%20%28Michel%20Pichon%202014%29.pdf

Genus: *Caulastrea*

Note: also spelt *Caulastraea*

Name:

Date:

***Caulastrea* have phaceloid corallites, meaning, they are long and tubular with separated walls**

PHACELOID

Corallites long and tubular with separated walls

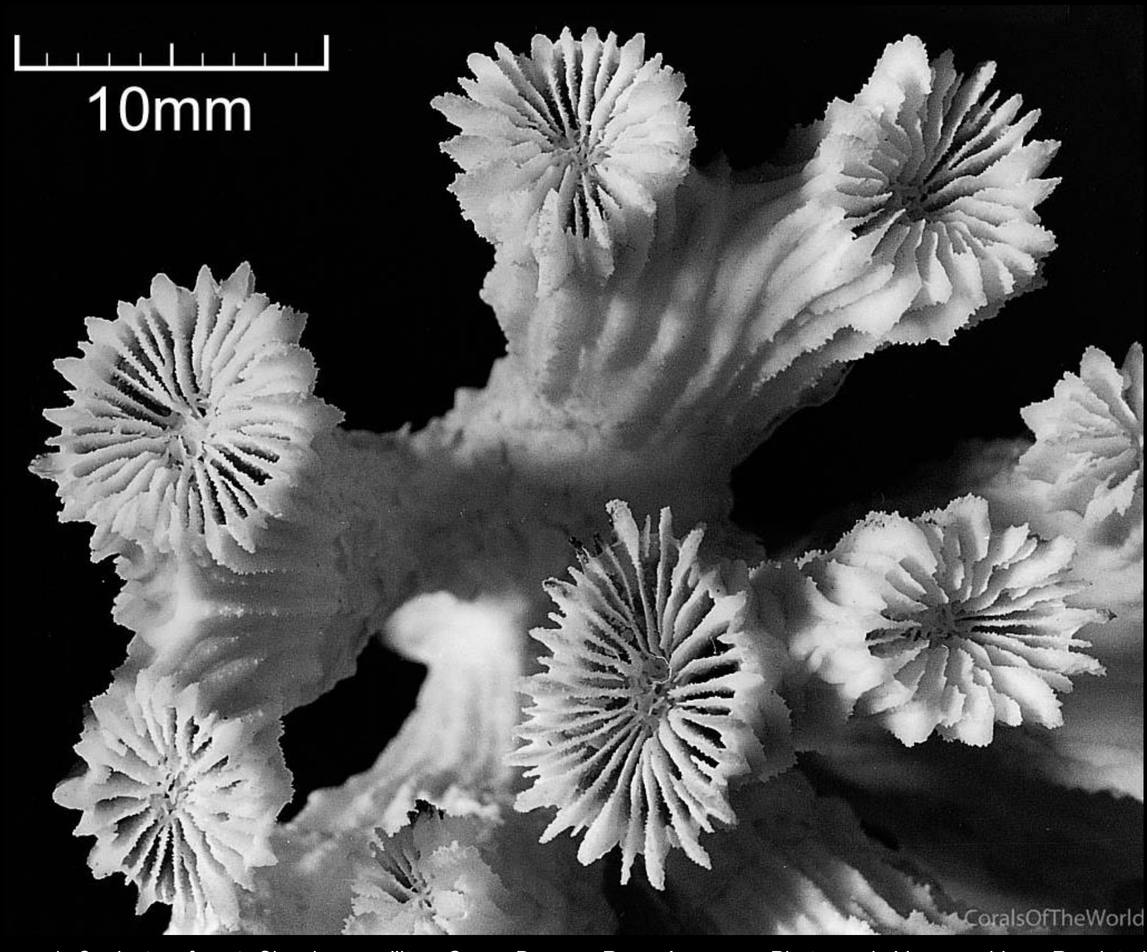


Figure 1: *Caulastrea furcata* Showing corallites. GREAT BARRIER REEF, AUSTRALIA Photograph: Veron archives. Reprinted with permission[1].

Q. How are plocoid and placeloid corallites the same? Ans.

Both have their own separate walls – not shared

Q. How are plocoid and placeloid corallites different? Ans.

Phaceloid corallites are longer and more tubular

---

[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/caulastrea-furcata/

Genus: *Lobophyllia*

Name:

Date:

Lobophyllia **have phaceloid to flabello-meandroid corallites.**
Flabello-meandroid means the corallites have formed valleys. But the valleys do NOT share walls.

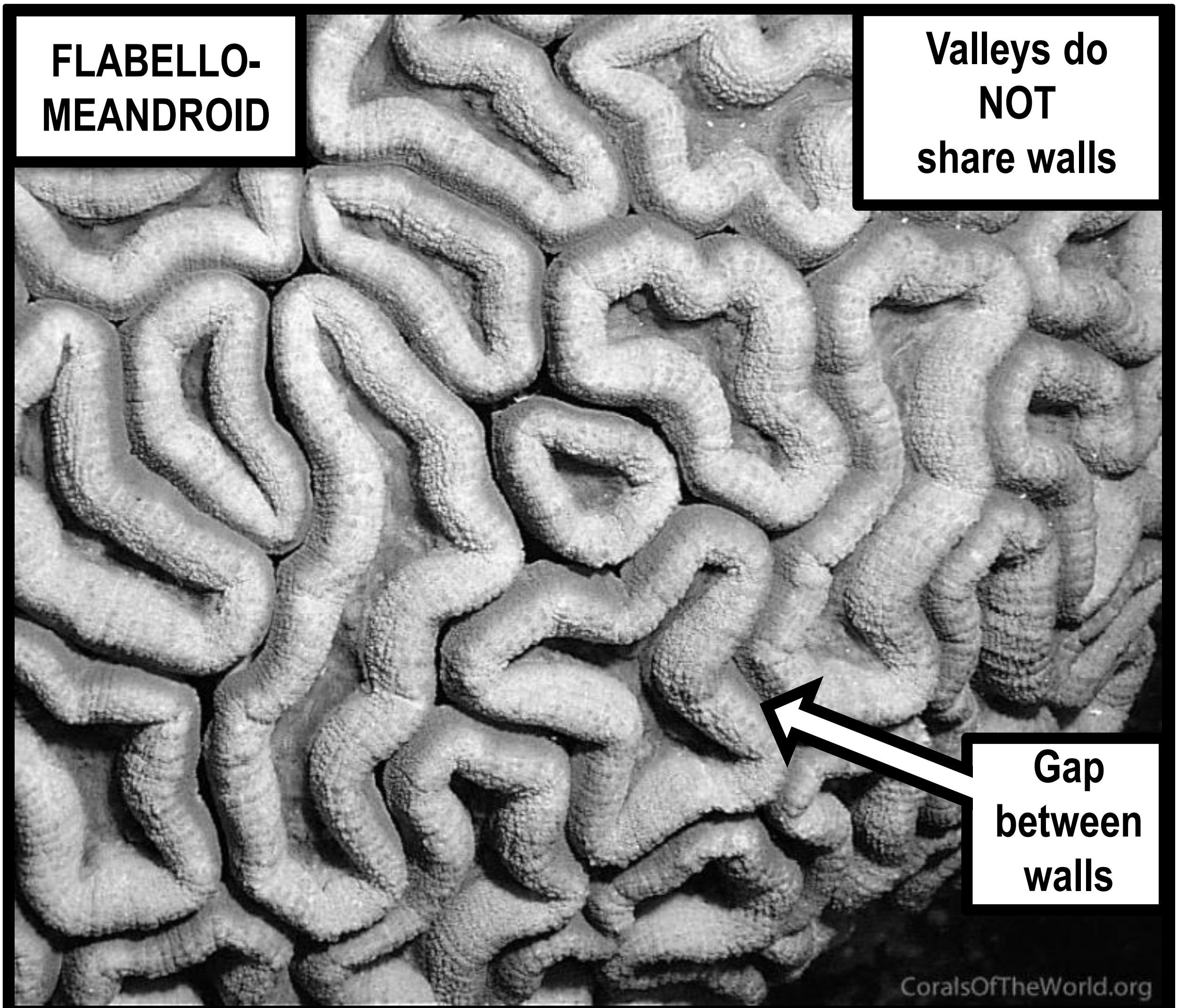


Figure 1: *Lobophyllia hemprichii* Corallite detail. VIETNAM. Photograph: Charlie Veron. Reprinted with permission[1].

Q. What is flabello-meandroid? Ans.

It is when the corallites have formed valleys. But the valleys do NOT share walls (unlike meandroid).

---

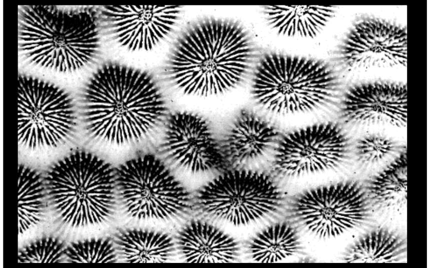
[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/lobophyllia-hemprichii/

KNOWLEDGE REVIEW 2

Name:

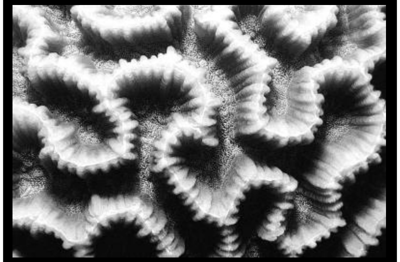
Date:

Favites



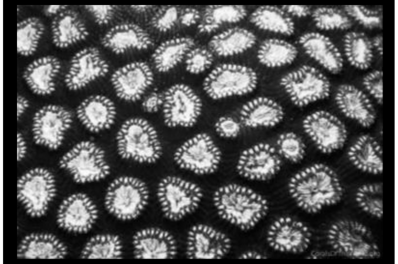
Photograph: Veron archives[1]

Platygyra



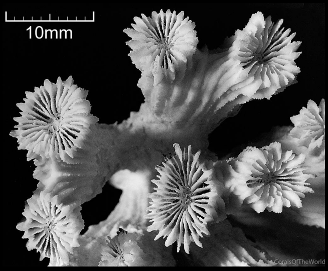
Photograph: Charlie Veron[1]

Favia (Dipsastraea)



Photograph: Charlie Veron[1]

Caulastrea



Photograph: Veron archives[1]

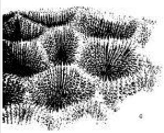
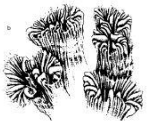
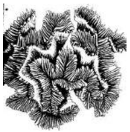
Lobophyllia

Photograph: Charlie Veron[1]

Favia (Dipsastraea)

Photograph: Charlie Veron[1]

Activity: Complete the table below (choose from one of the five Genus pictured above[1])

Shape	Diagram[2]	Description	Genus
CERIOID		The corallites share a common wall. No valleys.	*Favites*
MEANDROID		The corallites create valleys that share a common **wall.**	*Platygrya*
PLOCOID		The corallites have their own separate walls – not shared.	*Favia*
PHACELOID		The corallites have their own separate walls – not shared. But, unlike Placoid corallites, the walls are long and tubular.	*Caulastrea*
FLABELLO-MEANDROID		The corallites have formed valleys. But, unlike meandroid corallites, the valleys do NOT share walls.	*Lobophyllia*

---

[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/

[2] Adapted with permission from: Veron, J.E.N. and Stafford-Smith M.G. (2000). *Corals of the World: Volume 1.* Australian Institute of Marine Science and CRR Qld Pty Ltd. Townsville, Australia. Page 55.

Genus: *Galaxea*

Name:

Date:

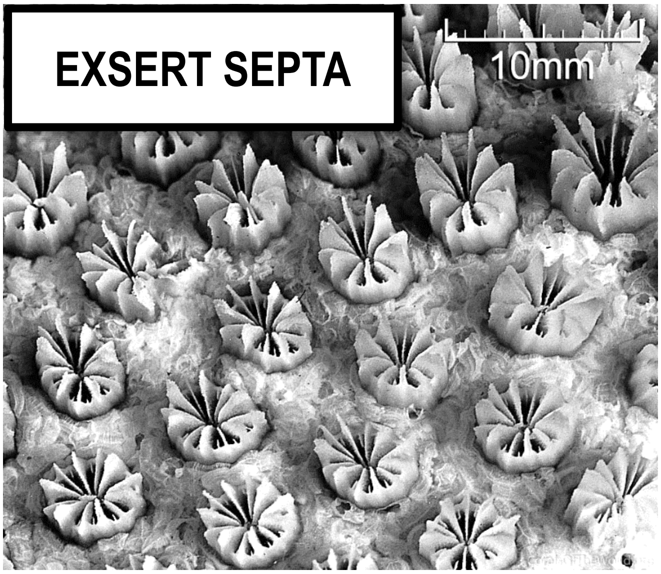


Figure 1: ***Galaxea astreata*** **showing corallites. GREAT BARRIER REEF, AUSTRLAIA. Photograph: Veron archives. Reprinted with permission[1].**

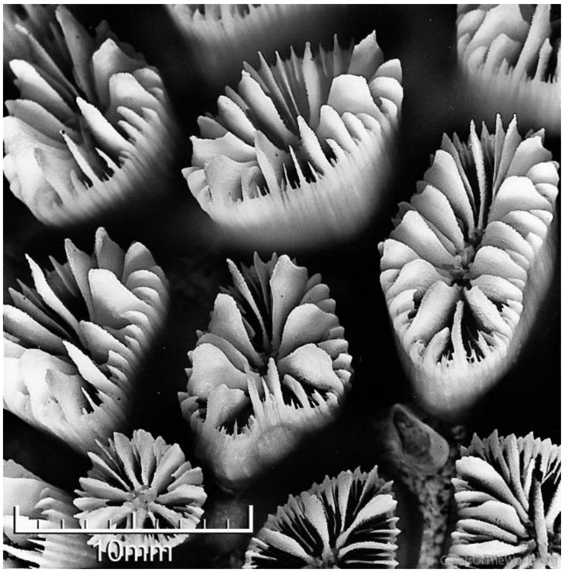


Figure 2: ***Galaxea fascicularis*** **showing corallites. GREAT BARRIER REEF, AUSTRALIA. Photograph: Veron archives. Reprinted with permission[2].**

Figure 3: ***Galaxea astreata*** **Corals growing in conditions of low light are usually flat plates with widely spaced corallites. PHILIPPINES. Photograph: Charlie Veron. Reprinted with permission[1].**

Figure 4: ***Galaxea acrhelia*** **showing corallites. GREAT BARRIER REEF, AUSTRALIA. Photograph: Veron archives. Reprinted with permission[3].**

Galaxea have **exsert** septa

Septa that extend above the top of the corallite wall are referred to as *exsert* septa.

Note: the term *'exsert'* can also be used to describe *corallites* that clearly project above surrounding structures (e.g. exsert corallites).

Q. What are EXSERT septa? Ans.

Septa that extend above the top of the corallite wall.

---

[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/galaxea-astreata/

[2] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/galaxea-fascicularis/

[3] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/galaxea-acrhelia/

Genus: *Euphyllia*

Name:

Date:

LARGE, FLESHY TENTACLES
(or vesicles)
EXTENDED night *AND* DAY

Common Names
Anchor Coral
Hammer Coral

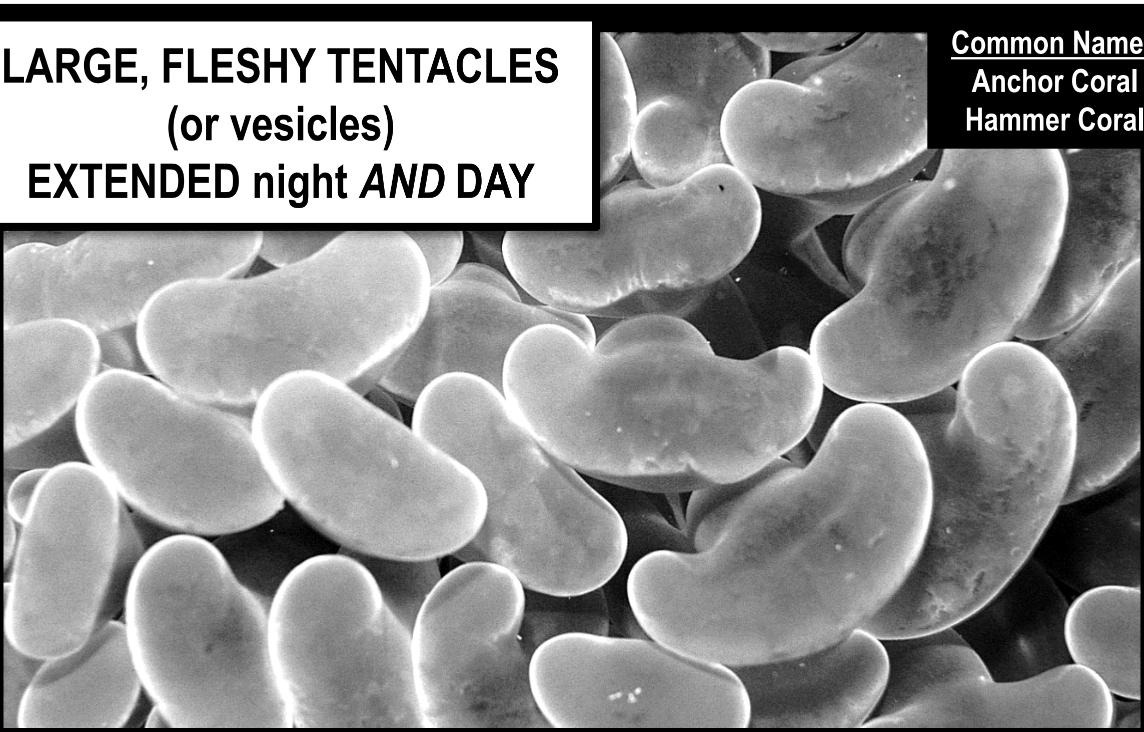


Figure 1: *Euphyllia ancora* variation in tentacle shape and colour. This variation is common throughout the geographical range. PHILIPPINES. Photograph: Charlie Veron. Reprinted with permission[1].

Phaceloid (trumpet-like) corallites

- Grape coral (*E. cristata*)
- Torch coral (*E. glabrescens)*
- Branching anchor coral (*E. paraancora*)
- Branching frogspawn coral (*E. paradivisa*)
- Bubble coral (E. baliensis)

Flabello-meandroid corallites

- Brain anchor coral (*E. ancora*)
- Frogspawn coral (*E. divisa*)

Phaceloid to Flabello-meandroid

- Thick branched frogspawn coral (*E. yaeyamaenesis*)

Figure 2: *Euphyllia cristata* Solitary polyp with tentacles fully extended. The tall primary septa radiating like spokes of a wheel. PAPUA NEW GUINEA. Photograph: Neville Coleman. Reprinted with permission[2].

Q. What large, fleshy structures are extended night *and day* making this Genus easy to ID? Ans.
Hint: the shape of this structure is often the inspiration for their common name!!

The tentacles (or vesicles: large grape-like sacs).

---

[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World*. Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/euphyllia-ancora/

[2] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World*. Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/euphyllia-cristata/

Genus: *Fungia*

Name:

Date:

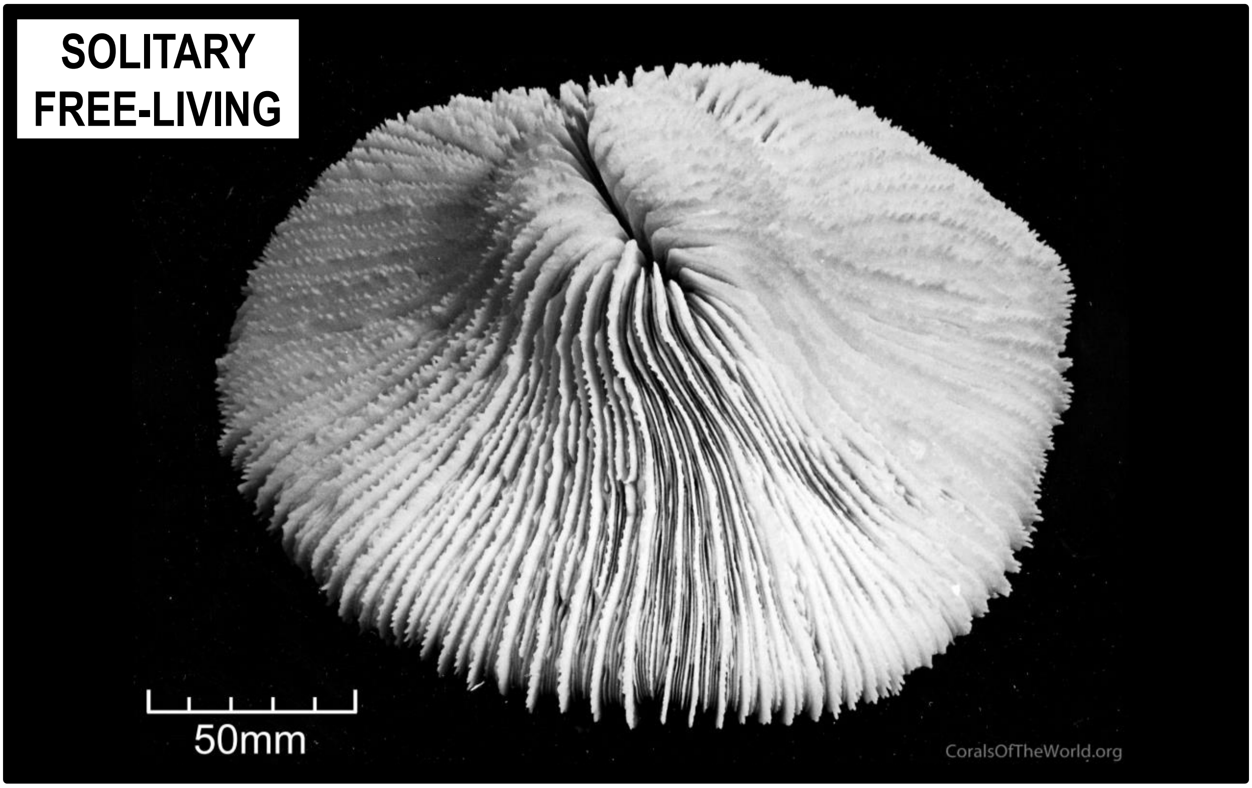


Figure 1: *Fungia danai* Showing upper surface. GREAT BARRIER REEF, AUSTRALIA. Photograph: Veron archives. Reprinted with permission[1].

Fungia **form domes or discs and detach from the reef when they grow larger.**
So, they are free to move about!

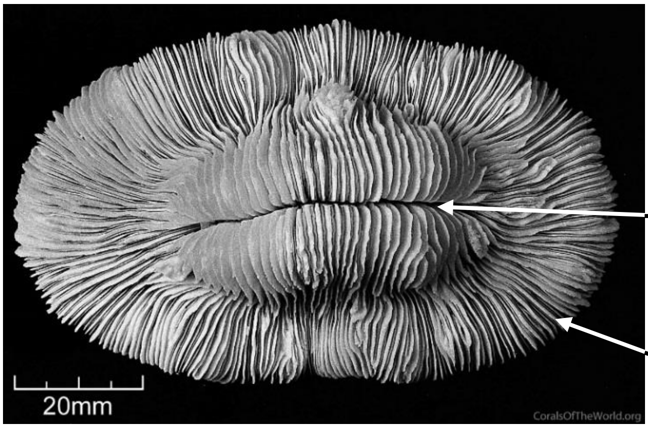


Figure 2: *Fungia paumotensis* showing upper surface. GREAT BARRIER REEF, AUSTRALIA. Photograph: Veron archives. Reprinted with permission[2].

Q. How many polyps are pictured left?
Ans. One

Q. What is the slit across the middle?
Ans. Mouth and Anus

Q. What are the teeth-like projections?
Ans. Septa

---

[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World*. Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/fungia-danai/
[2] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World*. Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/fungia-paumotensis/

Genus: *Pavona*

Name:

Date:

POORLY DEFINED WALLS. EXSERT SEPTO-COSTAE.

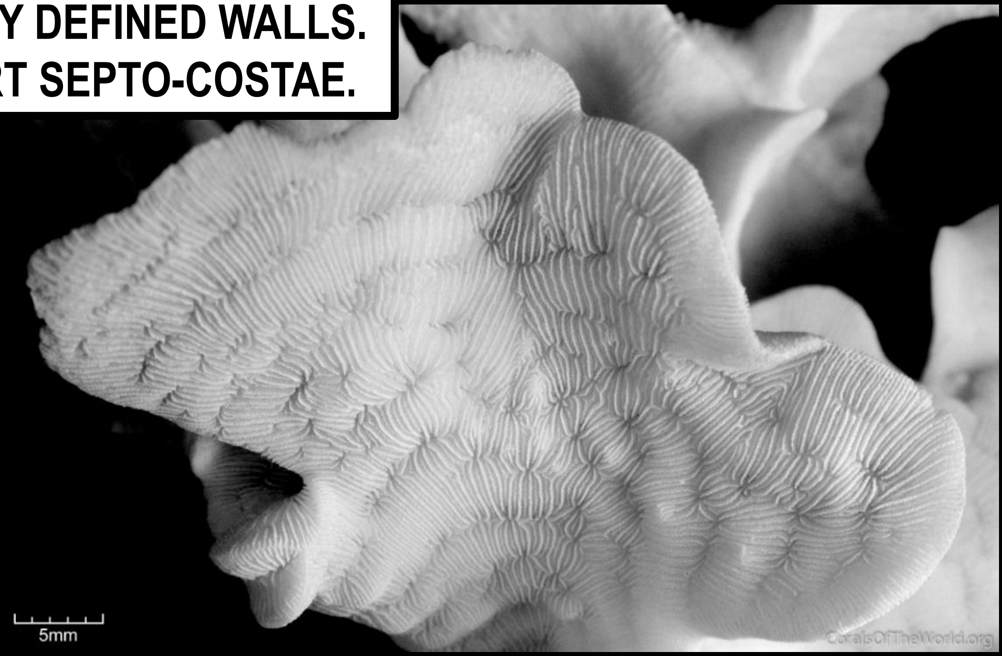


Figure 1: *Pavona cactus* Showing frond surface. COCOS KEELING ISLANDS, INDIAN OCEAN. Photograph: Emre Turak and Charlie Veron. Reprinted with permission[1].

Figure 2: *Pavona clavus* A large dome-shaped colony composed of compact columns. TANZANIA. Photograph: Charlie Veron. Reprinted with permission[2].

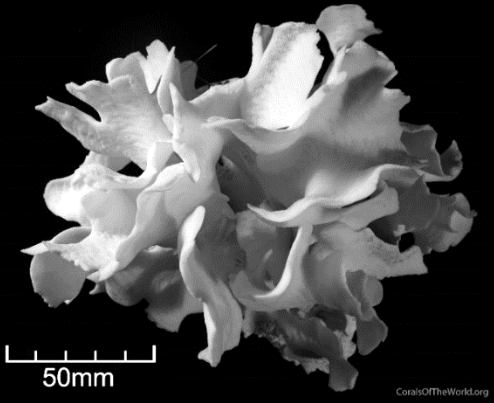


Figure 3: *Pavona cactus* Showing whole colony. GREAT BARRIER REEF, AUSTRALIA. Photograph: Charlie Veron. Reprinted with permission[2].

Pavona **have corallites with poorly defined walls. Corallites are interconnected by exsert septo-costae.**

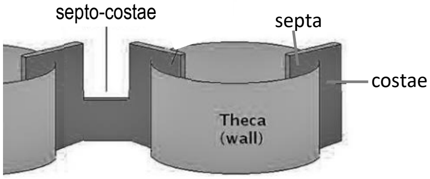


Figure 4: Location of septo-costae[3]

Q. What do septo-costae connect? Ans. corallites

---

[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). Corals of the World. Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/pavona-cactus/

[2] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/species_factsheet_summary/pavona-clavus/

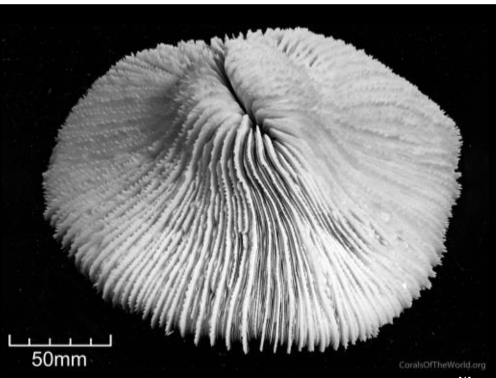
[2] Adapted from: Riddle, D. (2007). *Feature Article: Stony Coral Identification Primer for Aquarists, Part One*. Advanced Aquarist from: www.advancedaquarist.com/

KNOWLEDGE REVIEW 3

Name:

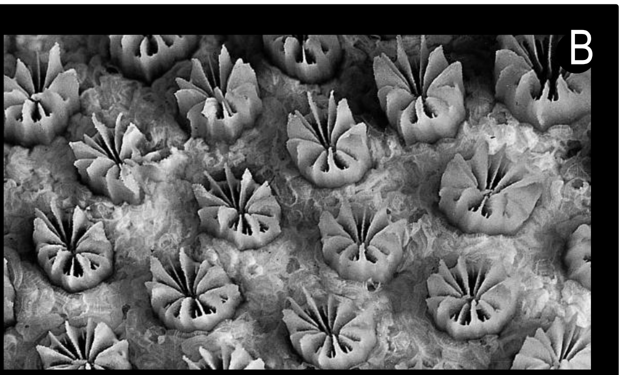
Date:

A



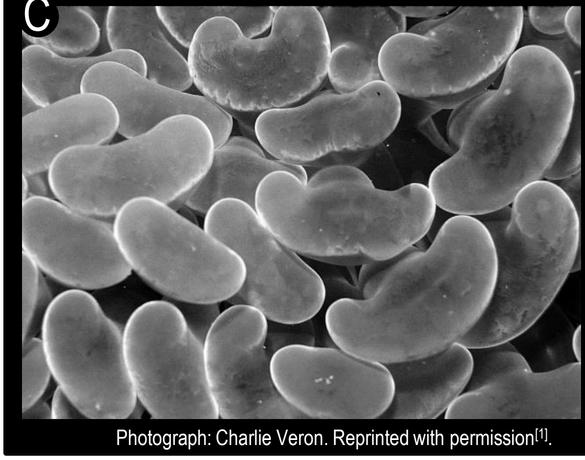
Photograph: Veron archives. Reprinted with permission[1].

B



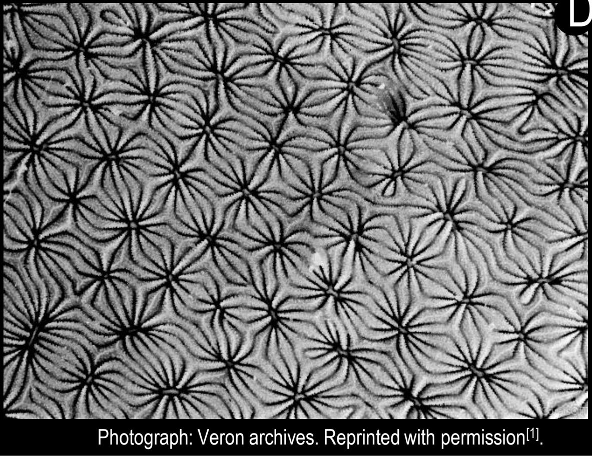
Photograph: Veron archives. Reprinted with permission[1].

C



Photograph: Charlie Veron. Reprinted with permission[1].

D



Photograph: Veron archives. Reprinted with permission[1].

Activity: Complete the table below (choose from one of the five Genus pictured above labelled A-D[1])

Genus	Description	A - D
Galaxea	Exsert SEPTA	B
Pavona	Poorly defined walls. Exsert SEPTO-COSTAE.	D
Fungia	Solitary and Free-living	A
Euphillia	Large, fleshy tentacles (or vesicles) extended night *AND* DAY	C

---

[1] Veron J.E.N., Stafford-Smith M.G., Turak E. and DeVantier L.M. (2016). *Corals of the World.* Accessed 28 May 2019. http://www.coralsoftheworld.org/species_factsheets/

Home Sweet Home – Recognise that corals are habitat formers or ecosystem engineers TO86

Name:

Date:

Everyone needs a place to live

Habitat formers are organisms that form a **habitat – a place for other organisms to live**. They are like the *builders*, creating living spaces for other organisms to live. Sometimes a *primary* habitat former creates a living space for a *secondary* habitat former that, in turn, creates a living space for *focal* organisms in what is called a ***habitat cascade***. Habitat cascades *increase* species richness and species abundance by providing more spaces for more organisms to live[1].

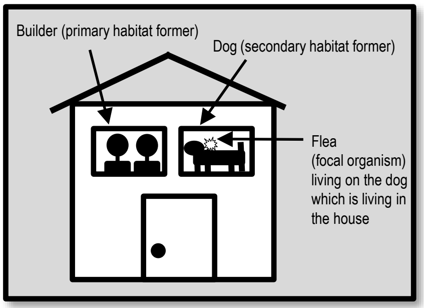
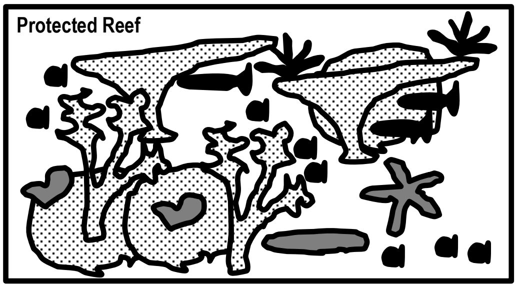


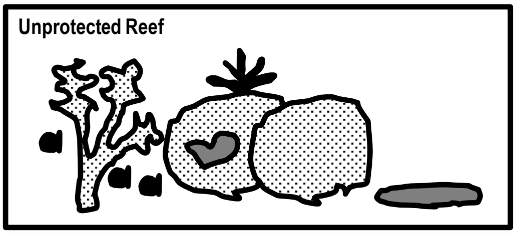
Figure 1: Example of a habitat cascade

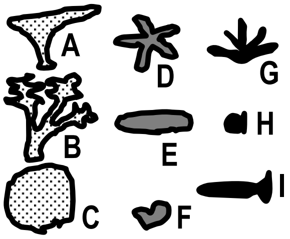
Activity: Complete the table below right ('unprotected' column)



Legend

- ▨ Primary Habitat Formers
- ▩ Secondary Habitat Formers
- ■ Focal Organisms





Species	Protected	Unprotected
A	2	0
B	2	1
C	3	2
D	1	0
E	1	1
F	2	1
G	2	1
H	8	3
I	3	0
TOTAL	24	9

Q. Which reef has more coral (A-C) and hence more residents (D-I)? Ans. Protected Reef

Job Description: Ecosystem Engineer

Ecosystem engineers are organisms that directly or indirectly *modulate* (alter, control) *the availability of resources to other species*, by causing physical state changes in biotic or abiotic material. In doing so, they create, modify and maintain habitats[2]. For example, hard corals build coral reefs. As a result, they modulate the availability of resources to other species by creating habitat (i.e. reef, sand) and by changing the velocity of currents (that carry food and larvae). The term '*ecosystem engineer*' became popular when Jones *et al*. (1994) published an article[2] elucidating the ecological importance of organisms that (inadvertently) dictate the fate of other species by altering the availability of resources (i.e. energy, food, water, sunlight) due to their form and structure (autogenic engineers such as corals) or due to their behaviour (allogenic engineers such as marine burrowing macrofauna)[3].

Q. What are ecosystem engineers? Ans.

Organisms that directly or indirectly modulate the availability of resources to other species, by causing physical state changes in biotic or abiotic material.

---

[1] Thomsen, M.S., Wernberg, T., Altieri, A., Tuya, F., Gulbransen, D., McGlathery, K.J., Holmer, M. and Silliman, B.R. (2010). Habitat Cascades: The Conceptual Context and Global Relevance of Facilitation Cascades via Habitat Formation and Modification. *Integrative and Comparative Biology. v50 (2).158-175. DOI: 10.1093/icb/icq042.*

[2] Jones, G.J, Lawton, J. H. and Shachak, M. (1994). Organisms as ecosystem engineers. *OIKOS Volume 69, Number 3 pp. 373-386. DOI: 10.2307/3545850*

[3] Coleman, F. C. and Williams, S. L. (2002). Overexploiting marine ecosystem engineers: potential consequences for biodiversity. *Trends in Ecology and Evolution. Vol. 17 No. 1. DOI: 10.1016/S0169-5347(01)02330-8*

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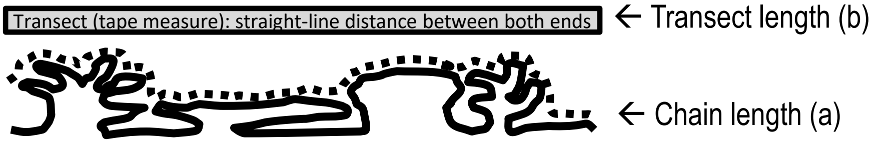
Bumpy or Flat? – Explain that habitat complexity (rugosity), established by corals, influences diversity of other species TO87

Name:

Date:

How to measure rugosity using the chain-and-tape method

Rugosity is a measure of habitat complexity (i.e. bumpy vs. flat). To measure rugosity using the chain-and-tape method, a light chain is laid over the contours of the reef in a straight line. Then, the **ratio** between the total length of the chain (a) and the straight-line distance between both ends of the chain (b) is calculated using the formula C=a/b whereby C is the rugosity index. The more bumps, the more chain, the greater the ratio, the more complex the habitat[1]. *Note:* some papers use the formula C=1-(b/a).



Q. What is the rugosity index if the chain length is 40m and the transect length is 20m? Ans. 2

Thriving Cities vs Barren Deserts

Healthy, thriving, busy, city-like coral reefs, with high rugosity, provide more organisms with more places to live, and more places to hide than unhealthy, struggling, desert-like coral rubble banks with low rugosity. Structurally complex habitats have more surface area for larvae settlement, more refuge (shelter) for prey species, more vertical relief, and more microhabitat variability for a greater diversity of species to live in[1][3].

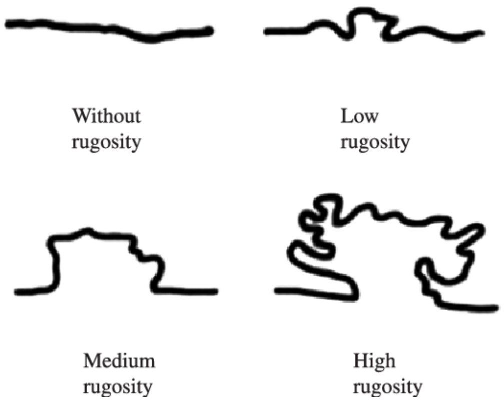


Figure 1: Visual topographic estimate of substrates with different rugosity[2]

> *"A coral reef affords shelter for animals including fish of all shapes and sizes. For the agile swimmer, there is a forest of coral branches through which to weave an escape; for the reticent, there is a cave or crevice in which to hide or sleep; for the predator, there is a grotto in which to lurk, ready for ambush. As a result, after thousands of years in which marine life has been able to adapt to these opportunities, the bommies, reefs and coral beds have become like a high-density urban housing development"* [4].

Activity: In the space provided below, explain how habitat complexity (rugosity), established by corals, influences diversity of other species.

Structurally complex habitats increase species diversity by providing more habitat for coral colonisation, more surface area for larval settlement, more refuge (shelter) for prey species, more vertical relief, and more microhabitat variability.

---

[1] Filip L. A. (2010). *Habitat complexity in coral reefs: patterns of degradation and consequences for biodiversity*. Thesis. UK.

[2] Martinez, A.S., Mendes, L.F. and Leite, T.S. (2012). Spatial distribution of epibenthic molluscs on a sandstone reef in the Northeast of Brazilian *Journal of Biology. Vol 72. no 2. p.287-298. DOI: 10.1590/S1519-69842012000200009*

[3] Faud, M.A.Z. (2010). *Coral Reef Rugosity and Coral Biodiversity.* Thesis. The Netherlands.

[4] McGregor, C. (1974). *The Great Barrier Reef: The World's Wild Places.* Time-life Books. Amsterdam. Page 66.

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S.O.S. – Explain connectivity between ecosystems and the role this plays in species replenishment TO88

Name:

Date:

Connectivity in a *land-sea ecology* context is defined as: *the interaction (convenience or hindrance) of certain physical, chemical and biological processes between terrestrial and marine ecosystems*[1].
Connectivity in a *landscape ecology* context is defined as: *the degree to which the landscape facilitates or impedes the movement of organisms among patches, and; the ease with which individuals can move about within the landscape*[2].
Connectivity in a *coral reef resilience* context is defined as: *the extent to which populations are linked by the exchange of eggs, larval recruits or adults, and ecological links associated with adjacent and distant habitats*[3].

Connectivity - ReCONNECTing populations

Coral reefs must be able to replenish (restock, recruit) their population year after year, disturbance after disturbance, in order to survive. Usually a population can, to some degree, self-replenish (via births).
But often, the population will rely on the arrival of larvae, juveniles or adults from neighbouring populations (via immigration) to come to the rescue, or to simply maintain genetic diversity. The role of connectivity is to ensure the successful arrival of new recruits to replenish a population and maintain genetic diversity.

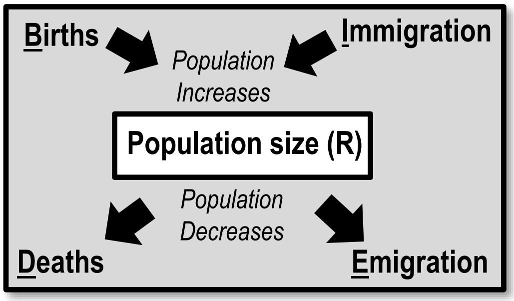

Figure 1: Population size (R) = (B+I) – (D+E)

Figure 2: a cartoon to explain the importance of the arrival of new recruits (including larvae) to rescue declining populations needing help

Q. What is the role of connectivity in species replenishment? Ans.

To ensure the successful arrival of new recruits to replenish a population and maintain genetic diversity.

Coral Dispersal

Unlike fish that can swim to disperse, corals can only disperse at the beginning stages of life. How far can their larvae travel? The distance varies depending on the type of reproductive mode of the species (e.g. brooders vs broadcasters) and the movement of the water in which they travel. Not surprisingly, not as many coral larvae survive the *longer* journeys (Fig. 3)[4][5].

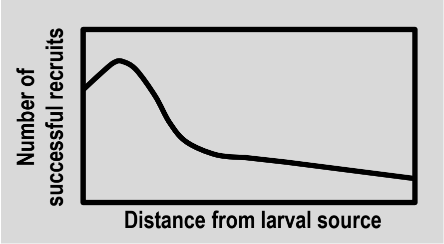

Figure 3: The dispersal kernel for corals[5].

Activity: Explain connectivity using an analogy (e.g. network of train stations)

Network of flight paths, roads, world wide web, etc.

Suggested practical: conduct a plankton tow to I.D. the 'travellers'

---

[1] Fang, X., Hou, X., Li, X., Hou, W., Nakaoka, M. and Yu, X. (2018). Ecological connectivity between land and sea: a review. *Ecological Research. Volume 13 Issue 1 pp 51-61. DOI: 10.1007/s11284-017-1549-x*

[2] Kindlmann, P. and Burel, F. (2008). Connectivity measures: A review. *Landscape Ecology. 23(8): 879-890. DOI: 10.1007/s10980-008-9245-4*

[3] Reef Resilience Network (2018). *Resilient MPA Design: Connectivity: Principle 4.* The Nature Conservancy. Accessed 08.12.2018 from www.reefresilience.org/

[4] Cowen, R. and Sponaugle S. (2009). Larval Dispersal and Marine Population Connectivity. *Annual Review of Marine Science. 1:443-66. DOI: 10.1146/annurev.marine.010908.163757*

[5] Adapted from: Raphael Ritson-Williams, Suzanne N. Arnold, Nicole D. Fogarty, Robert S. Steneck, Mark J. A. Vermeij, and Valerie J. Paul. 2009. *New Perspectives on Ecological Mechanisms Affecting Coral Recruitment on Reefs .Smithsonian Contributions to the Marine Sciences : 437 -457. https://nsuworks.nova.edu/occ_facarticles/503.*

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Something Fishy – Understand that fish life cycles are integrated within a variety of habitats including reef and estuarine systems TO89

Name:

Date:

Hermaphrodites: Fish that have both male and female reproductive organs.
- **Protandry: Fish that change gender from male to female (e.g. clownfish).** Yes, Marlin should have changed sex and become Nemo's mum!
- **Protogyny: Fish that change gender from female to male (e.g. groupers, parrotfishes and many wrasses).**

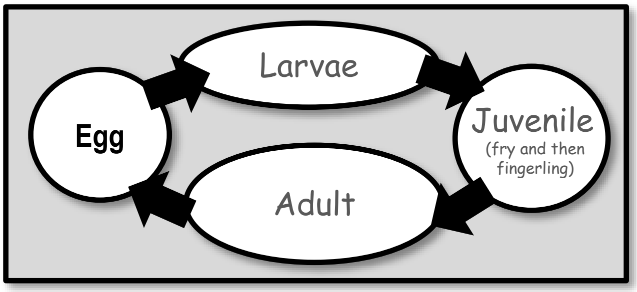
Diadromous: Fish that spend portions of their life cycles partially in freshwater estuaries and partially in saltwater oceans.
- **Anadromous Life Cycle: Fish that live in the ocean but migrate to the estuary to spawn (e.g. salmon).**
- **Catadromous Life Cycle: Fish that live in the estuary but migrate to the ocean to spawn (e.g. anguillid eels).**

Bearers: Fish that carry their embryos (and sometimes their young) either externally or internally (e.g. seahorse, cichlids).
Guarders: Fish that guard their embryos until they hatch and, frequently, tend the larval stages as well (e.g. clownfish).
Non-guarders: Fish that do *not* protect their eggs and young once spawning has been completed (e.g. spawners, brood hiders)[1].

Fish Life Cycle Stages

Nearly all fish (~95%) are external fertilisers. The fertilised **eggs** hatch and become **larvae**. The larvae undergo metamorphosis to become **juveniles** (to *fry* and then *fingerlings*), that later become **adults** (when the gonads are mature).

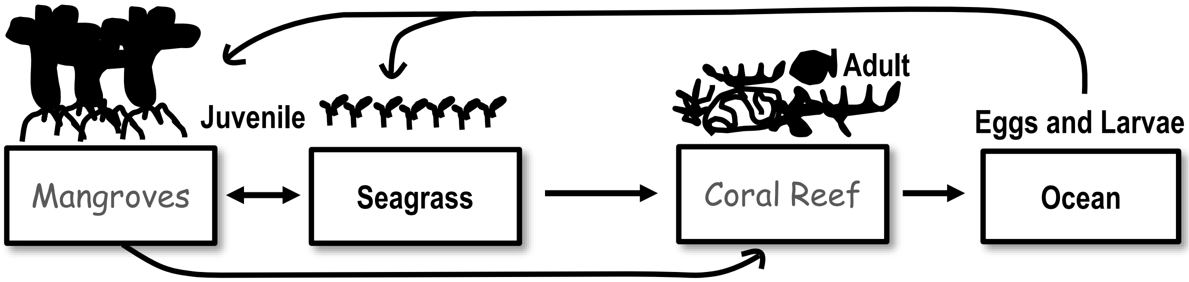
Activity: Complete the life cycle stages (right).



'Frank' the reef FISH (is back!)

The diagram below demonstrates the ontogenetic[2][3] migrations of 'Frank' the reef fish. When Frank was little, he grew up in the mangroves and seagrass beds. When his gonads started to mature, he moved to the reef!

Activity: Fill in the blanks to complete the diagram below of Franks journey through life[4].



Activity: Below, describe the life cycle of the Mangrove Jack *(Lutjanus argentimaculatus)*.

Spawning occurs on deeper offshore reefs during the summer months (oviparous pelagic spawners). Juveniles around 2cm in length settle out from the plankton into coastal estuaries during late summer. Juveniles and young adults spend several years in estuaries, amongst mangroves and in tidal creeks. Sometimes they are found in the lower reaches of freshwater streams. Tagging studies indicate that Mangrove Jacks migrate offshore to deeper reef areas at 40-50 cm in length. Adults usually inhabit coral reefs, often sheltering in caves or under ledges during the day (fishesofaustralia.net.au).

---

[1] Moyle, P. B. and Cech, Jr. J. C. (2004). *Fishes: An Introduction to Ichthyology: 5th Ed.* Pearson Benjamin Cummins. USA. pg. 141-165 .

[2] Some coral reef fishes undergo **ontogenetic** shifts where they use different habitat types (e.g. mangroves and seagrasses) as nursery grounds before moving to their adult habitat on coral reefs (e.g. some parrotfishes, grunts, snappers, surgeonfishes, jacks, barracuda, emperors, groupers, goatfishes, wrasses and rabbitfishes)[3]

[3] Green, A. L. (2014). Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. *Biological Reviews. Volume 90. Issue 4. DOI: 10.1111/brv.12155*

[4] Adapted from: Dorenbosch, M. (2006). *Connectivity between fish assemblages of seagrass beds, mangroves and coral reefs. Evidence from the Caribbean and the western Indian Ocean.* Thesis. Faculty of Science. Radboud University Nijmegan, The Netherlands. ISBN: 90-9020790-2.

Heroic Herbivores – Describe how fish, particularly herbivore populations, benefit coral reefs TO90

Name:

Date:

Figure 1: Blenny sitting in bleached coral. Reproduced with permission[1].

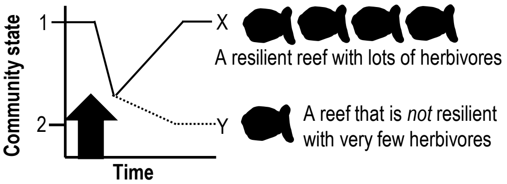
Meet Bob the Blenny

This is Bob. Unfortunately, Bob is sitting in coral that has bleached, and a thin film of algae covers the branches. However, Bob is busy farming his patch and cropping the algae so that it does not become overgrown. Herbivores, like Bob, benefit coral reefs by eating the algae that compete with corals for space, to (hopefully) avoid a phase-shift following disturbances such as coral bleaching events. Good on ya Bob!!

Avoiding a Phase-Shift to ALGAE DOMINATION!!!!

When there are not enough herbivores (like Bob) to keep eating algae, the reef can become overgrown with algae. This puts the reef at risk of undergoing a *phase-shift* from a coral-dominated state to an algae-dominated state. Sadly, once a phase-shift has occurred, it is very difficult to shift back (due to positive feedback loops and hysteresis)[2]. For example, some algae produce chemicals that inhibit the settlement of tiny coral larvae that would otherwise aid reef recovery. And, some herbivores avoid eating algae when it gets too dense[2]. Importantly, when a reef is already damaged and struggling to recover (low resilience) it is more susceptible of undergoing a phase-shift[3].

Figure 2: Reef X is resilient and eventually recovers from an intense and severe disturbance (big arrow). On the other hand, reef Y is not resilient and undergoes a phase-shift to a new community state[3].



Note: the term 'phase-shift' has also been called a 'regime-shift' or 'movement between alternate stable states' or 'basins of attraction'[4].

Activity: Describe how fish, particularly herbivore populations, benefit coral reefs.

They eat the macroalgae that compete with corals for space, to (hopefully) avoid a phase-shift following disturbances such as mass coral bleaching events.

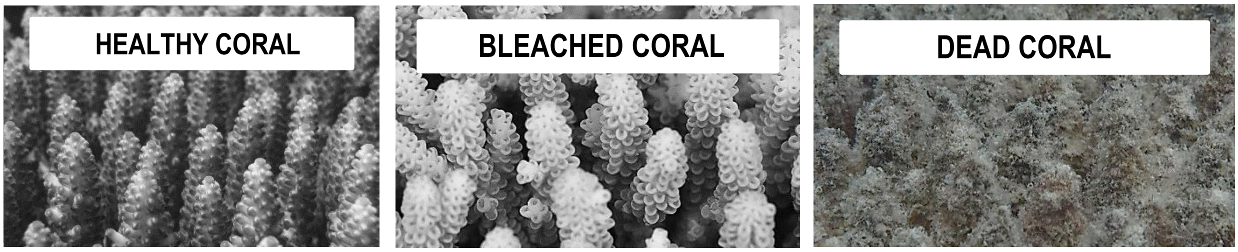


Figure 3: Comparing healthy-looking coral to bleached coral and dead coral. Notice the layer of algae on dead coral. Reproduced with permission[1].

Q. True or False? Herbivores decrease CORAL reef *resilience* (ability to recover)**. Ans.** False

---

[1] Photograph © Justin Marshall (2016). *In pictures: a close up look at the Great Barrier Reef's bleaching*. Accessed 09/12/2018 from http://theconversation.com/in-pictures-a-close-up-look-at-the-great-barrier-reefs-bleaching-57495

[2] Hoey, A.S. and Bellwood, B. D. (2011). Suppression of herbivory by macroalgal density: a critical feedback loop on coral reefs? *Ecology Letters 14: 267-273. DOI:10.1111/j.1461-0248.2010.01581.x*

[3] Adapted from Connell S. D.and Gillanders G. M. (2007). *Marine Ecology*. Oxford University Press. Vic. Australia. pg.147

[4] Hughes, T., Graham, N.A., Jackson, J.B., Mumby, P.J. and Steneck, R.S. (2010). Rising to the challenge of sustaining coral reef resilience. *Trends in Ecology and Evolution. Vol. 25. No. 11 pp. 619-680. DOI: 10.1016/j.tree.2010.07.011*

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Tipping over the Edge – Identify ecological tipping points and how this applies to coral reefs TO91

Name:

Date:

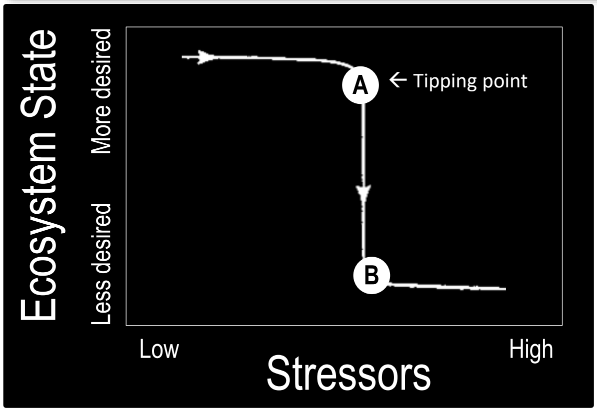
Figure 1: The tipping point[3]

Over the Edge – Ecological Tipping Points

Ecological tipping points are when natural systems cross a biophysical threshold as a result of human induced stressors, dramatically altering ecosystem function and services[1]. An example would be the point in time when a phase-shift begins. Like the straw that breaks the camel's back, sometimes a system can take a substantial amount of stress, until it reaches a critical breaking point. At that point, it's resilience (ability to recover) is so low that it only takes a small amount of further strain to initiate a significant change to the system[1].

Q. What is an ecological tipping point? Ans.

When natural systems cross a biophysical threshold as a result of human induced stressors, dramatically altering ecosystem function and services. E.g. a phase-shift from a coral-dominated reef to an algae-dominated reef.



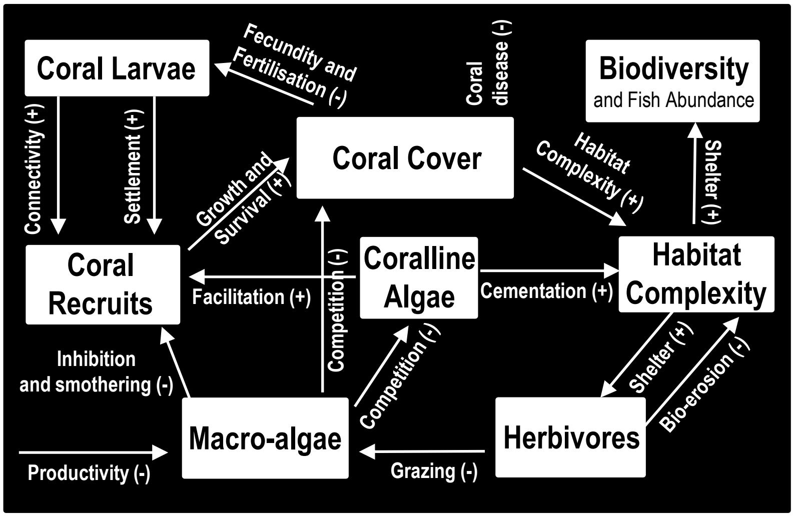
Q. What happens to a reef when it crosses its tipping point? Ans. a phase **-shift begins**

Q. In Figure 2, is the shift in ecosystem state linear or non-linear? Ans. Non-linear

(a straight line) (*not* a straight line)

Q. True or False? At low resilience, a small change in stressor intensity can drive a dramatic change in ecosystem state. Ans. T

Figure 2: At low resilience, a small change in stressor intensity can drive a dramatic change in community state (e.g. point A to point B)[1][4].



Q. What happens to a reef when macro-algae dominates? Ans.

Macro-algae outcompete coral, inhibit and smother coral recruits, reducing the growth and survival of coral, which reduces habitat complexity, which, in turn, reduces biodiversity and fish abundance (including herbivores).

Figure 3: Conceptual model of interrelations among key habitat and ecosystem variables[2].

---

[1] Adapted with permission from: Kelly, R.P., Erikson, A.L. and Mease, L.A. (2015). How Not to Fall Off a Cliff, or, Using Tipping Points to Improve Environmental Management. *Ecology Law Quarterly. 41(4):843. DOI:10.15779/Z38FP1H*

[2] Adapted with permission from: Pratchett, M.S., Hobbs, J.A., Hoey, A.S., Baird, A.H. Ayling, A.M., Gudge, S. and Choat, J.H., (2011). *Elizabeth and Middleton Reef Reserves Marine Survey 2011.* Draft Report. Commonwealth of Australia.

[3] Dibble, B.J. MD. (2012). *Comprehending the Climate Crisis: Everything you need to know about the Global Warming and how to stop it.* iUniverse Star. Bloomington, IN 47403.

[4] Hughes, T., Graham, N.A., Jackson, J.B., Mumby, P.J. and Steneck, R.S., (2010). Rising to the challenge of sustaining coral reef resilience. Trends in Ecology & Evolution. Vol. 25. No. 11. pp. 619-680. DOI: 10.1016/j.tree.2010.07.011.

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Road Blocks to Recovery – Describe hysteresis and how this applies to the concept of reef resilience TO92

Name:

Date:

Hysteresis: returning along a different path

When a phase-shift occurs on a coral reef, it is very sad. Corals die. Algae grows. Colours fade. Life disappears. It is only natural to feel compelled to want to change it back. However, it is not that easy. Because of **hysteresis.** Hysteresis is when the return pathway to recovery (e.g. back to a coral-dominated state) *differs* from the original pathway of degradation (Figure 1). So, even if the stressor that caused the reef to undergo a phase-shift in the first place is removed, unfortunately, the reef will still remain in the (less desired) algae-dominated state[1][2]. ☹

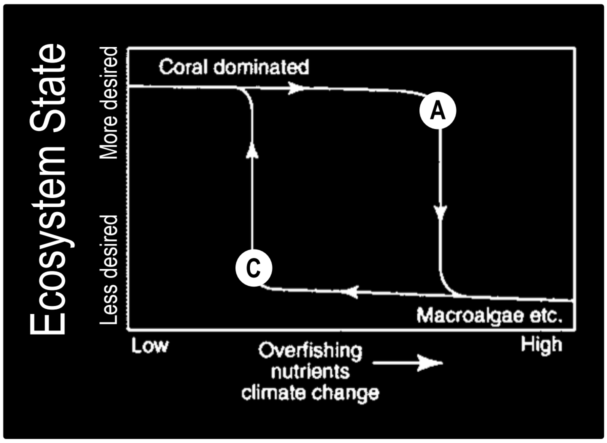


Figure 1: Hysteresis: the reversal of a phase shift follows a different trajectory to the original pathway of degradation[2].
***Note*: the level of stress on the community is much lower at the reversal tipping point (C) than at the original tipping point (A).**

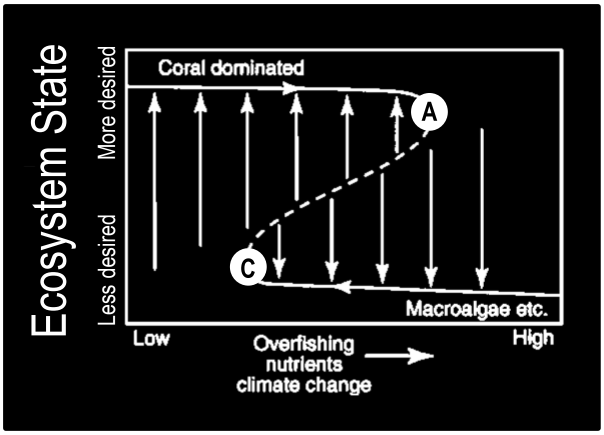


Figure 2: Drivers of change (i.e. acute disturbances) cause a reef to move from a more desired state to a less desired state. However, the reef will return to the more desired state (arrows pointing UP) provided it does not cross the dotted line separating the two alternate states (one dominated by coral, the other dominated by macroalgae etc.). The vertical arrows also represent resilience - the ability to absorb acute disturbances without undergoing a phase-shift - whereby the long arrows have high resilience and the short arrows have low resilience. As the trajectory (solid line) approaches its tipping point, resilience decreases (arrows get shorter)[2][3].

Q. What is Hysteresis? Ans.

Hysteresis is when the return pathways to recovery differs from the original pathway of destruction.

The Coral's Immune System

How do reefs avoid a phase-shift in the first place? A reef ecosystem will remain in a more desired state, for longer, when its resilience is strong. Resilience is the ability to absorb acute disturbances without undergoing a phase-shift[1]. For example, think of resilience like your immune system. If your immune system is weak, it will take you longer to recover from an illness. You may even catch another bug to make you feel even worse! In contrast, if your immune system is strong, your recovery will be faster. The same applies to reefs.

Q. What happens to resilience when an ecosystem approaches its tipping point?

Ans.. **[it increases]** [✓ **[it decreases]**] Circle correct answer

Q. What does it take to reverse a phase-shift? How do we reduce the resilience of an algae-dominated reef so that it returns back to a coral-dominated reef (i.e. overtakes C)? Ans.

Reduce/remove ALL the stressors. E.g. MPA's, reduce pollution, improve water quality, protect species that eat algae in high densities, etc.

---

[1] Kelly, R.P., Erikson, A.L. and Mease, L.A. (2015). How Not to Fall Off a Cliff, or, Using Tipping Points to Improve Environmental Management. *Ecology Law Quarterly. 41(4):843. DOI: 10.15779/Z38FP1H*

[2] Reprinted from Trends in Ecology & Evolution, Vol. 25. No. 11, Hughes, T., Graham, N.A., Jackson, J.B., Mumby, P.J. and Steneck, R.S., Rising to the challenge of sustaining coral reef resilience, pp. 619-680, 2010, with permission from Elsevier.

[3] Adapted from: Toh, T.C., Ng, C.S.L. and Chou, L.M. (2013). *Enhancing Coral Reef Resilience through Ecological Restoration: Concepts and Challenges. The Asian Conference on Sustainability, Energy and the Environment: Official Conference Proceedings 2013.* Osaka, Japan. Volume: 528-545. Accessed 07.04.2019 from: https://coralreef.nus.edu.sg/publications/Toh2013IAF.pdf

Data Detectives - Assess the diversity of a reef system using a measure that could include (but not limited to) line intercept transects, quadrats and fish counts using underwater video survey techniques, benthic surveys, invertebrate counts and rugosity measurements TO93

Name:

Date:

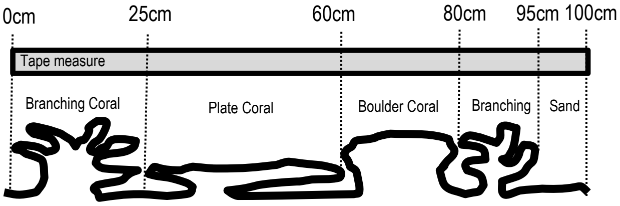
Bottom dwellers

Benthos attach to, burrow or crawl on the seabed (as opposed to *pelagics* that swim or float).

Q. What do *benthic* surveys measure? Ans. Benthos biodiversity

Line Intercept Transects

The Line Intercept Method identifies and records the substrate underneath a transect (i.e. tape measure).



$$\text{Percentage Cover} = \frac{\text{Total length of transect occupied by a species}}{\text{Total transect length}} \times 100$$

Activity: Complete Table (refer to transect left)

Start	Finish	Category	% Cover
0 cm	25 cm	Branching	**25 %**
25 cm	60 cm	Plate	35 %
60 cm	80 cm	Boulder	20 %
80 cm	95 cm	Branching	15%
95 cm	100 cm	Sand	5 %
TOTAL	**100cm**	**TOTAL**	**100%**

Smile for the camera: Counting fish using video

Underwater video survey techniques are commonly used for surveying *fish*. The video camera can be controlled remotely (e.g. BlueROV2)[2] or by a person in the water. Filming can be **stationary** (camera stays in the one spot) or along a **belt transect** (surveying a certain distance either side, or above, a transect). Some systems use *bait* to attract the fish. Some use more than one camera (Figure 1).

Hint: if filming stationary, one way to avoid counting the same fish twice, is to pause the video when the maximum number of your target fish are in the one frame.

Activity: Check out James Cook University's *Classroom on the Reef* Live Cam Footage on Orpheus Island!!![3]

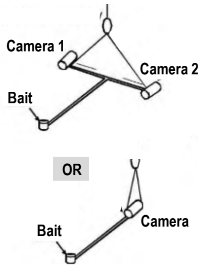
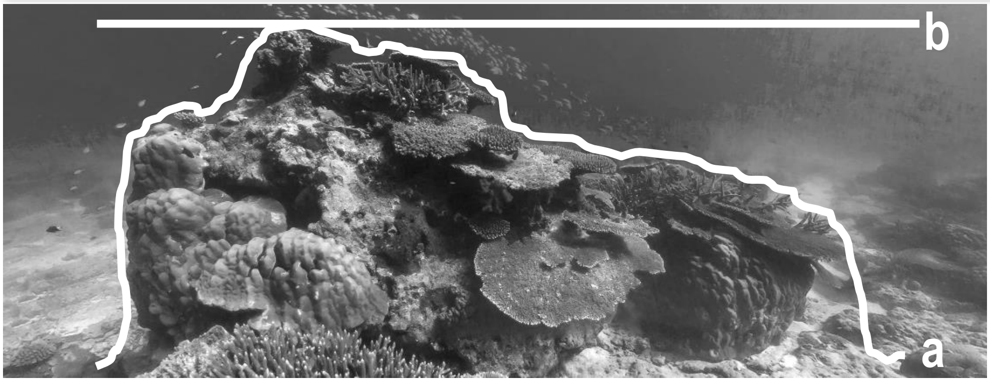


Figure 1: Two different baited underwater video set-ups[1]

Q. What is the RUGOSITY (C) of the reef below? Use the formula C=a/b Ans. 19/12=1.5833'



Hint: Use a ruler to measure the length of b. Then, use a piece of string to follow the contours of the chain (a) to measure its length.

Figure 2: Measuring rugosity using the chain-and-tape method by laying a chain down over the substrate and comparing its length to the transect length. Image (of Lady Elliot Island) sourced from the XL Catlin Global Reef Record. © Underwater Earth / XL Catlin Seaview Survey[4]

[1] Langlois, T.J., Chabanet, P., Dominique, P. and Harvey, E.S. (2006). Baited underwater video for assessing reef fish populations in marine reserves. Secretariat of The South Pacific Community Fisheries Newsletter #118. July-September 2006. Pg. 53-56.

[2] Blue Robotics (2019). *BlueROV2*. Blue Robotics. Accessed 07.04.2019 from: https://www.bluerobotics.com/store/rov/bluerov2/bluerov2/

[3] James Cooks University (2019). Classroom on the Reef. Accessed 07.04.2019 from: https://www.jcu.edu.au/classroom-on-the-reef

[4] Reproduced with permission from Lorna Parry. www.catlinseaviewsurvey.com/

Life in One Number – Analyse reef diversity data, using an index, to determine rank abundance TO94

Name:

Date:

Homer is back!

A **diversity index** is a formula that we use to convert diversity data (what and how many) into a single value. Why? Usually to *compare* ecosystems, *classify* ecosystems, or *rank* ecosystems (to better manage them). Today, we are *ranking* ecosystems. We are using **Simpson's Diversity Index (SDI)** formula to calculate the SDI value for three different reefs to rank them in order of highest diversity to lowest diversity.

Index	Formula	Interpretation	Explanation
Simpsons Diversity Index (SDI)	$1-\left[\frac{\sum n(n-1)}{N(N-1)}\right]$ N = total number of organisms of all species n = number of organisms of one species	**0 – 1** 0 = no diversity 1 = infinite diversity	The probability that 2 randomly selected individuals will be 2 different species (or categories). 100% chance = infinite diversity

Activity: Complete the Tables to calculate the SDI value for each (hypothetical) **reef below**

Bailey Reef		
IDENTIFY	COUNT	STATS
Name	**n**	**n(n -1)**
Species A	19	342
Species B	20	380
Species C	30	870
Species D	5	20
Species E	0	0
Total	**N** 74	∑n(n-1) 1612
SDI Calculations	N(N-1)= 74x73 5402	**SDI =** 1-(1612//5402) 0.70

Xenia Reef		
IDENTIFY	COUNT	STATS
Name	**n**	**n(n -1)**
Species A	2	2
Species B	1	0
Species C	3	6
Species D	2	2
Species E	1	0
Total	**N** 9	∑n(n-1) 10
SDI Calculations	N(N-1)= 72	**SDI =** 0.86

Maxwell Reef		
IDENTIFY	COUNT	STATS
Name	**n**	**n(n -1)**
Species A	1	0
Species B	3	6
Species C	100	9900
Species D	5	20
Species E	0	0
Total	**N** 109	∑n(n-1) 9926
SDI Calculations	N(N-1)= 11772	**SDI =** 0.16

REEF DIVERSITY SCOREBOARD

(rank the reefs from highest diversity to lowest diversity)

1st Xenia Reef
2nd Bailey Reef
3rd Maxwell Reef

Q. Which reef has the highest *species richness?*
species richness = number of rows

Ans. Xenia Reef

Q. Which reef has the lowest *species evenness?*
...whereby one or two species dominate in abundance?

Ans. Maxwell Reef

Recommended: Understand what is *species richness* and species *evenness* on a *Whittaker Plot*

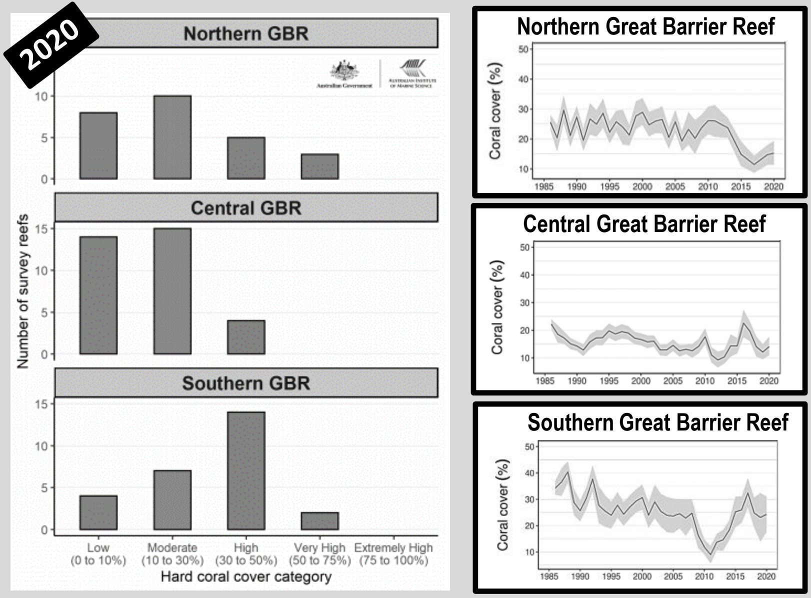
Reef Reports – Interpret, with reference to regional trends, how coral cover has changed on a reef over time TO95

Name:

Date:

AIMS Long Term Monitoring Program

We are very fortunate that the Australian Institute of Marine Science (AIMS) have been conducting surveys of the Great Barrier Reef, for decades now, as part of its *Long Term Monitoring Program*[1].



Northern Great Barrier Reef

Central Great Barrier Reef

Southern Great Barrier Reef

Northern Great Barrier Reef:
81% of reefs severely bleached in mass bleaching event 2016/17 (N=129)

Central Great Barrier Reef:
Cyclone YASI in 2011. Mass bleaching event and Crown-of-Thorns outbreaks in 2016/17 (N=212).

Southern Great Barrier Reef:
Cyclone HAMISH 2009. Crown-of-thorns outbreak in 2018 (N=151).

LEFT: Mean % Hard Coral Cover in 2020[1]. MIDDLE: Trends in Mean % Hard Coral Cover based on broadscale (manta tow) surveys every year from 1985 to June 2020. Shading represents 95% certainty[1]. RIGHT: Summary Report for each region, including impacts affecting % Hard Coral Cover and Recovery[1].

Activity: Tick the box when you find a graph showing coral cover changing over time

- ☐ **www.aims.gov.au** Go to Menu and expand: Research…Measuring Change…Reef Monitoring…Survey Reports…Sector-Wide Reports
- ☐ **www.reefcheckaustralia.org** Go to menu and expand: Science...Publications..(select your region. e.g. GBR)…Summary Report
- ☐ **www.coralwatch.org** Go to menu and expand: Data….Surveys….(select a location). *Note*: Subscribe for the best data

Activity: In the space provided below, INTERPRET, with REFERENCE to regional trends, how coral cover has changed on a reef over time

Answers may vary

Note: AIMS release a new (annual) summary report very year.

Trend: when the data overall is moving in one particular direction over time, usually represented by a line or curve on a graph.

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[1] Adapted with permission from: Australian Institute of Marine Science (2011). *Long-Term Monitoring Program – Annual Summary Report on coral reef condition for 2019/20.* AIMS Data Centre. Accessed 30.06.2021 from: https://www.aims.gov.au/reef-monitoring/gbr-condition-summary-2019-2020

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Marine Education

Water Quality Woes – Recognise that some of the factors that reduce coral cover (e.g. crown of thorns) are directly linked to water quality TO96

Name:

Date:

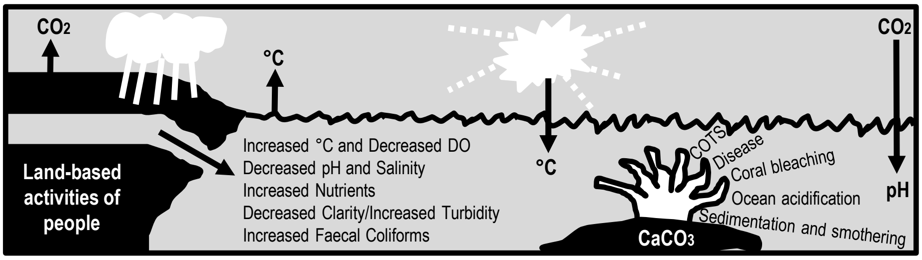

Figure 1: Schematic diagram summarising key factors that reduce coral cover, directly linked to water quality[1].

Land-based inputs

Factors that reduce coral cover, that are directly linked to water quality, are often derived from land-based activities of people[1].

Activity: Listed below are factors that reduce coral cover directly linked to water quality. Tick the water quality parameter/s that each factor is likely to change the most and cause a hard coral to die.

Factors that reduce coral cover			°C	D.O.	pH	Salinity	Nutrients	Clarity/ Turbidity	Faecal Coliforms
CLIMATE CHANGE	**Increased Sea Surface Temperatures**		✓	✓					
	Ocean acidification				✓				
	Increase in size and frequency of natural disasters	**Cyclones & Floods**	✓	✓	✓	✓	✓	✓	✓
		Fires (and its debris)						✓	
URBAN RUNOFF	**Sediments and suspended solids** (from streets, construction sites, storm drains, etc.)			✓				✓	✓
	Pathogens and excess nutrients (from ineffective sewage treatment, septic overflows)			✓			✓		✓
DESTRUCTION OF CRITICAL HABITAT	**Sediments and suspended solids** (from dredging, land clearing, development, etc.)			✓				✓	✓
	Acid sulphate soils (from exposed acid sulphate soils leaking acid)			✓	✓			✓	
	Excess nutrients (from the removal of mangroves and wetlands etc.)			✓			✓		

answers may vary

Q. What variable causes every one of these factors to increase? Ans. Human pop. density

Hungry Sea Stars

COTS *larvae* eat phytoplankton. It is hypothesised that a phytoplankton bloom (caused by flood waters carrying high nutrient loads) is a precursor to a COTS outbreak. COTS survival is *also* subject to spawning synchronisation and success, hydrodynamics and dispersal, settlement success, predation and disease[2][3][4].

Q. True or False? One adult COTS can produce up to 50 million eggs per year[4]. Ans. True

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[1] Adapted from: Crabbe, M.J.C. (2009). Climate change and tropical marine agriculture. *Journal of Experimental Biology. 60(10):2839-44. DOI: 10.1093/jxb/erp004.*

[2] Hock, K., Wolff, N.H., Condie, S.A., Anthony, K.R.N. and Mumby, P. (2014). Connectivity networks reveal the risks of crown-of-thorns starfish outbreaks on the Great Barrier Reef. *Journal of Applied Ecology 51 (5). DOI: 10.1111/1365-2664.12320*

[3] Pratchett, M.S., Caballes, C.F., Wilmes, J.C., Matthews, S., Mellin, C., Sweatman, H.P.A, Nadler, L.E., Brodie, J., Thompson, C.A., Hoey, J., Bos, A.R., Byrne, M., Messmer, V., Valero-Fortunato, S., Chen, C.C.M., Buck, A.C.E., Babcock, R.C. and Uthicke, S. (2017). Thirty Years of Research on Crown-of-Thorns Starfish (1986-2016): Scientific Advances and Emerging Opportunities. *Diversity 9 (41). DOI: 10.20944/preprints201708.0076.v1*

[4] AIMS (n.d.). *Crown-of-thorns starfish.* AIMS. Queensland. Australia. Accessed 3/1/2019 from: https://www.aims.gov.au/documents/30301/2107187/cots-revised.pdf

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Marine Education

The Ultimate Board Game – Understand that the processes in this sub-topic interact to have an overall net effect. i.e. they do not occur in isolation TO97

Name:

Date:

Start

CORAL BLEACHING EVENT
4 Degree Heating Weeks (DHW)
Fish, coral and zooxanthellae Clade C all lose 1 lifeline

CORAL BLEACHING EVENT
8 DHW
Fish, coral and zooxanthellae Clade C all lose 2 lifelines

COTS OUTBREAK
Coral lose 1 lifeline

OIL SPILL
All organisms lose 1 lifeline

TRADITIONAL OWNERS WIN RIGHTS TO, AND PROTECT, THE REEF
All organisms gain 1 lifeline

LAWS PASSED TO PROTECT MORE REEFS
All organisms gain 1 lifeline (except macro-algae)

CORAL LARVAE REPLENISHMENT & RECRUITMENT
Swap a macro-algae for a coral (with 3 lifelines)

OIL MINING & EXPLORATION WITHIN THE EEZ BANNED
All organisms gain 1 lifeline

MORE FUNDING TO STOP ILLEGAL FISHING
FISH gain 1 lifeline. Macro-algae lose 1 lifeline

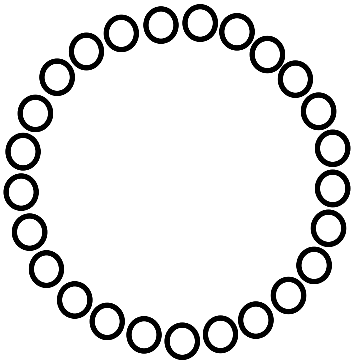
PROTECTION & REPLANTING OF MANGROVES
All organisms gain 1 lifeline. Macro-algae lose 1 lifeline

Activity: (Part A) Prepare your game play

(1) Allocate each student the name of a marine organism from the list below (start at the top of the list).
(2) Draw a human circle on the board, like the one pictured below (you may have less circles/people).
(3) Label each circle with the name of a person in your class and the name of their marine animal.
(4) Starting at the top circle, ask if that person's marine organism interacts with any other marine organisms on the board. For example, an interaction might exist between a habitat former and a habitat user, a predator and its prey, or between a coral and a clade of zooxanthellae. Draw a line between any 2 circles that represent 2 marine organisms sharing an interaction with each other.

List of Organisms
1. *Acropora* Branching Coral
2. Zooxanthellae Clade C
3. Brown macro-algae seaweed
4. *Porites* Boulder Coral
5. Zooxanthellae Clade D
6. Green macro-algae seaweed
7. Surgeon Fish (primary consumer/herbivore)
8. Coral Trout (secondary consumer)
9. Shark (tertiary consumer)
10. *Pocillopora* Branching Coral

You can make up the rest if you need more.



Activity: (Part B) Make a human model

(1) Get up out of your seat and make the human circle that is drawn on the board.
(2) Every person is given a bundle of strings. Each piece of string is the same length as the diameter of the circle.
(3) One by one, each person holds one end of a string and passes the other end to whom they share an interaction with (as per the lines on the board).
(4) Once complete, the circle should have a spider-like configuration. The more players, the more string *(note:* a biodiverse system, with lots of players, is a resilient one)!

Activity: (Part C) The Rules of the Game

(1) Each player starts with 3 lifelines. Except for *Porites*, *Zooxanthellae Clade D* and *Brown Macro-algae* that have 4 lifelines (because they are more resilient). Everyone in the circle should be able to see the number of lifelines you have at all times (e.g. raise that many fingers on your hand).
(2) The teacher places a game piece on 'start' and rolls the dice, moving *clockwise* to begin with.
(3) When a player runs out of lifelines, they must sit down and drop all their strings.
(4) Anyone holding a string that was let go by a removed species loses a lifeline and must assess if its remaining interactions (string connections) will be enough for it to survive. If not, they must also sit down and drop all their strings.
(5) When a coral sits down, it gets back up as a *macro-algae seaweed* and continues to play (making new connections with strings and starting with 4 lifelines).
(6) Likewise, when a *macro-algae seaweed* sits down, it gets back up as an *Acropora* branching coral and continues to play (making new connections with strings and starting with 3 lifelines).
(7) Stop playing when it becomes too difficult to reverse a phase-shift, or 15min before the end of the lesson, whichever comes first.
(8) Start again, from Part B (3). But this time, the teacher goes ***anti-clockwise*** around the board.

Activity: (Part D) Discus if (going anti-clockwise and) boosting resilience *before* disturbances makes a difference to the final outcome for the reef?

FLOOD
Coral lose 1 lifeline

Macro-algae gain 1 lifeline

GROUND WATER CONTAMINATION
All organisms lose 1 lifeline (except macro-algae)

DREDGING
Corals lose 1 lifeline

SEVERE AND DESTRUCTIVE STORM EVENT
Coral lose 1 lifeline

CORAL BLEACHING EVENT (4 DHW)
Fish, coral and zooxanthellae Clade C lose 1 lifeline

OCEAN ACIDIFICATION
IF you have passed this point more than once already, corals lose 3 lifelines. Otherwise, roll again.

FRACKING BAN
All organisms gain 1 lifeline (except macro-algae)

MASS SPAWNING EVENT
coral gain 1 lifeline

SEWAGE TREATMENT UPGRADES
All organisms gain 1 lifeline (except macro-algae)

MARINE DEBRIS CLEAN-UP
All organisms gain 1 lifeline (except macro-algae)

DISEASE OUTBREAK
Coral lose 1 lifeline

Mandatory Practical TO98

Name:

Date:

Examine the concept of connectivity within or between habitats by investigating the impact of water quality on reef health

Image (of Osprey Reef) sourced from the XL Catlin Global Reef Record. © Underwater Earth / XL Catlin Seaview Survey

Making OBSERVATIONS

Name:

Date:

What's in the Water?

For this practical, we want to investigate the impact of water quality on reef health, whilst examining connectivity. Thus, you get to visit the reef! Even if it's only a virtual visit, you still get to see it! Let's begin by looking at reefs from all around the world (see activity below). Whilst you are looking, find a reef that you would call 'unhealthy'. Ask yourself, why is it unhealthy? Do you think water quality has anything to do with it? Alas, corals do live in water! And, how does that water even get to that reef? Connectivity right?!

Activity: View quadrat photographs from the following websites (tick when done).

☐ **XL Catlin Global Reef Record** www.globalreefrecord.org 'Enter' and then click on 'Data'
☐ **Reef Life Survey** www.reeflifesurvey.com Access 'Survey Data'
☐ **Classroom on the Reef** www.jcu.edu.au/classroom-on-the-reef Curriculum → Coral identification practical
☐ **MarineEducation.com.au** Data tab

For example, pictured below are quadrats from Lady Elliot Island (1) and Belize (2). They were captured as screenshots from the XL Catlin Seaview Survey Virtual Tour with the camera pointing down.

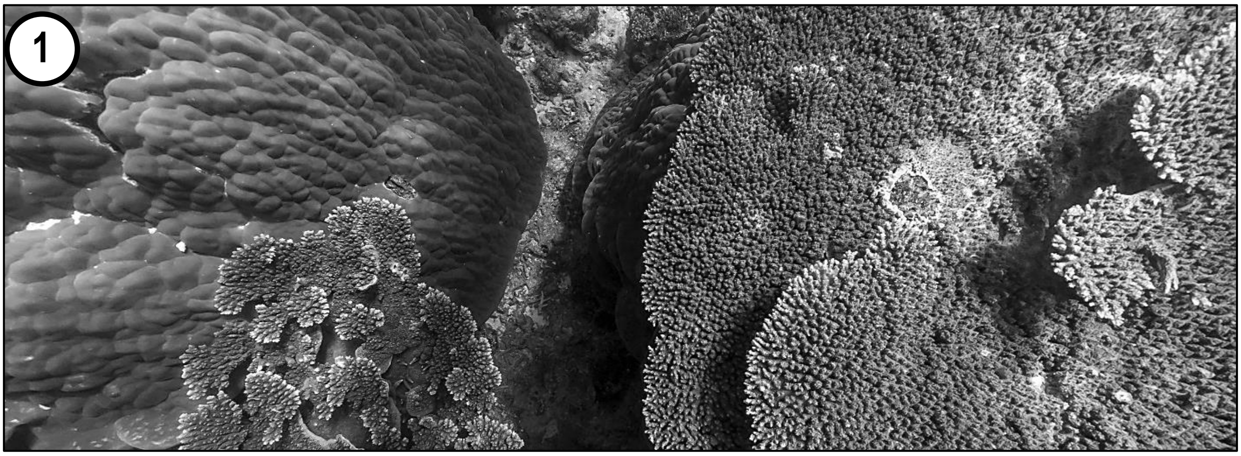


Figure 1: Image (of Lady Elliot Island) sourced from the XL Catlin Global Reef Record. © Underwater Earth / XL Catlin Seaview Survey

Figure 2: Image (of Belize Reef) sourced from the XL Catlin Global Reef Record. © Underwater Earth / XL Catlin Seaview Survey

Q. Which reef looks healthier? Ans. 1. Lady Elliot Island. Discuss why? Any bias? (i.e. one photo). How did they measure *health*?

GATHERING INFORMATION

Name:

Date:

☺ or ☹ Help or Hinder?

Connectivity can be a 'double-edged sword'. It can both help and hinder coral reefs.

- It can *help* reefs by delivering water carrying coral larvae and other hitch-hikers for replenishment.
- But, it can also *hinder* reefs by delivering water carrying unwanted COTS larvae[1] and pollutants.

Q. How might connectivity (1) help a reef and (2) hinder a reef? Ans.

(1) it helps by delivering water carrying coral larvae for reef replenishment.
(2) it hinders by delivering water carrying unwanted COTS larvae and pollutants

Eddying Around

Pictured right is a meso-scale eddy dubbed the 'Capricorn Eddy'. When water from the East Australian Current (EAC) flows past a huge 'wedge' in the continental shelf, the water 'swirls' around clockwise in a big circle. Inside the cyclonic feature is an **upwelling**, where **cool**, **nutrient-rich** waters rise up from the deep and spill onto the Capricorn-Bunker reefs[2]. One of those reefs is Lady Elliot Island (LEI), where many mantas rays visit.

Q. Is the Capricorn Eddy helping or hindering reefs of the Capricorn Bunker Group? Ans.

Could be both. Helping (if water is cold enough to mitigate bleaching); or, Hindering (corals don't like nutrient-rich water).

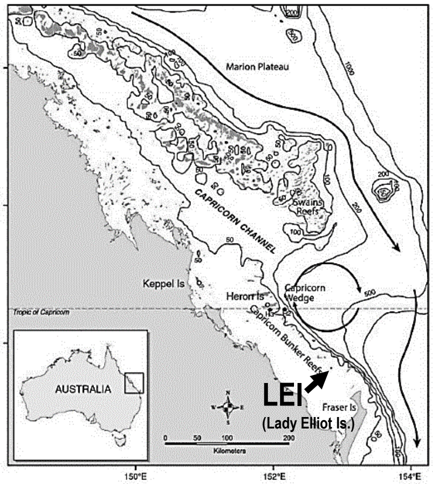


Figure 1: Schematic map of southern GBR. Solid dark arrows represent the southward flow of the EAC. Dark circular arrows show the location of the Capricorn Eddy with an indentation of 200-m isobath, referred to as the Capricorn Wedge[2].

Marvellous Mangroves: coastal kidneys and natural nurseries

Reefs are better off when close to mangroves. Mangrove forests filter the water, stabilise sediments (with their roots), reduce coastal erosion and siltation, and trap pollutants. Mangroves also act as natural nurseries for important reef fish species, such as herbivores[3]. How awesome are mangroves!
In a study by Olds *et al.,* (2011)[4] there were significantly more fish at protected coral reefs and mangroves that were close together (by <250m) as opposed to protected coral reefs and mangroves that were far apart (by >500m).

Q. How does connectivity between reefs and mangroves help the reef? Ans.

They filter the water, stabilise sediments (with their roots), reduce coastal erosion and siltation, and trap pollutants. Mangroves also act as nurseries for important reef fish species, such as herbivores.

---

[1] Hock, K., Wolff, N.H., Ortiz, J.C., Condie, S.A., Anthony, K.R.N., Blackwell, P.G. and Mumby, P.J. (2017). Connectivity and systemic resilience of the Great Barrier Reef. *PLoS Biol 15(11): DOI: 10.1371/journal.pbio.2003355*

[2] Weeks S.J., Bakun, A., Steinberg, C.R., Brinkman, R. and Hoegh-Guldberg, O. (2010). The Capricorn Eddy: a prominent driver of the ecology and future of the southern Great Barrier Reef. *Coral Reefs. 29 (4): 975-985. DOI: 10.1007/s00338-010-0644-z.* Adapted with permission from Professor Ove Hoegh-Gulberg. Director, Global Change Institute. Coral Reef Ecosystems Lab UQ.

[3] Spalding M., McIvor, A., Tonneijck, F., Tol, S. and Eijk, P.V. (2014). *Mangroves for coastal defence: Guidelines for coastal managers and policy makers.* Published by Wetlands International and The Nature Conservancy. 42 p. Accessed 09.04.2019 from: https://www.nature.org/media/oceansandcoasts/mangroves-for-coastal-defence.pdf

[4] Olds, A. D., Connolly, R. M., Pitt, K. A. and Maxwell, P. S. (2011). Habitat connectivity improves reserve performance. *Conservation Letters 5 (1). DOI: 10.1111/j.1755-263X.2011.00204.x*

RESEARCH QUESTIONS
Dependent and Independent Variable

Name:

Date:

Dependent and Independent Variable

Both the Dependent variable and Independent variable must feature in the research question. For example,

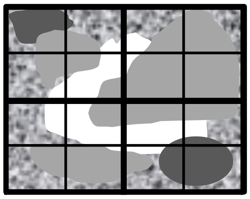
Q1. Is there a difference in ______ **between** ______ **and** ______ **?**
(Dependent variable) (Independent variable (e.g. two groups to compare))

Q2. Is there a linear relationship between ______ **and** ______ **?**
(Dependent variable) (Independent variable)

Dependent Variable – Reef Health

How do we measure reef health? There are many ways. A common way is to estimate the **percentage** of **hard coral cover** using **quadrats,** either with the help of a grid (below left) OR datum points (below right)[1].

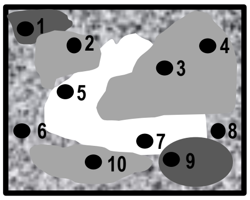
Grid



% Hard Coral = 40% (7.2 squares)

OR

Datum Points



% Hard Coral = 40% (2,3,4,10)

Coral Point Count with Excel Extension is a popular data analysis program that makes adding datum points to your quadrat photographs very easy. You can make the datum points as dots, crosses or even triangles, of any size. You can choose how many datum points to use, and if you want them randomly or evenly spaced[1].

▒ **Hard Coral** ▓ **Soft Coral** ░ **Coral Rubble** □ **Sand** ■ **Rock** ▥ **Silt/Clay** ▨ **Nutrient Indicator Algae** ◆ **Other**

You could also use **CoralWatch** data[2] (in combination with % coral cover) to measure reef health!!

Independent Variable – Water Quality

How do we measure water quality whilst incorporating the concept of connectivity? One way is to create a set of questions that, when answered, allocate each reef a score for water quality. Whereby every '*yes*' answer is worth 1 point. The questions must be about how connectivity either helps or hinders a reef. Below is an example. Of course, you can create your own set of criteria/questions and scores.

QUESTIONS (Yes=1 No=0) (*Note*: 1 nautical mile equals one minute of latitude or longitude)

1. **Is the reef within 1 nautical mile of a mangrove forest or seagrass meadow?**
2. **Is the reef within 2 nautical miles of the continental shelf?**
3. **Is the reef within 30 nautical miles of the continental shelf?**
4. **Is the reef >30 nautical miles away from a major river carrying urban runoff?**
5. **Is the reef >30 nautical miles away from a city with a population > 50,000?**
6. **Is the reef within a Marine Protected Area?**
7. **Is the reef within a Green *or* Pink Zone of a Marine Protected Area?**
8. **Is the reef within dispersal range of coral larvae from a *robust* source reef?**[3]

7-8 VERY HIGH QUALITY
5-6 HIGH QUALITY
3-4 MEDIUM QUALITY
0-2 LOW QUALITY

Alternatively, if you have access to water quality *samples* or water quality data[4], you could allocate each reef a score for water quality using a **water quality index,** such as a **Q value**[5] and then incorporate the concept of connectivity into your research question!

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[1] Nova Southeastern University (2019). *Tools and Resources.* NSU Accessed 09.04.2019 from: https://cnso.nova.edu/cpce/index.html (click on 'CPCe Download Request Form').
[2] Coral Watch (2019). *Data: Surveys.* Accessed 09.04.2019 from: https://coralwatch.org/index.php/data/surveys/
[3] Hock, K., Wolff, N.H., Ortiz, J.C., Condie, S.A., Anthony, K.R.N., Blackwell, P.G. and Mumby, P.J. (2017). Connectivity and systemic resilience of the Great Barrier Reef: **FIGURE 5**. *PLoS Biol 15(11): DOI: 10.1371/journal.pbio.2003355*
[4] eReefs (2019). *eReefs.* A collaboration between the GBR Foundation, BOM, CSIRO and AIMS. Accessed 09.04.2019 from: https://ereefs.org.au/ereefs
[5] Moffatt, B. (2019). *F45R Oceanography Study Guide.* Wet Paper Publications. Accessed 09.04.2019 from: http://www.wetpaper.com.au/media/F45ROceanographySample/176/

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EXPERIMENTAL DESIGN

Name:

Date:

Study SITES

Over the next 4 worksheets, you have access to photo quadrats from the 4 reef locations listed below.

Activity: Give each reef a score for water quality by completing the table (refer to previous page for 'calculations')

Reef Location	Calculations	Score	Water Quality
(i) Agincourt Reef	0, 1, 1, 1, 1, 1, 1, 1	7	Very High Water Quality
(ii) Lady Elliot Island	0, 0, 1, 1, 1, 1, 1, 1	6	High Water Quality
(iii) Magnetic Island (Nelly Bay)	1, 0, 0, 0, 0, 1, 0, 1	3	Medium Water Quality
(iv) Sloping Island (Keppel Group)	1, 0, 0, 0, 0, 1, 0, 1,	3	Medium Water Quality

Activity: Complete Question 1 below. DISCUSS your hypotheses for both research questions.

Q1. Is there a difference in Mean Percentage Hard Coral Cover **between** Very High Water Quality (Agincourt Reef) **&** Medium Water Quality (Sloping Is) **?**

Q2. Is there a linear relationship between Mean Percentage Hard Coral Cover **&** Water Quality **?**

Controlled Variables

Controlled variables are all the variables that are kept the same (so they do not influence the outcome). E.g. what do all 4 reefs have in common? How were they the same when photographed and analysed?

Activity: List the controlled variables below

E.g. The photo quadrat method was used to photograph all 4 reefs
Random datum points A-J were used for all photo quadrats
All reefs were classed as tropical or sub-tropical reefs (no temperate reefs)
All reefs were within the boundaries of the Great Barrier Reef Marine Park

Measured Variables

If variables can *not* be controlled, they must be measured, so their influence can be considered in the outcome of the study. E.g. How were the reefs different to each other when photographed and analysed? ***Note*: Do not** include any differences that were part of the criteria/questions used for scoring water quality.

Activity: List the measured variables below

E.g. photo quadrats were in different *spatial and temporal scales* (e.g. resolution, area, size, date)
Photo quadrats were from different sources using different methods
Reef types were different (e.g. fringing reef vs coral cay)
Depths were different (e.g. Magnetic Is. and Sloping Is. much shallower)
Habitat Complexity (rugosity) different for all 4 reefs

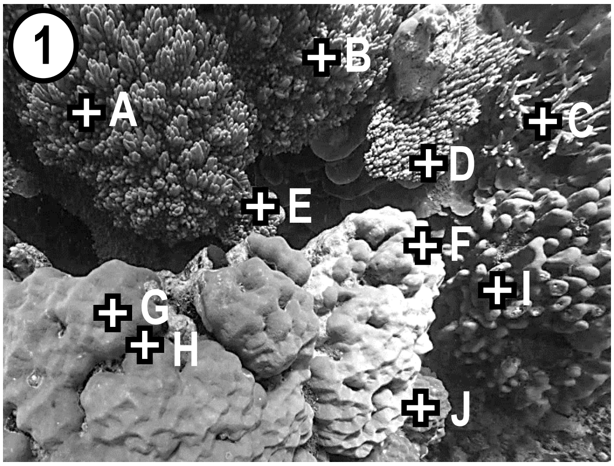
DATA COLLECTION: Example

(i) Agincourt Reef

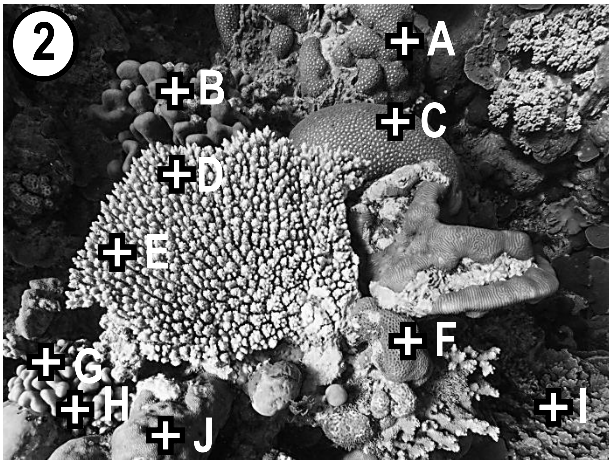
Name:

Date:

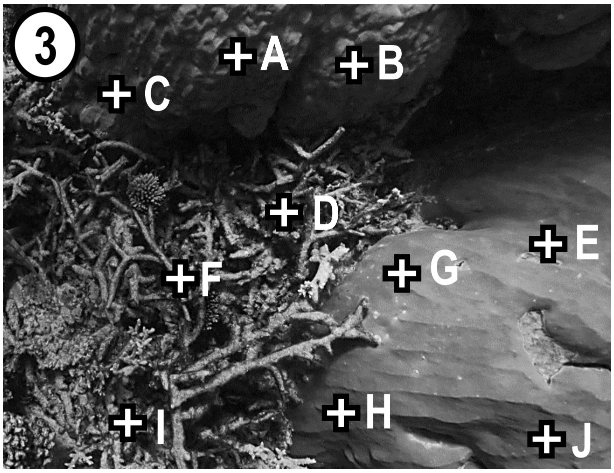
Original colour photos available on www.marineeducation.com.au (data)



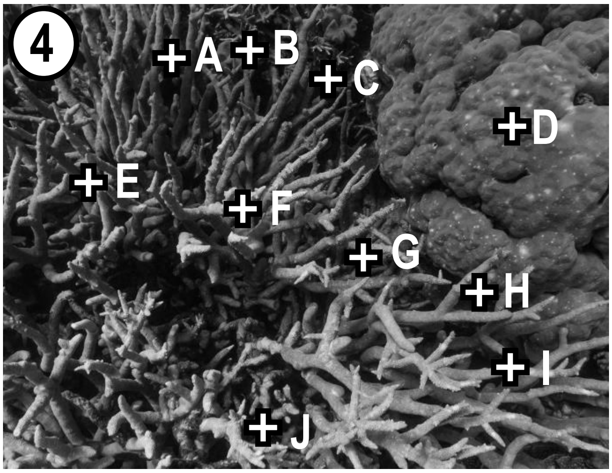
% hard coral cover: 100% (A-J)



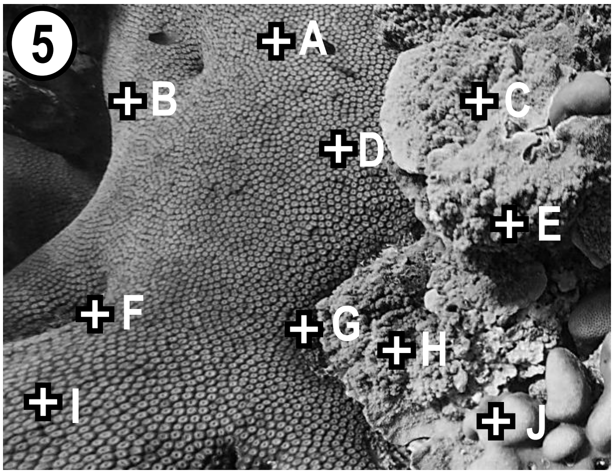
% hard coral cover: 100% (A-J)



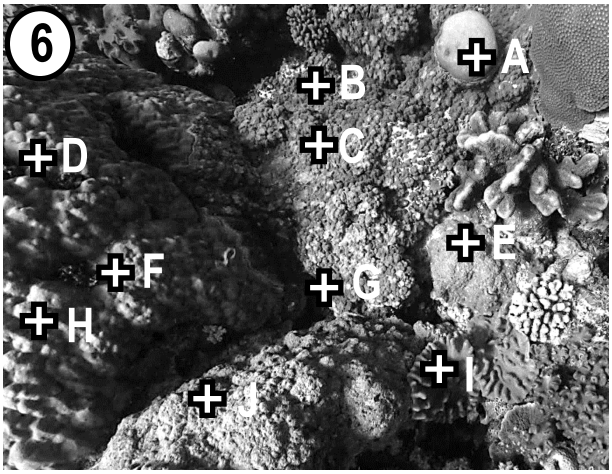
% hard coral cover: 70% (A,B,C,E,G,H,J)



% hard coral cover: 100% (A-J)



% hard coral cover: 100% (A-J)



% hard coral cover: 100% (A-J)

Images (of Agincourt Reef) sourced from the XL Catlin Global Reef Record. © Underwater Earth / XL Catlin Seaview Survey. Taken 23.11.2012. Accessed 24.01.2019 from www.catlinseaviewsurvey.com/ Datum points (A-J) were added at random.

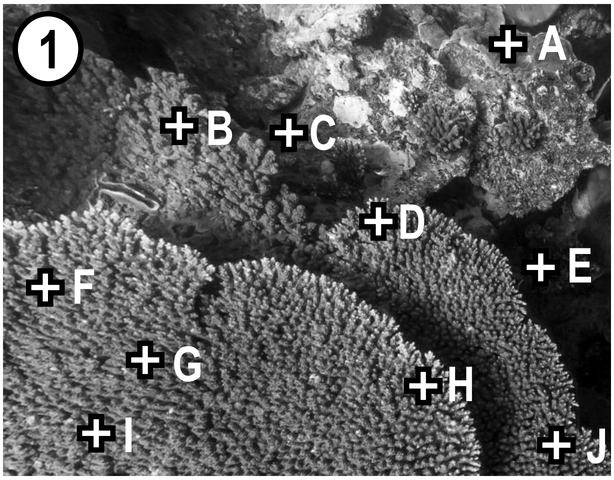
DATA COLLECTION

(ii) Lady Elliot Island

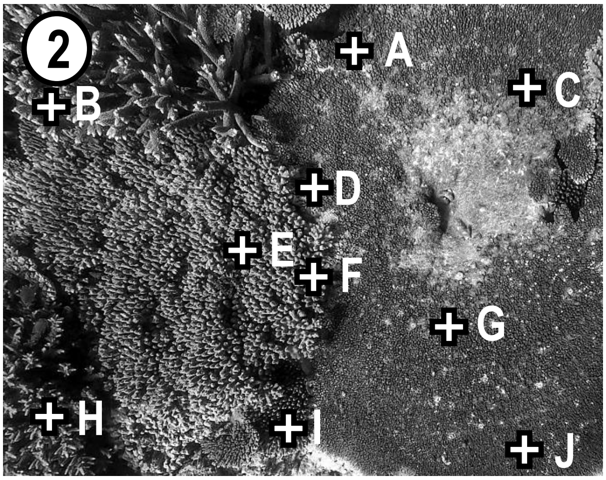
Name:

Date:

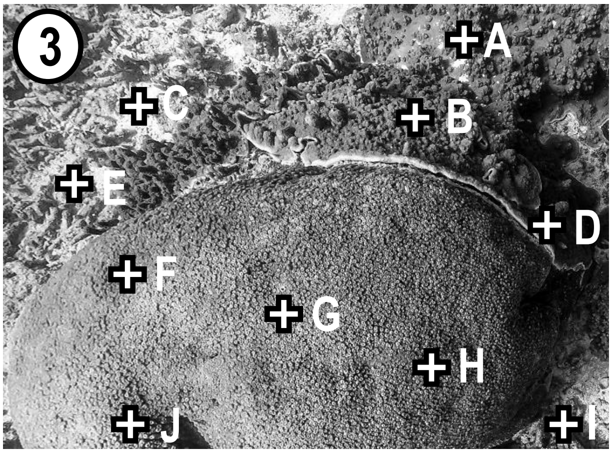
Activity: Estimate and record the percentage hard coral cover in each quadrat below



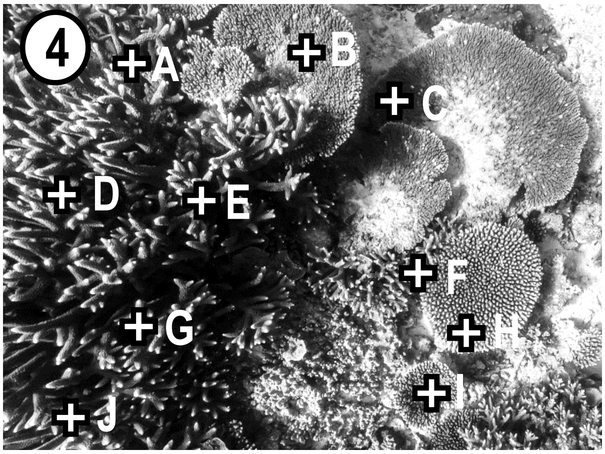
% hard coral cover: 80% (A,B,D,F,G,H,I,J)



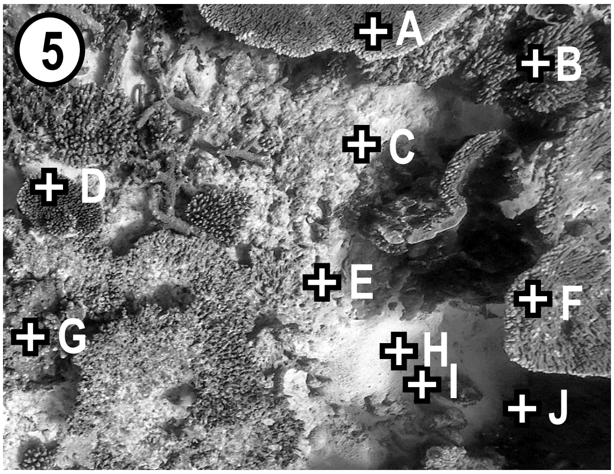
% hard coral cover: 100% (A-J)



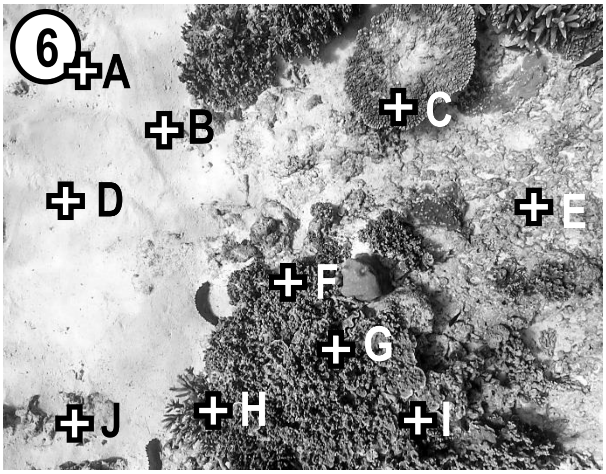
% hard coral cover: 70% (A,B,D,F,G,H,J)



% hard coral cover: 100% (A-J)



% hard coral cover: 50% (A,B,D,F,G)



% hard coral cover: 50% (C,F,G,H,I)

Images (of Lady Elliot Is.) sourced from the XL Catlin Global Reef Record. © Underwater Earth / XL Catlin Seaview Survey. Taken 29.06.2013. Accessed 24.01.2019 from www.catlinseaviewsurvey.com/ Datum points (A-J) were added at random.

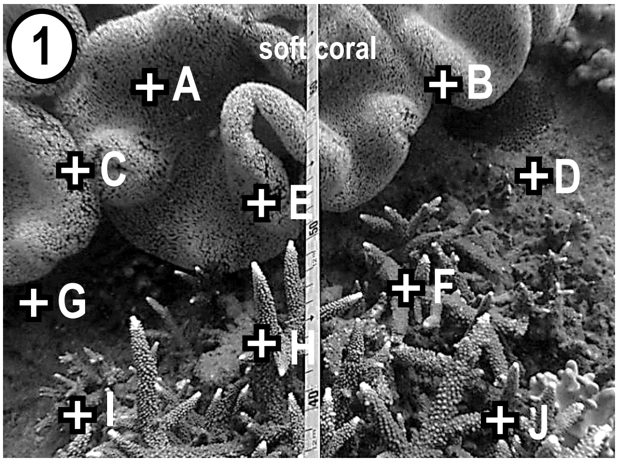
DATA COLLECTION

(iii) Magnetic Island (Nelly Bay)

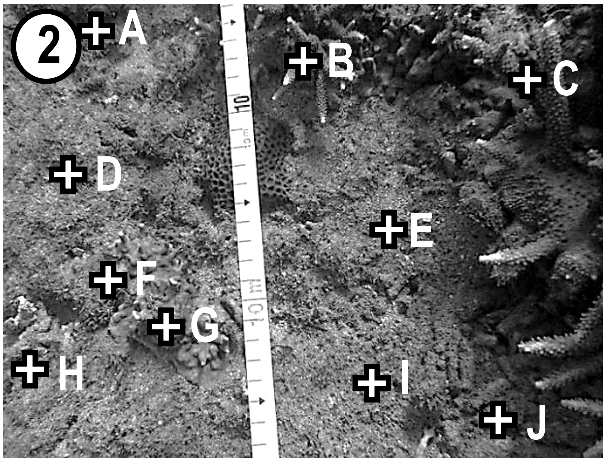
Name:

Date:

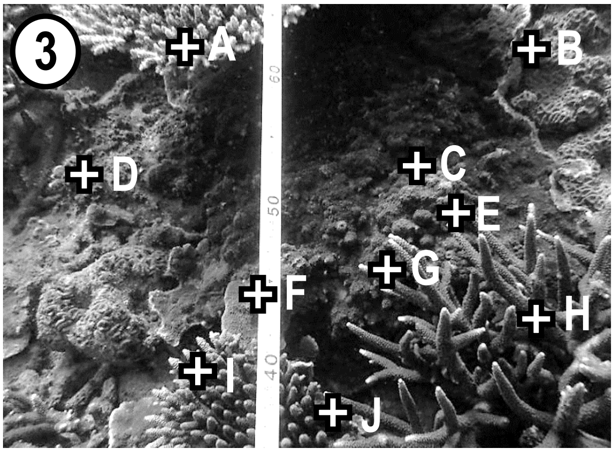
Activity: Estimate and record the percentage hard coral cover in each quadrat below



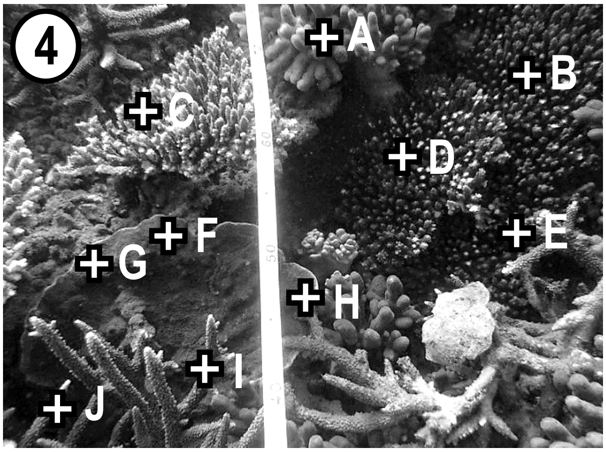
% hard coral cover: 40% (F,H,I,J)



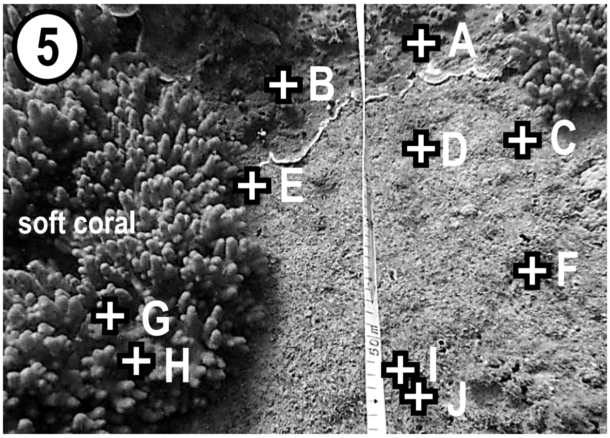
% hard coral cover: 20% (B,C)



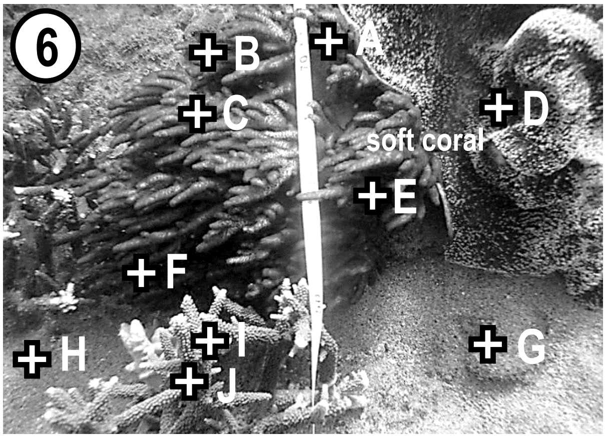
% hard coral cover: 100% (A-J)



% hard coral cover: 100% (A-J)



% hard coral cover: 20% (A,B)



% hard coral cover: 20% (I,J)

Photographs adapted from screenshots from Reef Life Survey Data Portal: Habitat Quadrats. Reprinted with permission. Date unknown. Accessed 24.01.2019 from www.reeflifesurvey.com/ All datum points (A-J) selected at random.

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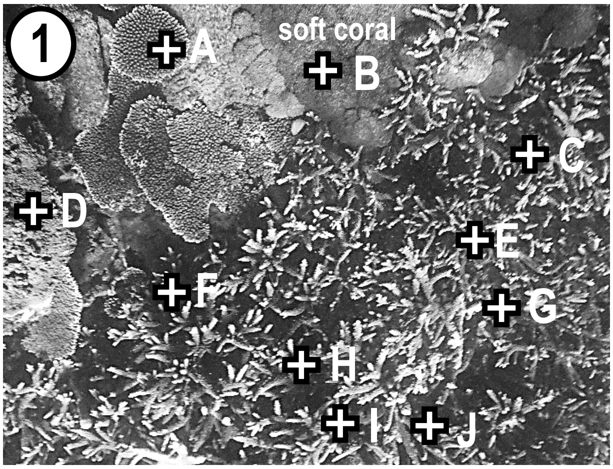
DATA COLLECTION

Name:

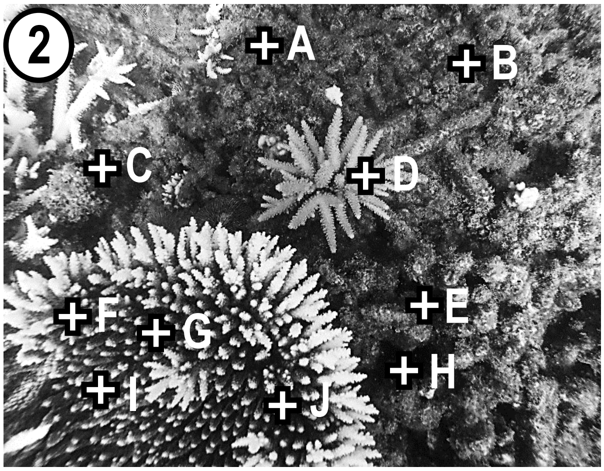
Date:

(iv) Sloping Island (Keppel Group)

Activity: Estimate and record the percentage hard coral cover in each quadrat below

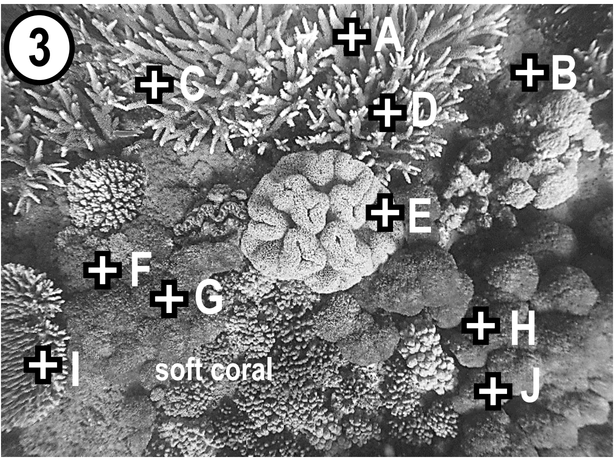


% hard coral cover: 90% (A,C,D,E,F,G,H,I,J)

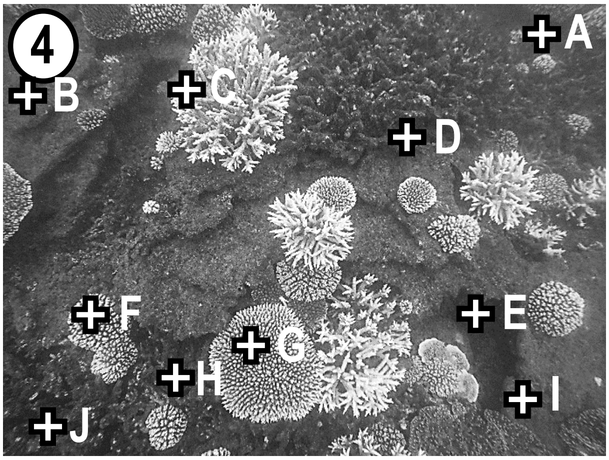


% hard coral cover: 50% (D,F,G,I,J)

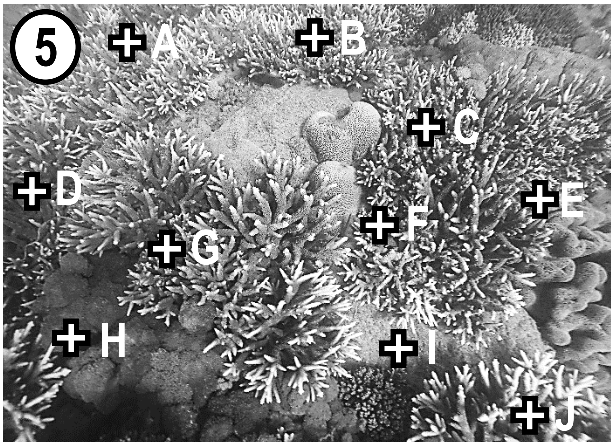
can you see the clam?



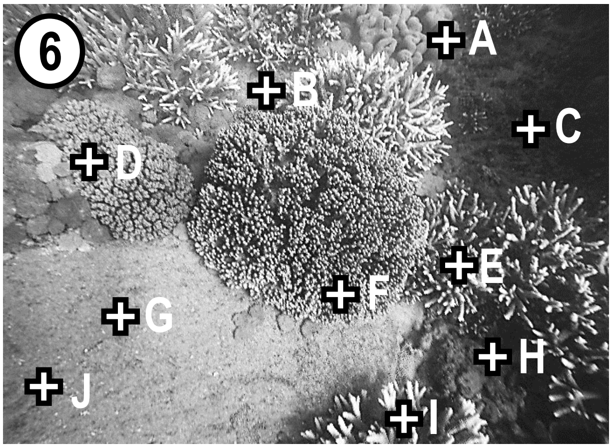
% hard coral cover: 40% (A,C,D,I)



% hard coral cover: 30% (C,F,G)



% hard coral cover: 80% (A,B,C,D,E,F,G,J)



% hard coral cover: 40% (D,E,F, I)

Photographs kindly provided by North Keppel Island Environmental Education Centre (found within the *Capricorn* GBRMPA Management Area). Date of photograph: Winter, 2018. Datum points (A-J) were selected at random.

DATA ANALYSIS
Results

Name:

Date:

Activity: Copy and complete the research questions from page 80 into the blank spaces below.

Q1. Is there a difference in Mean Percentage Hard Coral Cover **between** V. High Water Quality (Agincourt Reef) **&** Medium Water Quality (Sloping Island) **?**
Answer using a t-test (P-value)

Q2. Is there a linear relationship between y-axis Mean Percentage Hard Coral Cover **&** x-axis Water Quality **?**
Answer using a Pearson's correlation test (r-value)

Activity: Use your answers from the previous worksheets to complete the Results Table below

Excel cells	A	B	C	D	E	F	G	H	I	J	K
1	**Reef Location**	**Water quality score**	**Percentage Hard Coral Cover**						**Mean**	**Standard Deviation (s)**	**Confidence Interval (CI)**
2			①	②	③	④	⑤	⑥			
3	**(i) Agincourt Reef**	**7**	**100**	**100**	**70**	**100**	**100**	**100**	=AVERAGE(C3:H3) **95.0**	=STDEV(C3:H3) **12.25**	=CONFIDENCE.T(0.05,J3,6) **12.85**
4	**(ii) Lady Elliot Is**	6	80	100	70	100	50	50	75.0	22.58	23.70
5	**(iii) Magnetic Is**	3	40	20	100	100	20	20	50.0	39.50	41.45
6	**(iv) Sloping Is**	3	90	50	40	30	80	40	55.0	24.29	25.49

To calculate the **mean, s,** and **CI**, in Microsoft Excel, start by entering values from ①②③④⑤⑥ in to cells C3-H6. Starting with Agincourt Reef, in cell I3, type the formula: **=AVERAGE(C3:H3)** In cell J3, type the formula: **=STDEV(C3:H3)** And, in cell K3, type the formula: **=CONFIDENCE.T(0.05,J3,6)** Repeat for the other reefs, substituting the 3 in the formulas for 4, 5 and 6. Alternatively, just drag down the tiny square on the bottom right-hand corner of cell I3, J3 and K3.

Complete the table to find a P-value for Q1

Q1	**QUADRATS** ①②③④⑤⑥	**P**
(i) Agincourt Reef	**100,100,70,100,100,100**	0.0048
(iv) Sloping Is	90,50,40,30,80,40	

To calculate the P-value, google **GraphPad QuickCalcs: t test calculator.** Enter data for Agincourt Reef in to the Group 1 column. Enter data for Great Keppel Island in to the Group 2 column. Select unpaired test and click 'Calculate Now'. If the P-value is =< 0.05, the difference is significant.

Complete the table to find a r-value for Q2

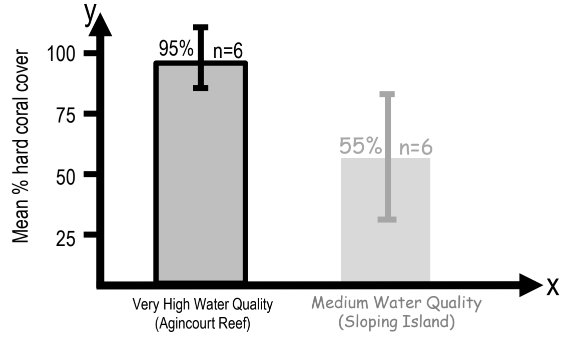
Q2	**Reef Locations →**	**(i)**	**(ii)**	**(iii)**	**(iv)**	**r**
y-axis	**Mean % hard coral cover** *hint:* Column I	**95**	75	50	55	0.97298
x-axis	**Water Quality Score** *hint:* Column B	**7**	6	3	3	

To calculate the r-value, in Excel, enter the water quality scores in to cells B3-B6. Then, click on any blank cell in Excel and type the formula: **=CORREL(I3:I6,B3:B6)** If the r value is between 0.5 and 1.0 or between -0.5 and -1.0, a *linear* relationship exists. The closer the r value is to ±1.0, the stronger the relationship.

comma !

Complete the Bar graph for Q1 Results

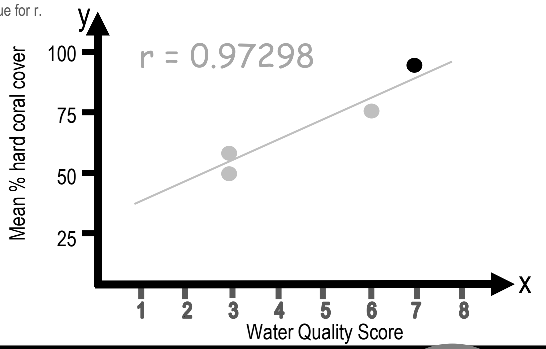
Note: the *top* of the error bar is the mean + CI. Whilst, the *bottom* of the error bar is the mean - CI



Answer to research question 1? [✓ Yes] [No]

Complete the scatter plot for Q2 Results

Note: Create a dot on the graph for each x and y co-ordinate pair. Draw a (straight) line of best fit and write the value for r.



Answer to research question 2? [✓ Yes] [No]

INTERPRETATION and EVALUATION

Name:

Date:

Activity: Analyse the evidence (i.e. results) to identify trends, patterns or relationships.

As water quality increases, reef health increases (and vice versa).

Activity: Analyse the evidence (i.e. methods and results) to identify uncertainty and limitations

Number of quadrats per site (6) not enough. Also, not enough reefs and not enough datum points per photo quadrat. Standard deviations were too high. Photo quadrats were from various online sources using different methods. Method used to calculate water quality (i.e. questions) were simply made up.

Activity: Interpret the evidence (i.e. results) to draw conclusion/s to the research questions

Note: the *null* hypothesis always states there is no difference or no relationship between this and that.

Q1. There was a significant difference in percentage hard coral cover between *Very High* water quality (Agincourt) and *Medium* water quality (Sloping Is.). The *null* hypothesis was rejected (P=0.0048).
Q2. There was a strong linear relationship between mean percentage hard coral cover and water quality. The *null* hypothesis was rejected (r=0.97298).

Activity: Evaluate the reliability and validity of the experimental process

Reliability: Needed more replicates. ‘s’ & ‘CI’ were too high and ‘n’ was too low.
Validity: accuracy compromised by uncertainties and limitations listed above.
Revisit measured variables and their influence on the outcome of the study.

Activity: Suggest possible improvements and extensions to the experiment

- Increase the number of replicates (i.e. reefs, photo quadrats, datum points)
- Collect dependent and independent data at the same time (e.g. go to Keppel)
- Keep the AREA of each photo quadrat the same (e.g. 1m x 1m).
- Base criteria/questions used to score water quality on scientific research.

Activity: *Plan* and *justify* a modification of the research question and methodology.

- Add coral watch data (i.e. for more information to add to your analysis).
- Change or add locations (e.g. more locations will give you more plots to add to Pearson’s correlation analysis).
- Change criteria/questions when scoring water quality (validated by science).
- Use a water quality index (e.g. Q-value) instead of criteria/questions
- See previous suggestions for possible improvements and extensions.

Unit 3 Marine Systems

Connections and Change

Topic 2:
Changes on the Reef

Anthropogenic change
Ocean equilibria
Implications for marine systems

A Pteropod *Limacina helicina* commonly known as 'sea buttlerfly'. Photograph © Alexander Semenov. Reprinted with permission.

Getting Warmer….Why 1.5°C Matters –

Analyse results from models to determine potential reef futures under various scenarios TO99

Name:

Date:

The IPCC

Governments from around the world came together in 1988 and created the **I**nternational **P**anel on **C**limate **C**hange (**IPCC**). The IPCC recruit world leading experts on climate change – lots of them – to author reports every 5-6 years, to help inform government policy decisions.

In 2018, the IPCC published **A Special Report: Global Warming of 1.5°C**[1]. With **91** authors, the report states: '*multiple lines of evidence indicate that the majority of warmer water tropical coral reefs that exist today (70-90%) will disappear* ***even if*** *global warming is constrained to 1.5°C (very high confidence)*'.

Q. How much has the Earth warmed already (since pre-industrial levels)? Ans. ~1°C

Representative Concentration Pathways (RCPs)

In 2014, the ICPP published a report that approximated radiative forcing (W/m^2) in 2100 for 4 different greenhouse gas (GHG) concentration pathways, called RCPs[2]. E.g. RCP8.5 is a future with high GHG concentrations, whereas RCP2.6 is a future with low GHG concentrations, expressed in ppm as *CO2 equivalent* (Fig. 1) or just CO2 (Fig. 2)[3].

Note: each RCP is simply a whole bunch of numbers that serve the purpose as inputs for climate models, to jump-start and standardise the climate modelling process. They are not a *complete* package of socio-economic, emissions, and climate projections[2].

Q. What does RCP stand for? Ans. Representative Concentration Pathways

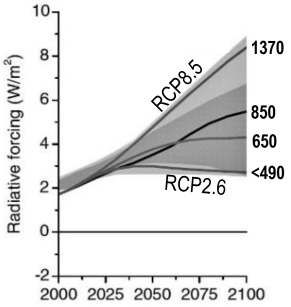


Fig. 1: CO2 concentration *equivalent* (ppm) in 2100 for each RCP[3]

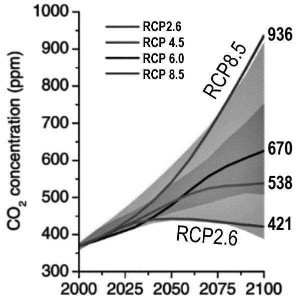


Fig. 2: CO2 concentrations (ppm) (and *only* for CO2) in 2100 for each RCP[3]

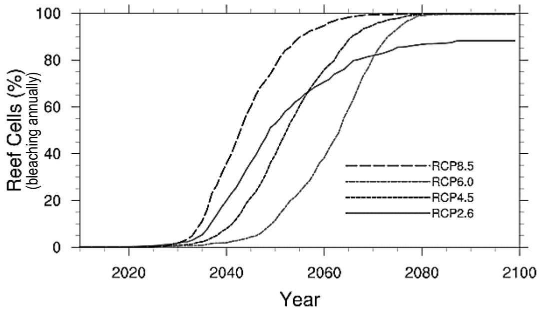


Fig. 3: Percentage of reefs globally projected to bleach every year. Bleaching will be an annual event for 3 out of 4 RCPs by 2100. Courtesy of Ruben van Hooidonk from data in van Hooidonk *et al.,* (2014)[4]

Activity: Complete the table below (*hint:* refer to Figures 1, 2 and 3 above, and Figure 1 on page 27)

RCP	Radiative Forcing W/m^2 in 2100	CO2 concentration *equivalent* (ppm) in 2100	CO2 concentration (ppm) in 2100	Likelihood of staying *below* a specific temperature level over the 21st Century (relative to 1850-1900)[5]				Potential Reef Futures in the year 2100
				1.5°C	2°C	3°C	4°C	
8.5	8.5	1370	936	Unlikely	Unlikely	Unlikely	More unlikely than likely	Reefs not dominated by coral [pg.27] Annual bleaching[4]
6.0	6.0	850	670			More unlikely than likely	Likely	Reefs not dominated by coral [pg.27] Annual bleaching[4]
4.5	4.5	650	538		More unlikely than likely	More Likely than not		Reefs not dominated by coral [pg.27] Annual bleaching[4]
2.6	2.6	<490	421	More unlikely than likely	Likely	Likely		10-30% of reefs might be saved[1]

---

[1] IPCC (2018) Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. In Press.

[2] Vuuren, D.P.V., Edmonds, J.A., Kainuma, M., Riahi, K. and Weyant, J. (2011). Special Issue: The Representative Concentration Pathways in Climate Change. *Climatic Change. 109 (1-2). DOI: 10.1007/s10584-011-0157-y*

[3] Adapted from: Climate Change in Australia (2015). *Greenhouse Gas Scenarios.* CSIRO. Accessed 16.02.2019 from https://www.climatechangeinaustralia.gov.au/en/climate-campus/modelling-and-projections/projecting-future-climate/greenhouse-gas-scenarios/

[4] van Hooidonk R.J, Maynard J.A, Manzello D, Planes S (2014). Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. *Global Change Biology, 20, 103–112. DOI: 10.1111/gcb.12394*

[5] Adapted from: IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Accessed 01.07.2019 from: https://www.ipcc.ch/report/ar5/syr/

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Footprints of the Anthropocene – Recall the global anthropogenic factors affecting the distribution of coral (i.e. coral mining, pollution: organic and non-organic, fishing practices, dredging, climate change, ocean acidification and shipping) T100

Name:

Date:

What do SCIENTISTS perceive as the greatest *global* threats?

An email survey in 2015[1] asked 171 leading academics in marine science (126 natural scientists and 45 social scientists) the following question. '*Could you tell us which five topics represent the greatest global threats or potential impacts in marine environments?'*. See the results of the survey in Figure 1 below:

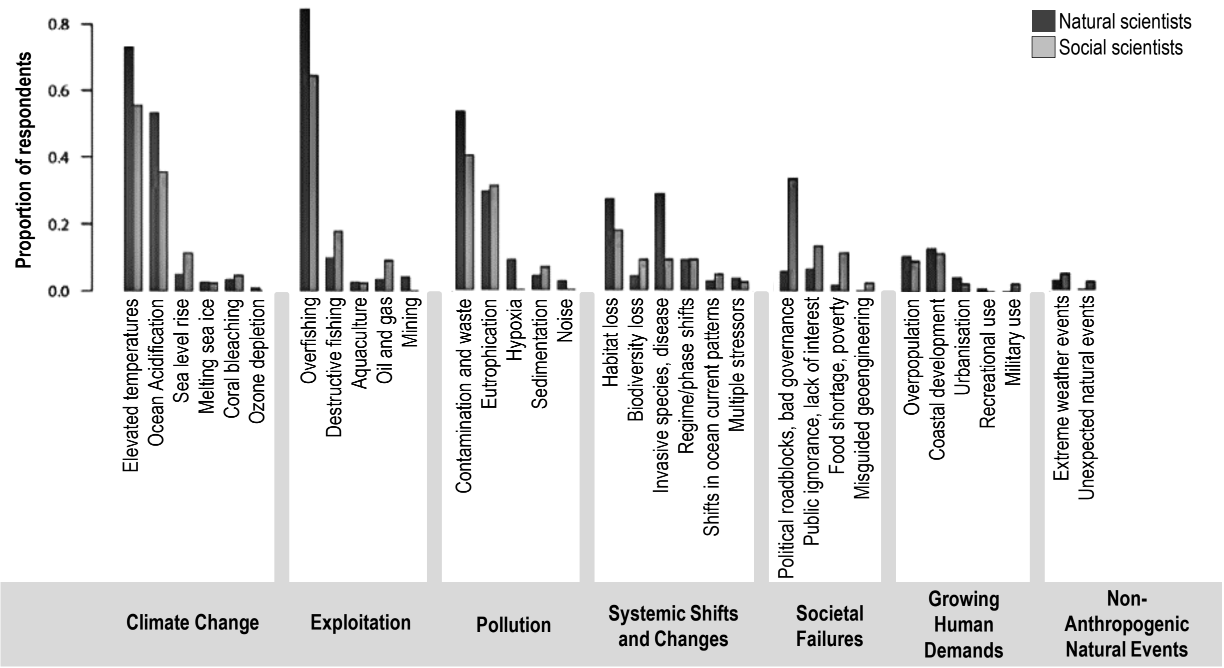

Figure 1: Global threats or potential impacts in marine environments, according to 126 natural scientists and 46 social scientists in an email survey[1].

Q. What is perceived as the greatest global threat in Figure 1? Ans. Overfishing

Activity: Rank what you perceive as the top 5 greatest *global* threats in marine environments

1.

2.

3.

4.

5.

---

[1] Adapted with permission from: Boonstra, W.J., Ottosen, K.M., Ferreira, A.S.A., Richter, A., Rogers, L.A., Pedersen, M.W., Kokkalis, A., Bardarson, H., Bonanomi, S., Butler, W., Diekert, F.K., Fouzai, N., Holma, M., Holt, R.E., Kvile, K.O., Malanski, E., MacDonald, J.I., Nieminen, E., Romagnoni, G., Snickars, M., Weigel, G., Woods, P., Yletyinen, J. and Whittington, J.D. (2015). What are the major global threats and impacts in marine environments? Investigating the contours of a shared perception among marine scientists from the bottom-up. *Marine Policy 60: 197-201 DOI: 10.1016/j.marpol.2015.06.007.*

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Under Pressure….Threats to Reefs –

Describe the specific pressures affecting coral reefs (i.e. surface run-off, salinity fluctuations, climate change, cyclic crown-of-thorns outbreaks, overfishing, spills and improper ballast) T101

Name:

Date:

What do coral reef MANAGERS perceive as the greatest *local* threats?

An email survey in 2016[1] listed six threats to coral reefs (see x-axis) and asked coral reef *managers to* (a) rate the level each threat posed to reefs *in their jurisdiction* (0=no threat and 6=extreme threat) and (b) report on how much money (% of budget) is allocated to abate each threat. Below are the results.

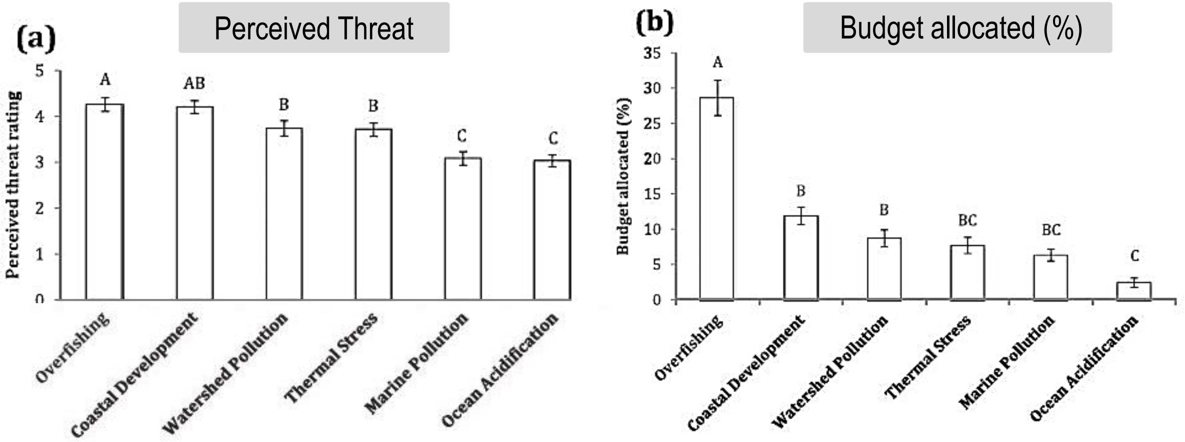

Figure 1: The results of an email survey asking coral reef managers to (a) rate their perceived threat level of six named threats to local coral reefs (threat rating scale of 0-6, with 0=no threat and 6=extreme threat) and (b) report on how much money (%) is allocated to abate each threat, n=110[1].

Q. What is perceived as the greatest local threat in Figure 1? Ans. Overfishing

Activity: Complete the table below. Describe each threat. Then, rate the level each threat poses to a reef close to your location (0=no threat; 6 =extreme threat). Reef Name:

Threat	Describe the threat	Rate the local threat (0-6)
Surface run-off	Sedimentation reduces clarity and causes smothering. Increased nutrient input leads to disease, COTS, etc.	
Salinity fluctuations	Freshwater inundation causes corals to bleach	
Climate change	Increasing temperatures causes corals to bleach	
Cyclic COTS outbreaks	COTS (Crown of Thorns Starfish) eat corals	
Overfishing	Functional contributions of fish are lost	
Oil spills	Large infrequent oil spills, and small chronic oil spills, impede coral growth, reproduction and much more…	
Improper ballast	Introduced species (entering via improper ballast water management) outcompete native species	

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[1] Adapted with permission from: Wear, S. L. (2016). Missing the boat: Critical threats to coral reefs are neglected at global scale. *Marine Policy 74: 153-157. DOI: 10.1016/j.marpol.2016.09.009.*

Sclerochronometer Secrets – Recognise that during the Holocene no evidence of coral bleaching or ocean acidification (OA) can be found within coral cores dating back 6000 years T102

Name:

Date:

Q. Was the *beginning* of the Holocene associated with a period of global warming or cooling? Ans. warming

Q. Was there a time during the Holocene when temperatures were warmer than today? Ans. Yes

Q. Is there evidence of bleaching then? Ans. No

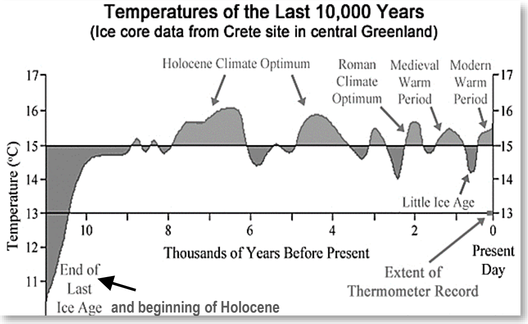


Fig. 1: Temperatures since the beginning of the Holocene[1].

Coral core climate records

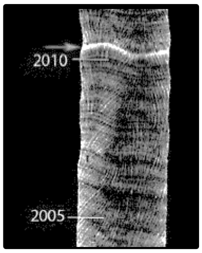


Fig. 2: Coral core stress band (in white) from the 2010 bleaching event[2].

Coral cores provide a very handy record of coral bleaching events from the past.
For example, any heat wave that causes a coral to become stressed, the coral records as a discrete, high density 'stress band' on its skeleton[2] (see white line in Figure 2).
Conveniently, the *date* of the stress band can be calculated using its position in relation to growth bands on the skeleton (which appear like the growth rings on a tree).
Note: coral cores can be taken from *live* corals (see p. 98, Fig. 2) or from *fossil* corals whereby radiocarbon (^{14}C) dating is used to obtain the initial calendar age of the coral[3].

Q. What does a high density 'stress band' indicate? Ans. Past stress (e.g. bleaching)

Mass Bleaching Events Timeline

Prior to 1979, reports of coral bleaching events in the primary literature are virtually non-existent[4].

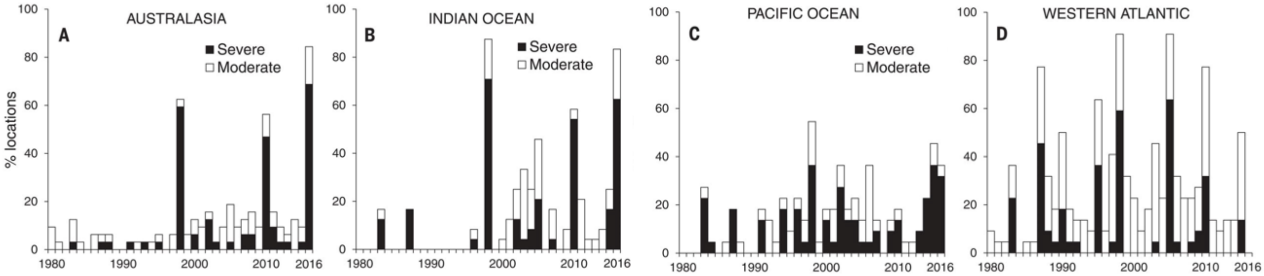


Fig. 3: Geographic variation in the timing and intensity of coral bleaching from 1980 to 2016. (A) Australasia (32 locations). (B) Indian Ocean (24 locations). (C) Pacific Ocean (22 locations). (D) Western Atlantic (22 locations). For each region, black bars indicate the % of locations that experienced severe bleaching, affecting >30% of corals. White bars indicate the % of locations per region with additional moderate bleaching affecting <30% of corals[5].

Q. When was the first *severe* bleaching event in Figure 3? (*hint:* 1st black line in all 4 graphs) **Ans.** 1983

Q. In what year did a *mass* coral bleaching event capture the world's attention? Ans. 1998

---

[1] Adapted with permission from: Wagg, G. (2015). *Lesson 1 – Palaeoclimatology.* Wordpress. London. UK. Accessed 26.06.2019 from: https://mrgeogwagg.wordpress.com/2015/06/22/lesson-1-palaeoclimatology/

[2] Adapted with permission from: Barkley, H.C. and Cohen, A.L. (2016). Skeletal records of community-level bleaching in Porites corals from Palau. *Coral Reefs. DOI: 10.1007/s00338-016-1483-3*

[3] Lough, J.M., Llewellyn, L.E., Lewis, S.E., Turney, C.S.M., Palmer, J.G., Cook, C.G. and Hogg, A.G. (2014). Evidence for suppressed mid-Holocene northeastern Australian monsoon variability from coral luminescence. *Paleoceanography, 29(6), 581–594. DOI: 10.1002/2014PA002630*

[4] Hoegh-Guldberg, O. (1999). Climate change, coral bleaching and the future of the world's coral reefs. *Marine Freshwater Research. Vol. 50, 839-66. DOI: 10.1071/mf99078*

[5] From Hughes, T., Anderson, K.D., Connonlly, S., Heron, S.F., Kerry, J.R., Lough, J.M., Baird, A.H., Baum, J.K., Berumen, M.L., Bridge, T.C., Claar, D.C., Eakin, M., Gilmour, J.P., Graham, N.A.J., Harrison, H., Hobb, J.A., Hoey, A.S., Hoogenboom, M., Lowe, R.J., McCulloch, M., Pandolfi, J.M., Pratchett, M., Schoepf, V., Torda, G. and Wilson, S.K. (2018). Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science 359, 80-83. DOI: 10.1126/science.aan8048.* Reprinted with permission from AAAS.

In Hot Water…How warm is too warm? –

Explain the concept of coral bleaching in terms of Shelford's Law of Tolerance T103

Name:

Date:

Threshold Theatre

The reason why there were so few bleaching events recorded prior to 1979 is because the **sea surface temperature (SST)** rarely exceeded the *upper thermal limit* of coral and zooxanthellae[1]. The *upper thermal limit* (also called the *thermal threshold, bleaching threshold* or a combination of both) is the temperature that corals are likely to bleach. That temperature varies between species, location and time. But for modelling purposes, it is generally set to **1°C above** a long-term average for that month and location (e.g. maximum monthly mean or MMM + 1°C)[2]. Whereby, any temperature above that threshold is considered as out of the ordinary, too warm, and likely to cause bleaching[2]. Conversely, the *optimal* temperature for reef-building corals is ~2-4°C below its upper thermal limit[3][5].

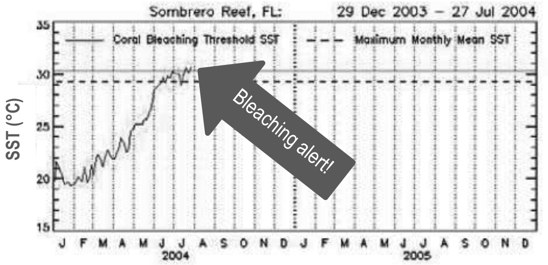


Figure 1: The SST of Sombrero Reef being plotted against, and rising above, the MMM (dashed line) and the bleaching threshold (solid straight line)[2].

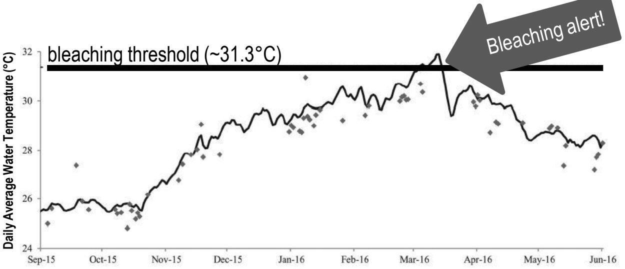
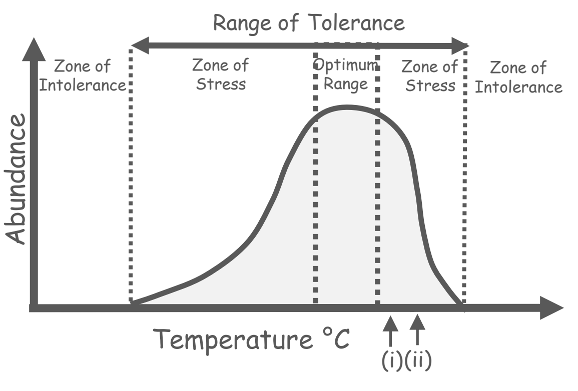


Figure 2: Thursday Island 2015-16 had 10 days above the thermal threshold and temperatures 2.6°C above normal (mid-March) causing bleaching[4].

Q. At what temperature are corals on Thursday Island likely to bleach (Fig. 2)? Ans. ~31.3°C

Activity: Draw a graph of Shelford's Law of Tolerance. Indicate the approximate position of (i) MMM and (ii) the upper thermal limit.



Adapted from: Buddemeier, R. W. and Smith, S. V. (1999). Coral Adaptation and Acclimatization: A Most Ingenious Paradox. Amer. Zool., 39(1):1-9

Activity: Explain the concept of coral bleaching in terms of Shelford's Law of Tolerance

Corals live close to their upper thermal limit. Therefore, water temperatures only need to warm up a few degrees before corals start to expel their zooxanthellae and turn white, known as 'coral bleaching'. *Note:* the damaging effects of high temperatures are also *time* dependent (see next page). Hence, it is not possible to cite a single *lethal* temperature without specifying the exposure period (unless it is *ridiculously* warm and the corals simply cook to death).

---

[1] Hoegh-Guldberg, O. (1999). Climate change, coral bleaching and the future of the world's coral reefs. *Marine Freshwater Research. Vol. 50, 839-66. DOI: 10.1071/mf99078*

[2] Liu, G., Strong, A. E., Skirving, W. J. and Arzayus, F. (2006). *Overview of NOAA Coral Reef Watch Program's Near-Real-Time Satellite Global Coral Bleaching Monitoring Activities.* Proceedings of the 10th International Coral Reef Symposium, Okinawa: 1783-1793. Accessed 23.02.2019 from www.coralreefwatch.noaa.gov

[3] Langlais, C., Lenton, A., Evenhuis, C., Gupta, A.S., Brown, J.N. and Kuchinke, M. (n.d.). *Local SST variability determines coral bleaching risk under global warming*. As: *Coral_variability_warming_MMM_resubmitted.docx* In: Langlais *et al.,* (2015). *Projections of coral bleaching risk in the Western Pacific under different levels sea surface temperature increases*. v1. CSIRO. Data Collection. *DOI: 10.4225/08/551413D6B8141*

[4] Adapted with permission from: Bainbridge, S. (2017). Temperature and light patterns at four reefs along the Great Barrier Reef during the 2015–2016 austral summer: understanding patterns of observed coral bleaching. *Journal of Operational Oceanography. 10:1. 16-29. DOI:10.1080/1755876X.2017.1290863.* Reproduced with permission.

[5] Cantin N.E. and Lough, J.M. (2014). Surviving Coral Bleaching Events: Porites Growth Anomalies on the Great Barrier Reef. *PLoS One. 9(2): e88720. DOI: 10.1371/journal.pone.0088720*

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In Hot Water...How long is too long? – Interpret thermal threshold data for reefs in the northern, central and southern sections of the Great Barrier Reef in relation to the likelihood of a bleaching event T104

Name:

Date:

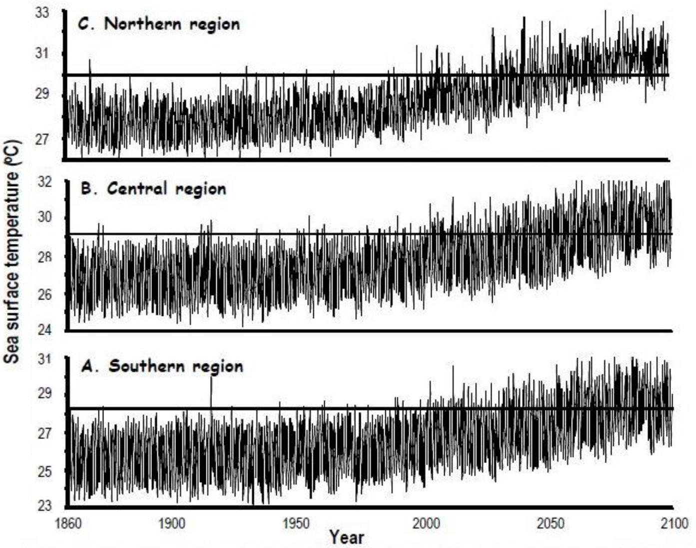

Figure 10. Sea surface temperature data generated the global coupled atmosphere-ocean-ice model (ECHAM4/OPYC3, Roeckner et al. 1996) and kindly provided by Dr Axel Timmermann of KNMI, Netherlands. Temperatures were generated for each month from 1860 to 2100, and were forced by Greenhouse warming that conformed to the IPCC scenario IS92a (IPCC, 1992). The effect of El Nino Southern Oscillation (ENSO) events included (see text for explanation). Horizontal lines indicate the thermal thresholds of corals at each site. The three regions that data were generated for were: a southern (149.5ºE, 23.5ºS), central (147.5ºE, 18ºS) and northern (143ºE, 11ºS) location on the Great Barrier Reef.

Reproduced with Permission[1].

Temperature Time Bomb

The graph pictured left[1] was published in a paper by Professor Ove Hoegh-Guldberg in 1999 - a paper that has been referenced >3000 times. The horizontal lines indicate the thermal threshold of corals for sites in the northern, central and southern locations of the GBR.

Activity: Estimate the likelihood of a bleaching event in 1950 vs. 2100 for each region of the Great Barrier Reef

Region	1950	2100
Northern	Very Low	Very High
Central	Very Low	Very High
Southern	Very Low	Very High

Bleaching Alert!

The severity of a mass bleaching event largely depends on how warm the water gets, and for how long. **Degree Heating Days (DHD)** is a measure of the accumulated heat stress over time (usually over 12 weeks). It is used to monitor the GBR for bleaching, and to issue bleaching alerts. For example, at 1DHD, the water has exceeded its thermal threshold temperature for 1 day*. Whereby, <60DHDs initiates a **mild** bleaching alert (<25% of reef affected), 61-100DHDs initiates a **moderate** bleaching alert (26-50% of reefs affected), and >100DHDs initiates a **severe** bleaching alert (>50% of reefs affected)[2]. Similarly, NOAA in the USA also issue bleaching alerts. But instead of DHD, NOAA use **Degree Heating Weeks (DHW or °C-weeks).** Whereby, 4DHW initiates a **Level I** alert to indicate that mass bleaching may be occurring, and 8DHW initiates a **Level II** alert to indicate that severe mass coral bleaching with some associated coral mortality may be occurring[3].

* *Note:* 1DHD could denote 1°C over the local long-term monthly average temperature for one day, or 2°C above the local long-term monthly average temperature, for half a day.

Activity: Complete the table below for today's date, using real-time data from *ReefTemp and eReefs* on the Bureau of Meteorology[4] and *Coral Reef Watch* on NOAA[5]

Region	MMM (long-term mean SST for hottest month of the year)	Thermal Threshold MMM + 1°C	DHD (read from map)	Alert Level (no alert, mild alert, moderate alert, severe alert)	DHW (read from map)	Alert Level (no alert, alert Level I, alert Level II)
Northern GBR	29.0°C	30.0°C				
Central GBR	28.1°C	29.1°C				
Southern GBR	27.2°C	28.2°C				

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[1] Hoegh-Guldberg, O. (1999). Climate change, coral bleaching and the future of the world's coral reefs. *Marine Freshwater Research. Vol. 50, 839-66. DOI: 10.1071/mf99078*

[2] Maynard, J. A. (2008). *ReefTemp*: An interactive monitoring system for coral bleaching using high-resolution SST and improved stress predictors. *Geophysical Research Letters (35)*

[3] Liu, G., Strong, A.E., Skirving, W. and Arzayus, L.F. (2006). *Overview of NOAA Coral Reef Watch Program's Near-Real-Time Satellite Global Coral Bleaching Monitoring Activities.* Proceedings of the 10th International Coral Reef Symposium, Okinawa. June 28-July 2, 2004. 1783-1793. Accessed 23.02.2019 from www.coralreefwatch.noaa.gov

[4] Bureau of Meteorology (2019). *ReefTemp Next Generation* (BOM>Environmental Information>Coastal Information). URL: www.bom.gov.au/environment/activities/reeftemp/reeftemp.shtml

[5] NOAA Satellite and Information Service (2019). *Coral Reef Watch Home Page.* URL: https://coralreefwatch.noaa.gov/satellite/index.php

What's the Damage Bill? – Use a specific case study to evaluate the ecological effects on other organisms (e.g. fish) after a bleaching event has occurred T105

Name:

Date:

Assessing the damage

How organisms *respond* to bleaching events varies depending on the severity of the bleaching event, and the ecology and life-history of the species[1]. For example, when a bleaching event is severe and lots of live coral dies, coral-dependent fishes (e.g. butterflyfish and damselfish) are most at risk because of their direct reliance on corals for food, habitat and recruitment[1]. In particular, coral-dependent fish that depend on live coral for food (e.g. *Chaetodon spp.*) experience significant declines in abundance (although sometimes these declines are not observed for a few years)[1]. Importantly, if a hard coral colony is dead, it still remains structurally intact, contributing to the reef's topographic complexity[2]. It usually takes ~4 years* for the colony to break down from erosion and for a decline in topographic complexity to be observed (unless a cyclone hits before then). When the reef loses its topographic complexity, the effects are more widespread[2].

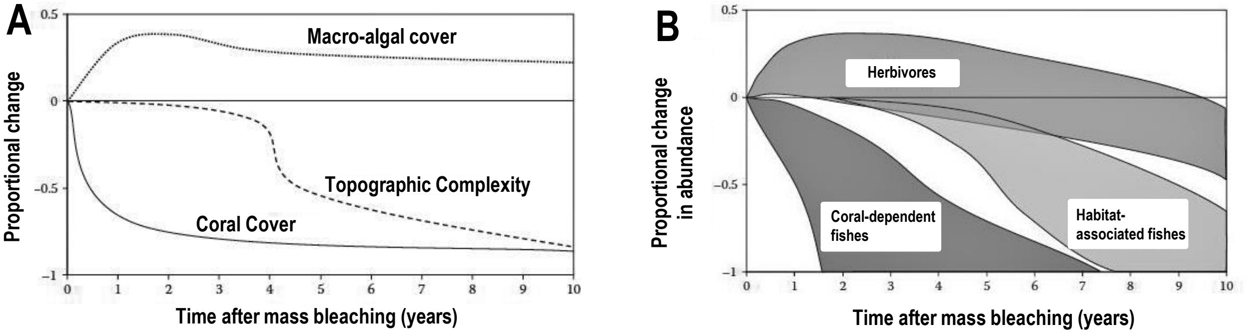

Figure 1: Conceptual diagram of changes in coral reef habitats and fish communities following climate-induced coral bleaching. (A) Timing and magnitude of proportional changes in macro-algal cover, topographic complexity and coral cover. (B) Response envelops for strongly coral-dependent fishes (e.g., obligate corallivores), habitat-associated fishes and herbivores[2].

Activity: Use a specific case study to evaluate the ecological effects on other organisms (e.g. fish) after a bleaching event has occurred. *Reference* the case study in the space provided.

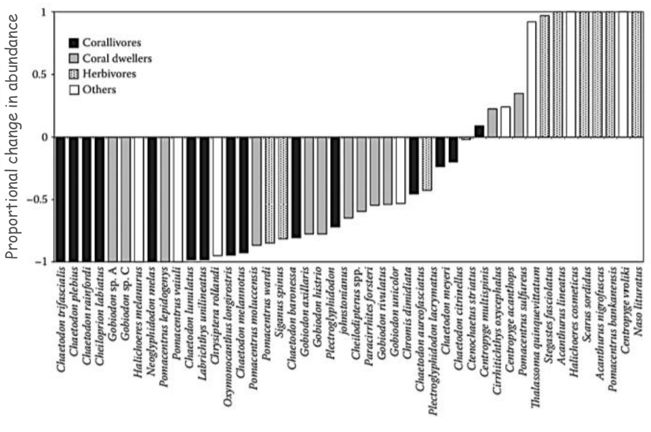

Figure 2: Changes in the abundance of coral reef fishes (corallivores in black, coral dwellers in grey, herbivores with dots, and others in white) 1-3 years following climate-induced coral bleaching. Data presented for 45 (of 116) species that exhibited significant changes in abundance following mass bleaching that caused >50% coral loss[2].

Reference

[2] Pratchett, M. S. *et al.*, (2008). Effects of Climate-Induced Coral Bleaching on Coral Reef Fishes – Ecological and Economical Consequences. *Oceanography and Marine Biology: An Annual Review (46) 251-296. DOI: 10.1201/9781420065756.ch6*

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* However, Eakin *et al.*, (2019)[3] suggest bioerosion might be more rapid than previously understood, with a significant reduction in topographic complexity observed within less than a year after bleaching.

[1] Coker, D. J. (2012). The importance of live coral habitat for reef fishes and its role in key ecological processes. *PhD thesis. James Cook University.*

[2] Adapted with permission from: Pratchett, M. S., Munday, P. L., Wilson, S. K., Graham, N.A.J., Cinner, J. E., Bellwood, D.R., Jones, G.P., Polunin, N.V.C., and McClanahan, T.R. (2008). Effects of Climate-Induced Coral Bleaching on Coral Reef Fishes – Ecological and Economical Consequences. *Oceanography and Marine Biology: An Annual Review (46) 251-296. DOI: 10.1201/9781420065756.ch6*

[3] Eakin, M.C., Sweatman, H.P.A. and Brainard, R.E. (2019). The 2014-2017 global-scale coral bleaching event: insights and impacts. *Coral Reefs. P. 1-7. DOI: 10.1007/s00338-019-01844-2*

Recipe for Rebuilding – Describe the conditions necessary for recovery from bleaching events T106

Name:

Date:

Reefs need zooxanthellae to come back – quickly

Corals do *not* always die after they bleach. After the heat wave has passed, the zooxanthellae can 'come back' and re-establish their relationship with the coral to carry on living a happy life together. But, this only happens if (a) the water does not get too hot (cooking the corals to death)[1] and (b) the heat wave passes within a *short* time frame (ensuring zooxanthellae return before the corals starve to death). Coral mortality starts at approximately 3-8 degree heating weeks[2][3] (the number of DHWs varies between *Genus species*).

Q. How many Degree Heating Weeks do reefs have before corals start dying? Ans. 3-8 **DHW**

Reefs need lots of coral survivors

Lots of coral survivors means lots of corals to regrow, reproduce and reseed affected areas.

Q. WHY does it matter how many corals survive? Ans.

Surviving corals regrow, reproduce and reseed affected areas

Reefs need herbivores

Reefs need herbivores to eat algae that would otherwise deter incoming larvae from settlement.

Q. How do herbivores keep reefs healthy and help them to recover after a bleaching event? Ans.

They eat algae that would otherwise deter incoming larvae from settlement

Reefs need time

Reefs need enough time to recover before the next disturbance hits.

Q. Is 4 years enough time to recover between *large* disturbance events? Ans. **[Yes] [✓ No]** Circle correct answer

Reefs need structural complexity

Reefs need structural complexity to sustain the diversity of life that, in functioning, helps the reef to recover. Figure 1 illustrates the importance of complexity (and depth) to avoid a phase shift from a coral-dominated state to an algae-dominated state (which, as you know, is very difficult to reverse). For example, if the initial complexity is low (3.0), there is a high probability (0.9) that shallow sites (4.5m) will undergo a phase shift. Then, as the initial complexity increases (3.2), and the depth increases (6.3m), the probability of a phase shift decreases (0.2)[4].

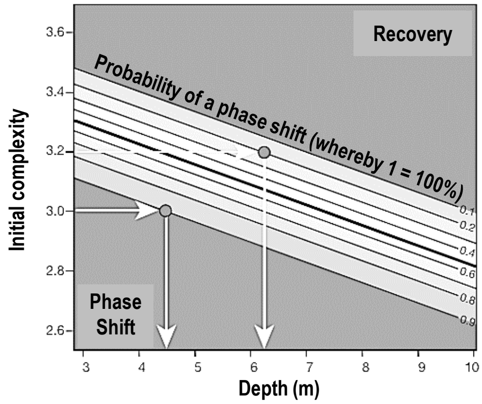

Figure 1: Contour biplot of the probability of a phase shift based on initial structural complexity and water depth[4].

Q. True or False? As complexity increases, the probability of a phase shift decreases. Ans. True

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[1] Hughes, T., Kerry, J.T., Baird, A.H., Connolly, S. R., Dietzel, A., Eakin, C.M., Heron, S.F., Hoey, A.S., Hoogenboom, M.O., Liu, G., McWilliam, M.J., Pears, R.J., Pratchett, M.S., Skirving, W.J., Stella J.S. & Torda, G. (2018). Global warming transforms coral reef assemblages. *Nature 556, 492-496. DOI: 10.1038/s41586-018-0041-2*

[2] De Carlo, T.M., Harrison, J., Gajdzik, L., Alaguarda, D., Rodolfo-Metalpa, R., D'Olivo, D., Liu, G., Patalwala, D. & McCulloch, M.T. (2019). Acclimatization of massive reef-building corals to consecutive heatwaves. *Proc. R. Soc. B. 286.*

[3] Kayanne, H. (2017). Validation of degree heating weeks as a coral bleaching index in the Northwestern Pacific. *Coral Reefs. Vol. 36, Issue 1, pp 63-70. DOI:10.1007/s00338-016-1524-y*

[4] Adapted by permission from Springer Nature Customer Service Centre GmbH: Nature. Predicting climate-driven regime shifts versus rebound potential in coral reefs. Graham, N.A.J., Jennings, S., MacNeil, M.A., Mouillot, D. & Wilson, S.K., 2015.

Reef-cover-y? – Compare the responses to bleaching events between two regions, while recognising that coral cover increases on resilient reefs once pressures are reduced or removed

T107

Name:

Date:

Table 1: Mean percentage cover of hard coral and macroalgae at 12 reefs before major coral mortality (Pre), when the lowest coral cover was recorded (Post-initial), and five years later.[1]

			Coral cover (%)			Macroalgal cover (%)				
Reef type and shelf	Sector	Reef	Pre	Post-initial	5 yr later	Pre	Post-initial	5 yr later	Max	Disturbance period and type (C, S, B)†
Resilient reefs (no phase shift)										
Inshore	Cairns	Fitzroy Island	31.9	6.3	16.6	0.2	0.1	0.2	2.1	1999–2001: B, C
	Cairns	Low Isles	35.4	8.9	16.0	0.1	3.9	0.0	8.0	1997–2000: C, S
Mid-	Cairns	Thetford	36.1	3.9	23.4	1.3	0.5	1.9	3.2	1999–2003: C, S, B
	Townsville	John Brewer	28.9	0.7	3.5	1.6	0.0	1.4	1.4	1999–2004: S, B, C
	Townsville	Rib	44.4	3.2	11.0	1.0	0.3	1.2	1.3	1999–2003: C, B
	Swain	Gannett Cay	44.4	3.7	16.7	0.1	0.1	0.3	0.3	1996–2002: C
	Swain	Horseshoe	52.0	10.7	30.6	0.1	0.1	0.4	0.4	1997–2003: C
Outer	Townsville	Chicken	37.0	12.9	15.6	1.3	0.1	3.1	6.2	2002–2004: C
	Swain	Turner Cay	31.0	12.9	19.1	0.1	0.1	0.6	0.8	2001–2004: C
	Capricorn Bunker	Lady Musgrave	95.7‡	8.6	65.4	?	0.3	0.0	0.5	1989: S
	Capricorn Bunker	One Tree	92.9‡	8.1	64.3	?	1.5	0.1	3.0	1989: S
Mean			48.2	7.3	25.7	0.6	0.6	0.8	2.5	
Degraded reefs (phase shift)										
Inshore	Townsville	Havannah Island	42.8	5.9	6.9	0.5	46.6	42.1	60.4	1997–2002: B, S, C

Notes: Reefs were designated as resilient or degraded depending on whether macroalgal cover exceeded coral cover after disturbances (i.e., a phase shift occurred). "Max" is the maximum cover of macroalgae recorded in the five-year period following disturbances. Question marks (?) show that no data were collected. Benthic data were obtained from surveys conducted on the same sites between 1995 and 2009, except for two cases, as noted. Disturbances were deemed to have started in the year when annual declines in absolute coral cover exceeded 5% and then continued on a downward trajectory.

† The types of disturbances included crown-of-thorns starfish outbreaks (C), large storms or cyclones (S), and bleaching (B).

Note: **Inshore reefs were 5-30km from land; Mid-shelf reefs were located on the Continental shelf within the bulk of the GBR matrix; and Outer-reefs were seaward, exposed to oceanic influences of the Coral Sea[1].**

Activity: Compare the responses to bleaching events between two regions in Table 1 (pick 2).
Note: the disturbances on a number of reefs did *not* involve bleaching (so do not pick those).

Notably, all reefs in Table 1 suffered a coral decline that was great enough to favour a phase shift[1]. Thus, students could pick any two reefs or regions from Table 1 that experienced a bleaching event (B). All 'resilient' reefs recovered with mean coral cover increasing post disturbance/s once pressures were reduced or removed.

Note: some recovered faster than others (more resilient).

Only Havannah Island underwent a phase shift whereby mean coral cover declined from 42.8% to 5.9%, while macroalgal cover increased from 0.5% to >40%[1].

So why did Havannah Island undergo a phase shift when the other reefs did not? At Havannah Island, the species richness and abundance of four herbivore functional groups (i.e. scrapers, excavators, grazer/detrivores and algal browsers) were among the lowest recorded on any of the 12 reefs. However, One Tree Island also had low herbivore numbers but did *not* undergo a phase shift. Which lead the author to suggest that the relative vulnerability to a phase shift varies spatially depending on a wide range of biological, physical and hydrodynamic factors that interact to raise or lower phase shift thresholds[1].

---

[1] Adapted with permission from: Cheal, A. J., Emslie, M., MacNeil, M.A., Miller, I. and Sweatman, H. (2013). Spatial variation in the functional characteristics of herbivorous fish communities and the resilience of coral reefs. *Ecological Applications, 23 (1). Pp. 174-188. DOI:10.1890/11-2253.1*

Natural Archives – Interpret data, including qualitative graphical data of coral cores, that demonstrates that coral cores can act as a proxy for the climate record (i.e. they provide information on the changes in weather patterns and events affecting the composition of coral communities) T108

Name:

Date:

Porites power on

Porites corals often survive mass bleaching events when other corals (i.e. Tabular *Acropora*) do not (Fig. 1). A stressful mass bleaching event leaves its mark on the skeleton of a *Porites* coral as a **stress band,** which can act as a proxy for the climate record (i.e. *warm weather* events cause bleaching)[1].

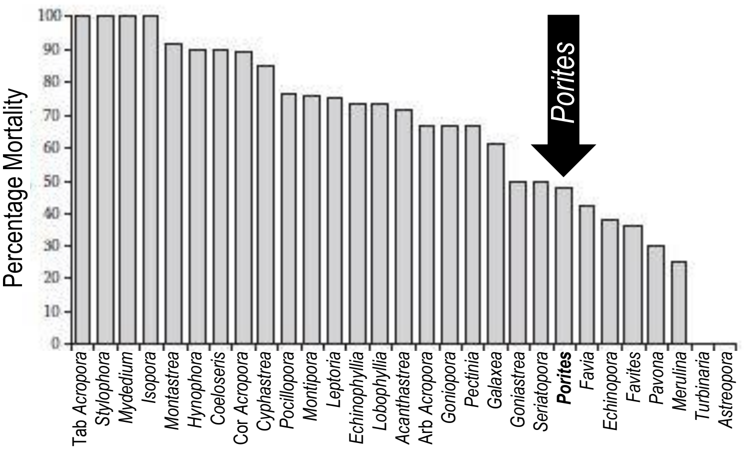


Fig. 1: Variation in bleaching susceptibility among different coral types (genera plus growth forms: Tab, tabular; Cor, corymbose; Arb, arborescent) on the Great Barrier Reef[1]

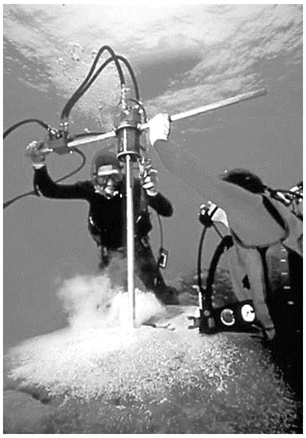


Fig. 2: Drilling a core from a *Porites*. *Note*: the hole is filled with a cement plug so the colony does not die[2].

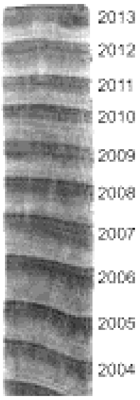


Fig. 3: *Porites* annual growth bands used to date stress bands[3].

Q. What do the dates on the coral cores in Figure 4 (below) represent? Ans. Stress Bands

El Nino is a time when sea surface temperatures (SSTs) are warmer than usual, and reefs become more susceptible to mass bleaching events.

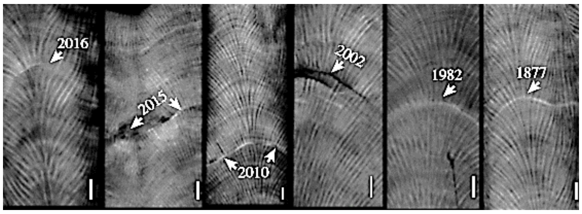


Fig. 4: Stress bands on *Porites* cores from the Great Barrier Reef[4].

Table 1: Strength of El Nino (based on SOI values) since 1916[5]

Weak		Moderate		Strong	Very Strong
Weak	Weak-Moderate	Moderate	Moderate-strong		
1951-52 1957-58 1963-64 1969-70 2002-03 2006-07	1919-20 1946-47 2009-10	1925-26 1972-73 1977-78 1993-94	1965-66 1987-88 1991-92 2015-16 SST very high in 2015-16	1940-41 1941-42 1994-95 1997-98 SST very high in 1997-98	1982-83

Q. What is the likelihood that there was an El Nino in 1877? Ans. Circle correct answer [✓ High] [Low]

In the past, El Nino had to be *strong* or *very strong* for corals to bleach. But not anymore. **Discuss why.**

Q. Do *all* the stress bands in Fig. 4 coincide with a *strong* or *very strong* El Nino? Ans. No

Q. Which summer had *very high* SSTs but only a *moderate-strong* El Nino? Ans. 2015/16

---

[1] Adapted with permission from: Pratchett, M.S., Munday, P.L., Wilson, S.K., Graham, N.A.J., Cinner, J.E., Bellwood, D.R., Jones, G.P., Polunin, N.V.C. and McClanahan, T.R. (2008). Effects of Climate-Induced Coral Bleaching on Coral Reef Fishes – Ecological and Economical Consequences. *Oceanography and Marine Biology: An Annual Review (46) 251-296*.

[2] Maris Kazmers of Sharksong Photography. Published In: Russell, R. M. (2010). *Coral Reef Cores – Paleoclimate proxy records.* UCAR Office of Education and Outreach. Accessed 07.03.2019 from: https://eo.ucar.edu/staff/rrussell/climate/paleoclimate/coral_reef_proxy_records.html

[3] Adapted with permission from: De Carlo, T. M. and Cohen, A. L. (2017). Dissepiments, density bands and signatures of thermal stress in Porites skeletons. *Coral Reefs. DOI 10.1007/s00338-017-1566-9*

[4] Adapted with permission from : De Carlo, T.M., Harrison, H.B., Gajdzik, L., Alaguarda, D., Rodolfo-Metalpa, R., D'Olivo, J., Liu, G., Patalwala, D. and McCulloch, M.T. (2019). Acclimatization of massive reef-building corals to consecutive heatwaves. *Proc. R. Soc. B. 286. DOI: 10.1098/rspb.2019.0235*

[5] Adapted from: Bureau of Meteorology (2018). *El Nino – Detailed Australian Analysis* (Bureau Home > Climate > ENSO Wrap Up > El Nino Summaries). Accessed 09/03/2019 from www.bom.gov.au/

Balancing Act – Explain the reason for differences between ocean pH and freshwater – presence of carbonate buffering system T109

Name:

Date:

Note: a rise in salinity decreases the solubility of gases[2].

Activity: Use a straw to blow into a beaker of water. Use a pH probe[1] to watch the pH go down!

When CO_2 is added to water (H_2O), it reacts with the water molecules to make carbonic acid (H_2CO_3)[1].

Q. What is the chemical equation for this reaction? Ans. $CO_2 + H_2O \rightarrow H_2CO_3$

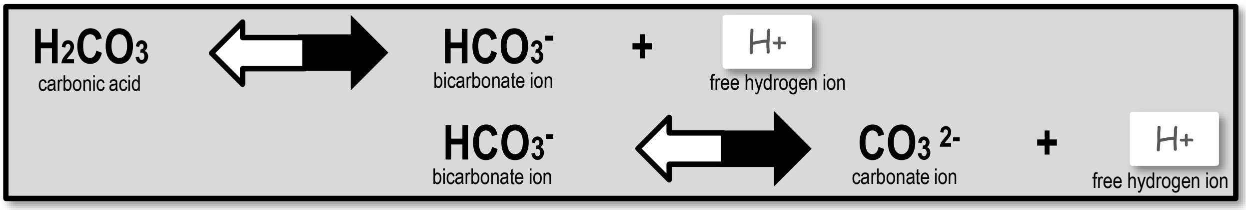
The pH of water is controlled by the number of free hydrogen ions (H+). More free H+ means lower pH[1].

Q. What is the pH of seawater? Ans. 8.1 **Q. What is the pH of freshwater? Ans.** ~7.0

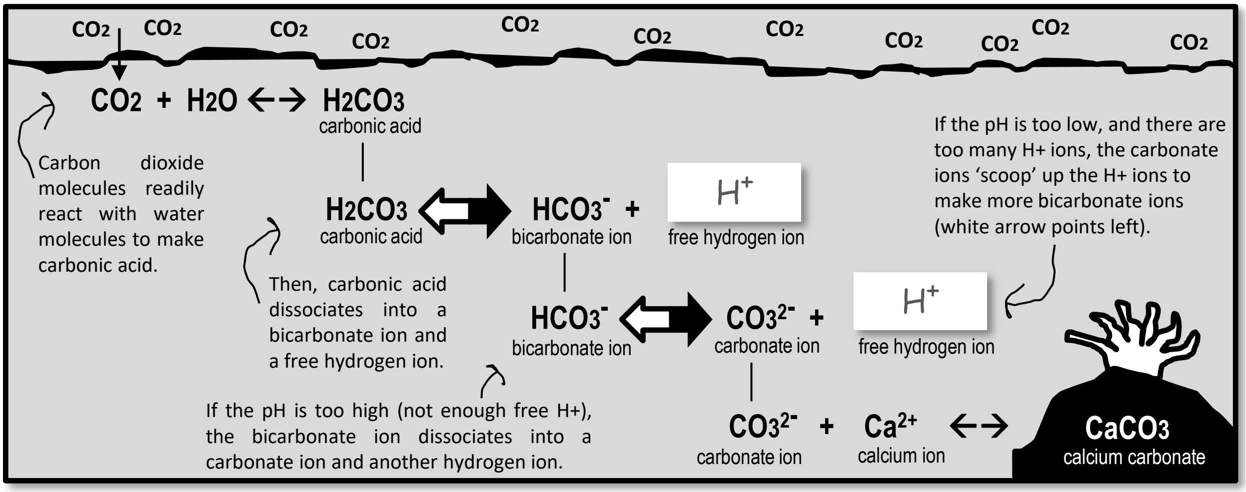
Q. Which one has more free hydrogen ions (H^+), *sea*water or *fresh*water? Ans. Fresh **Discuss why**

Abrupt changes in pH can really stuff up marine life. Hence, *sea*water has a unique system, called the *carbonate buffering system,* that (tries to) keep the pH more or less stable. Whereby, if the pH is too high (not enough *free* H^+) seawater releases *more* H^+ to fix the problem (black arrows point right, below). In contrast, if the pH is too low (*too many* free H^+) seawater *removes* them (white arrows point left, below).

Activity: Fill in the blanks (white boxes).



Activity: Fill in the blanks (white boxes).



Carbon dioxide molecules readily react with water molecules to make carbonic acid.

Then, carbonic acid dissociates into a bicarbonate ion and a free hydrogen ion.

If the pH is too high (not enough free H+), the bicarbonate ion dissociates into a carbonate ion and another hydrogen ion.

If the pH is too low, and there are too many H+ ions, the carbonate ions 'scoop' up the H+ ions to make more bicarbonate ions (white arrow points left).

Figure 1: carbonate buffering system[2]. Black arrows point right when pH is too high. White arrows point left when pH is too low.

Q. When the white arrows point left, does CO_3^{2-} *increase* or *decrease*? Ans. decrease

---

[1] You can purchase a hand held pH meter for $64.95 from any Jaycar store (category number QM1670) or online from: https://www.jaycar.com.au/hand-held-ph-meter/p/QM1670

[2] Pinet, P. A. (1998). *Invitation to Oceanography: Oceanlink.* Jones and Bartlett Publishers, Inc. London. http://science.jbpub.com/oceanlink/

Race Against Time – Explain that the carbonate system is linked to geological processes and operates over geological timescales T110

Name:

Date:

Buffer capacity overwhelmed

Ocean carbonate chemistry throughout the Holocene (and before industrialisation) was extremely stable. Atmospheric CO_2 levels did not change much, and nor did ocean pH (remaining at 8.2)[1]. But all that has changed now. The ocean is struggling to cope with the large amounts of CO_2 that have been released to the atmosphere over a geologically short period of time. Geological processes, that are part of the carbon cycle and act as a neutralising process (i.e. chemical weathering*) operate over geological timescales and can *not* keep up with the *rate* of CO_2 being released into the atmosphere and absorbed by the ocean[2]. As a result, for the first time in thousands of years, the pH has declined, from 8.2 to 8.1 (~30% more H^+)[1].

*"*The gradual process of weathering break down rocks on land, washing them into the ocean and, in doing so, buffer the seas against acidification like a Tums to an upset stomach*" [3].

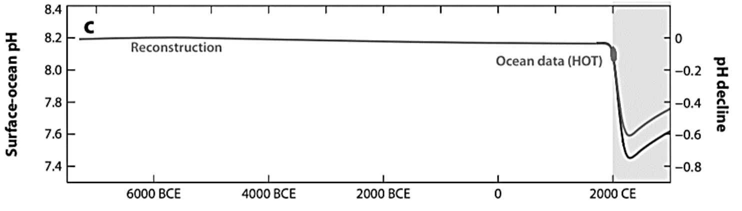


Figure 1: Holocene versus Anthropocene. Results of modelling surface-ocean pH using reconstructed and future pH for 5000 PgC and 3000 PgC. Ocean data is the Hawaii Ocean Time (HOT)-series pH data at 25°C in 2012[1].

> *"It is the **pace** of carbon dioxide emissions (not the absolute volume) that is making the pH decline"*[3]

Activity: Discuss the imbalance that is identified by the following statement:

Fossil fuels take million of years to make…..but only seconds to burn.

Q. Why is the pH declining? Ans.

The *rate* of CO_2 emissions is too fast.

Bjerrum Plot explains

What happens when ocean pH declines?

The concentration of carbonate ions (CO_3^{2-}) declines ☹. For example, the concentration of carbonate ions at pH 8.1 is less than the concentration of carbonate ions at pH 8.2 (Fig. 2). Corals need carbonate ions to make their skeletons. Importantly, carbonate ion supplies take geological timescales to replace (via geological processes). The 'Expected change' (shaded area) is a continued decline in pH *and* in carbonate ions concentrations.

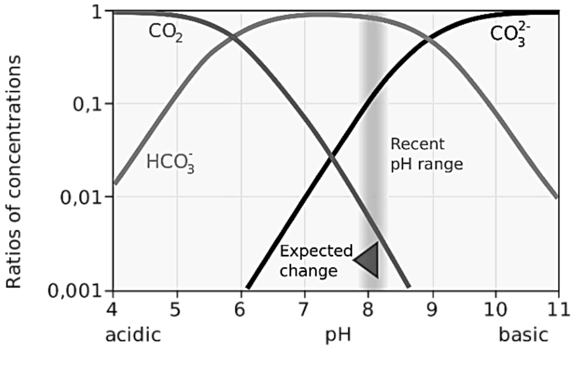


Figure 2: Bjerrum Plot - ratios of Dissolved Inorganic Carbon (DIC) for various pH values. Source: Wikapedia at: https://en.wikipedia.org/wiki/Bjerrum_plot

Q. What form of DIC dominates the ratio of concentration at pH 8.2? Ans. HCO_3^-

---

[1] Republished with permission of Annual Reviews, Inc., from: History of seawater carbonate chemistry, atmospheric CO_2 and ocean acidification, Zeebe, R., 40:141-65, 2012; permission conveyed through Copyright Clearance Center, Inc.

[2] Raymond, P. A. and Hamilton, S. K. (2018). Anthropogenic influences on riverine fluxes of dissolved inorganic carbons to the oceans. *Limnology and Oceanography Letters 3: 143-155. DOI: 10.1002/lol2.10069*

[3] Brannen, P. (2017). *The Ends of the World.* Oneworld Publications. London. England. Page 132

Disrupting Nature's Balance – Recognise that increases in atmospheric carbon dioxide influences both global temperature and ocean pH T111

Name:

Date:

The Greenhouse Effect

Imagine the Earth is wrapped in a thermal blanket to keep it warm. Imagine no more. It actually exists! Except, the blanket is made of greenhouse gasses, such as water vapor, CO_2, nitrous oxide and methane (and any reactive gasses that absorb wavelengths longer than 4 μm[1]). The 'blanket' traps heat in the atmosphere. Similar to how glass traps heat in a greenhouse. Hence the name, **the greenhouse effect.**

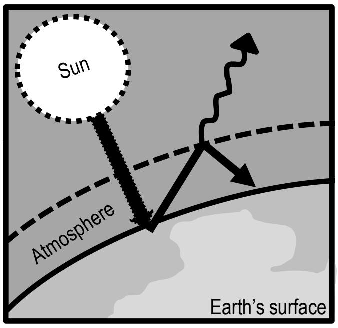


Fig. 1: The Greenhouse Effect

Q. What is the Greenhouse Effect? Ans.

When gasses in Earth's atmosphere, such as water vapour, CO_2, nitrous oxide and methane, act as a blanket by trapping the Sun's heat (i.e. wavelengths longer than 4μm) and keeping the Earth warm. Discussion point: *without* the greenhouse effect, the average global temperature would be -18°C

Global Warming

As you know, CO_2 is one of the greenhouse gasses. Adding more CO_2 to Earth's atmosphere is like adding an extra blanket. Earth warms up. This warming effect is global in scale. Hence the name, **global warming**.

Q. What did Mann, Bradley and Hughes[1] say was causing the temperature to rise in their famous Hockey-stick graph? Ans.

Anthropogenic emissions of CO_2, mainly from the increase of industrialisation and the use of fossil fuels[2]

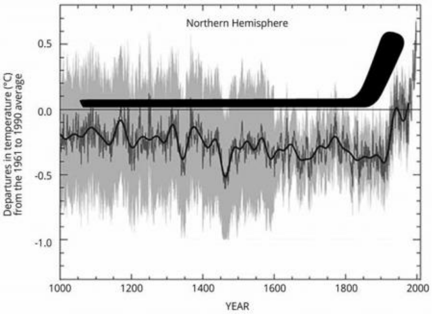
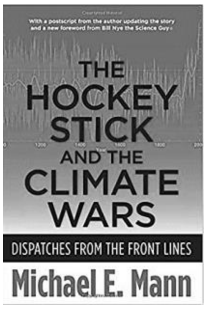


Fig. 2: The hockey-stick graph[1]



With a postscript from the author updating the story and a new foreword from Bill Nye the Science Guy

THE HOCKEY STICK AND THE CLIMATE WARS

DISPATCHES FROM THE FRONT LINES

Michael E. Mann

Fig. 3: Mann's book[2]

Ocean Acidification

The term *ocean acidification* can be a little misleading. It does not mean the ocean is *acidic* as such. The pH of the ocean is still basic (above pH 7). Indeed, the addition of CO_2 adds more free hydrogen ions (H+) to the ocean. And, the chemical activity of these free hydrogen ions can be very powerful, measured as an indirect function of their concentration level known as **pH** = $-\log_{10}(H+)$. Thus, ocean acidification simply refers to the increasing number of free hydrogen ions in the ocean (due to high CO_2 input rates), and the corresponding drop in pH…towards the *acidic* end of the pH scale. Hence the name, **ocean acidification.**

Q. What is Ocean Acidification? Ans.

The increasing number of free H+ in the ocean (due to high CO_2 input rates) and the corresponding drop in pH towards the *acidic* end of the pH scale.

---

[1] Espach, R., Zvijac, D. and Filadelfo, R. (2016). Impact of Climate Change on U.S. Military Operations in the Western Pacific. *MCU Journal. 89-113. DOI: 10.21140/mcuj.2016si05.*

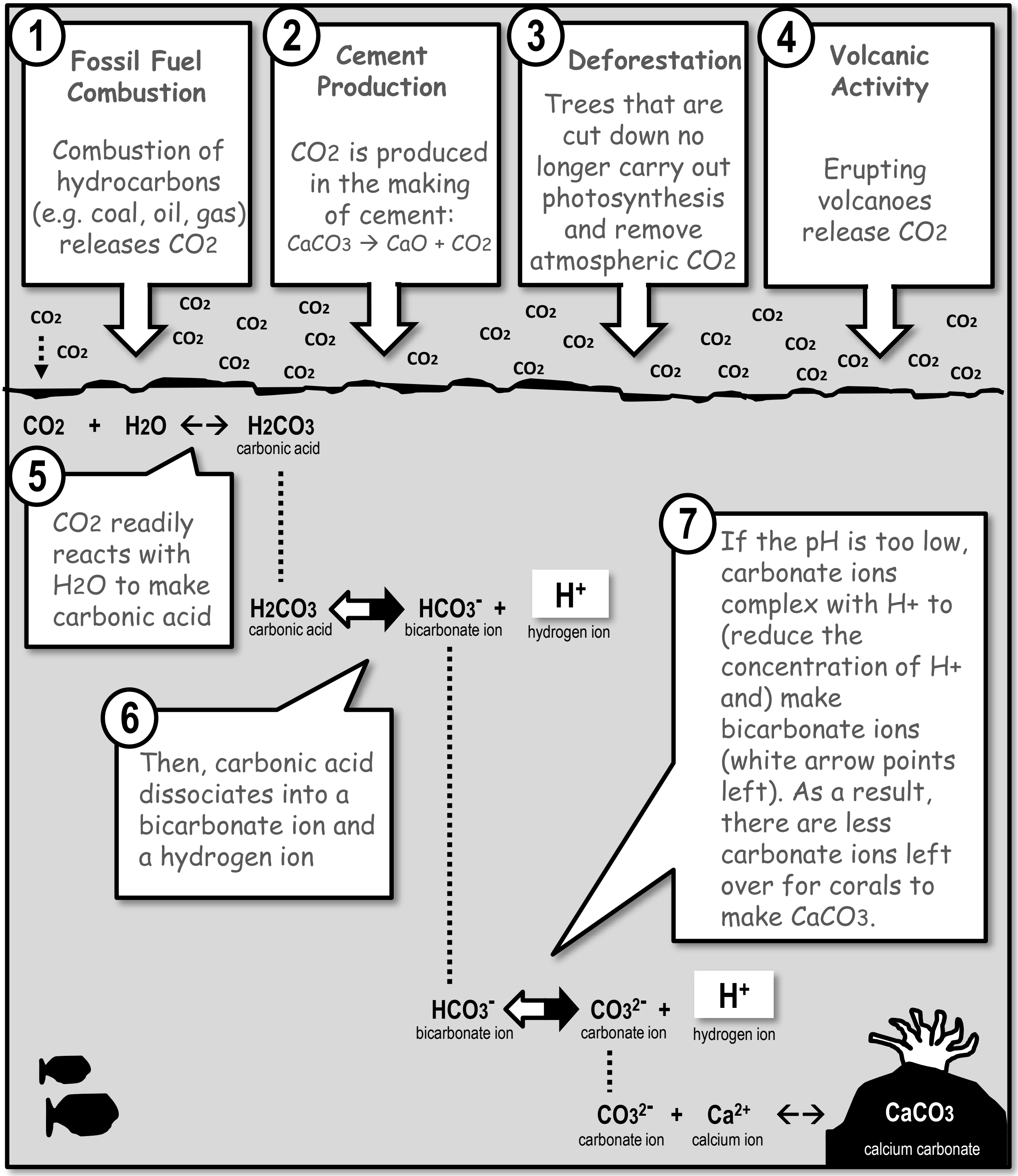
[2] Mann, M. E. (n.d). *Books: The Hockey Stick and the Climate Wars.* Michael E. Mann. Accessed 12.04.2019 from: http://www.michaelmann.net/books/hockey-stick

Source of Imbalance – Describe sources of carbon dioxide in the atmosphere and how this influences ocean chemistry T112

Name:

Date:

**Activity: In boxes 1-4, name and describe four sources of CO_2 in the atmosphere.
In boxes 5 and 6, describe each chemical reaction (with arrows pointing right).
In box 7, describe the chemical reaction when the pH is too low (with white arrow pointing left).**



1 **Fossil Fuel Combustion**

Combustion of hydrocarbons (e.g. coal, oil, gas) releases CO_2

2 **Cement Production**

CO_2 is produced in the making of cement: $CaCO_3 \rightarrow CaO + CO_2$

3 **Deforestation**

Trees that are cut down no longer carry out photosynthesis and remove atmospheric CO_2

4 **Volcanic Activity**

Erupting volcanoes release CO_2

$CO_2 + H_2O \leftrightarrow H_2CO_3$ (carbonic acid)

5 CO_2 readily reacts with H_2O to make carbonic acid

H_2CO_3 (carbonic acid) $\leftrightarrow$ HCO_3^- (bicarbonate ion) + H^+ (hydrogen ion)

6 Then, carbonic acid dissociates into a bicarbonate ion and a hydrogen ion

7 If the pH is too low, carbonate ions complex with H+ to (reduce the concentration of H+ and) make bicarbonate ions (white arrow points left). As a result, there are less carbonate ions left over for corals to make $CaCO_3$.

HCO_3^- (bicarbonate ion) $\leftrightarrow$ CO_3^{2-} (carbonate ion) + H^+ (hydrogen ion)

CO_3^{2-} (carbonate ion) + Ca^{2+} (calcium ion) $\leftrightarrow$ $CaCO_3$ (calcium carbonate)

Carbonate ion Count – Describe the effect of ocean acidification on sea water in terms of increasing the concentration of hydrogen ions decreasing the concentration of carbonate ions T113

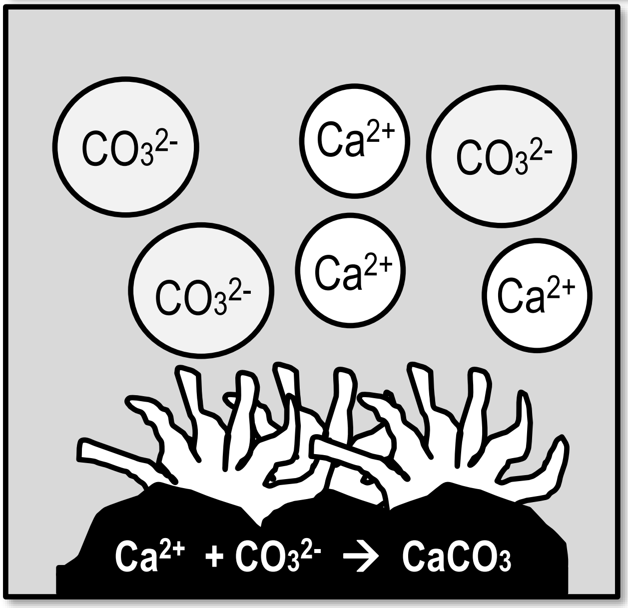
Name:

Date:

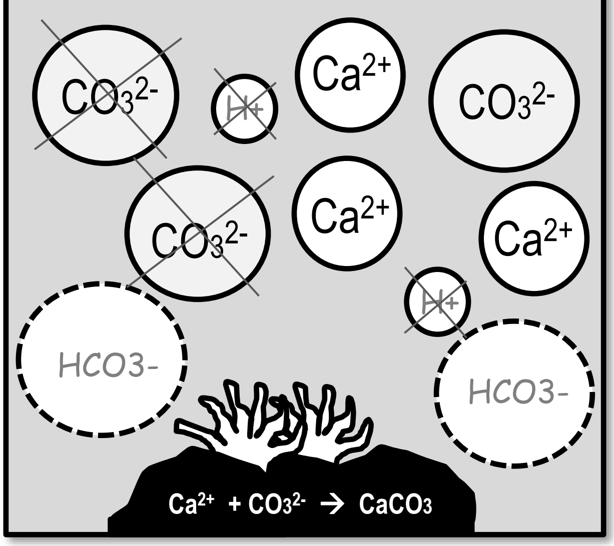
Carbon creating chaos

When CO_2 is added to seawater, most of it turns into HCO_3^- . For example, if you look at a **Bjerrum plot** (p. 100) you will see that most dissolved inorganic carbon (DIC) is in the form of HCO_3-. This transformation of CO_2 (+H_2O) into (**H**$_2$$CO_3$ and then) **H**CO_3- releases a free hydrogen ion (**H**+) which, as you know, lowers pH (‘*not good’,* says the ocean). So, CO_3^{2-} quickly scoops up the free H+ (making more HCO_3^-) to maintain the balance of pH (as best it can). But in doing so, there is now less CO_3^{2-} left behind for marine critters (e.g. corals, marine molluscs, forams) to make their $CaCO_3$ body parts[1].

Activity: Write [H+] in the *small* circles below right to represent CO_2 being added to water. Cross out two [H+] and two [CO_3^{2-}]. Instead, write [HCO_3^-] in the 2 large empty circles provided below.



CO_2 is added to the water (adding H+)



Q. How many CO_3^{2-} pictured above? Ans. 3

Q. How many CO_3^{2-} left over? Ans. 1

Activity: Describe the effect of ocean acidification on sea water in terms of increasing the concentration of hydrogen ions decreasing the concentration of carbonate ions

With respect to ocean acidification students should understand that carbon dioxide (CO_2) is absorbed from the atmosphere and it bonds with sea water forming carbonic acid. This acid then releases a bicarbonate ion and a hydrogen ion. The hydrogen ion bonds with free carbonate ions in the water forming another bicarbonate ion. That carbonate would otherwise be available to marine animals for making calcium carbonate shells and skeletons. The more dissolved carbon dioxide in the ocean, the less free carbonate ions available for making calcium carbonate[1].

---

[1] Queensland Curriculum and Assessment Authority (2018). *Marine Science 2019 v1.2: General Senior Syllubus.* QCAA. Pg. 40. Accessed 13.04.2019 from: https://www.qcaa.qld.edu.au/senior/senior-subjects/sciences/marine-science/syllabus

Ooze Clues – Explain how the carbonate compensation depth (CCD) varies due to depth, location and oceanographic processes such as upwellings and coastal influences T114

Name:

Date:

It's snowing!

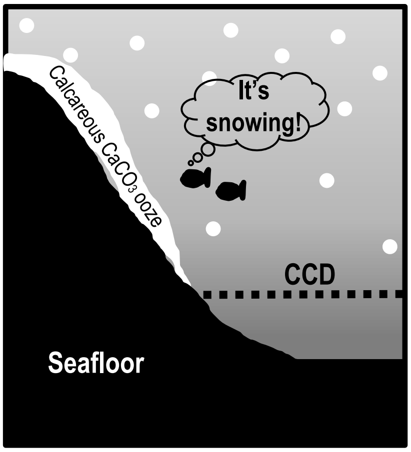


Figure 1: The 'snow line' or 'CCD'.

Did you know it snows in the ocean? The snow is called 'marine snow'. It is created when marine life dies (or defecates) to make particles that fall like 'snow' to the depths below. Particles made of $CaCO_3$ (i.e. dead forams and coccolithophores) that reach the seafloor, settle on the bottom as '**calcareous ooze**'. But only when the seafloor is above the carbonate compensation depth or **CCD**. **Below the CCD they dissolve (faster than they accumulate).** The CCD can be compared to the snow line of a mountain front where the supply of snow is exactly balanced by melting (but, in this case, *dissolving*) leaving only the elevations above the CCD (i.e. tops of seamounts and mid-ocean ridges) draped in snow.

Q. Does calcareous ooze exist below the CCD (i.e. below the dotted line in Figure 1)? Ans. No

Cold and Under Pressure

The CCD is often deep. Deep water is cold water. Deep water is also under a lot of (hydrostatic) pressure. Therefore, it holds a lot of carbon dioxide. Lots of carbon dioxide makes calcium carbonate dissolve.

Activity: Tick the factors listed below that *increase* the solubility of gasses, such as CO_2

☑ **A decrease in temperature** (e.g. cold water)

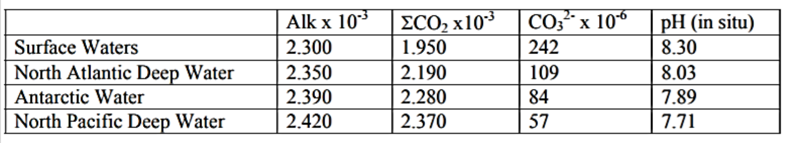
☑ **An increase in (hydrostatic) pressure** (e.g. deep water)

As CO_2 increases, pH

[increases] [✓ decreases]

(circle correct answer)

Table 1: Measurements from water masses in thermohaline circulation[1]



	Alk x 10^{-3}	ΣCO_2 x10^{-3}	CO_3^{2-} x 10^{-6}	pH (in situ)
Surface Waters	2.300	1.950	242	8.30
North Atlantic Deep Water	2.350	2.190	109	8.03
Antarctic Water	2.390	2.280	84	7.89
North Pacific Deep Water	2.420	2.370	57	7.71

The snow line

The snow line, or CCD, is *NOT* the same depth all around the globe. The depth of the CCD is determined by the rate of dissolution versus the rate of accumulation. **The rate of dissolution** depends on the CO_2 content of the water. The higher the CO_2 content, the shallower the CCD. For example, the CCD is shallower in the Pacific Ocean than in the Atlantic Ocean because the CO_2 content in North Pacific Deep Water is higher than the CO_2 content in North Atlantic Deep Water (Table 1). **The rate of accumulation** depends on how much marine snow is falling. The heavier the snow fall, the deeper the CCD*.

Q. What (formula) determines the depth of the CCD? Ans. (*hint:* second sentence)

The rate of dissolution (i.e. CO_2 content) versus the rate of accumulation

Activity: Discuss what the composition of the seafloor can tell us about past ocean chemistry?

---

*But only if the water below, through which it must fall, is not too rich in CO_2 from being too cold (e.g. polar regions) or from prolonged, high decomposer activity.

[1] Adapted from: Samford University (n.d.). *Lecture 10 – Acids and Bases: Ocean Carbonate System*. Accessed 13.04.2019 from: http://ocean.stanford.edu/courses/bomc/chem/lecture_10.pdf

Oceans…the sponges of our climate –

Understand that the ocean's capacity to absorb carbon dioxide is changing and is linked to temperature (uptake) and changes in primary productivity (storage, e.g. biological pump) T115

Name:

Date:

The carbon couriers: phytoplankton

The ocean removes CO_2 from the atmosphere. Not just chemically (see page 99). But also biologically! When phytoplankton bloom, they use up lots of CO_2 via photosynthesis. Then, when they die, they sink as marine snow.

Q. What is the equation for photosynthesis? Ans. $6CO_2 + 6H_2O \xrightarrow[\text{sunlight energy}]{} C_6H_{12}O_6 + 6O_2$

Biological Pump

Marine snow sinks very slowly. If it makes it all the way to the seafloor, or a least below the thermocline barrier, and into the bathypelagic zone, it stays there for a very long time[1]. Which is a good thing. Because one more carbon atom in the bathypelagic zone (as marine snow) is one less carbon atom in the atmosphere (as CO_2). For example, a coccolithophore fixes CO_2 in the sunlit zone, via photosynthesis, to make its $CaCO_3$ body parts, and later dies and sinks as marine snow. If it makes it all the way down to the bathypelagic zone, its carbon atoms will be removed from circulation with the atmosphere for a very long time (see Figure 1).

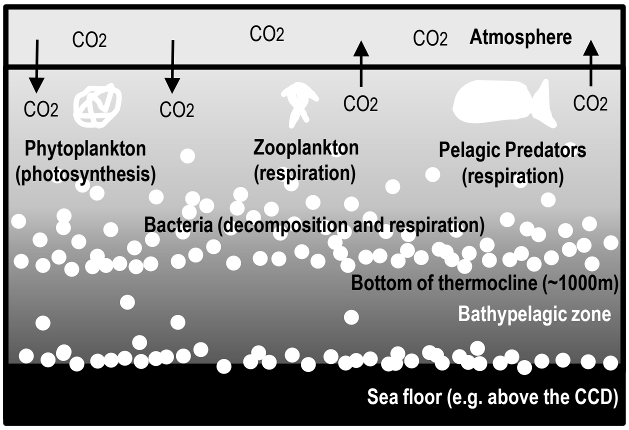


Figure 1: Schematic of the biological pump. Phytoplankton fix $\underline{C}O_2$ in the euphotic zone to produce particulate organic carbon (PO$\underline{C}$) of which a small percentage makes it down to the deep ocean[1]. Meanwhile, decomposition and respiration continues to return organic carbon back to CO_2, where it can recirculate with the atmosphere[1].

Activity: Circle the correct answer...

If phytoplankton numbers decline, you might expect:

- **the amount of carbon sinking all the way down to the deep sea would** [increase] [✓ decrease]
- **the amount of CO_2 in the atmosphere would** [✓ increase] [decrease]

Phytoplankton need light, carbon dioxide and **nutrients** to bloom.

Q. What do phytoplankton need to bloom? Ans. light, carbon dioxide, nutrients

Warm Water Barriers

Nutrients in the bathypelagic zone remain there for a very long time. Until, **upwellings** bring them back UP to the surface, triggering a phytoplankton bloom[3]. That is, IF the nutrients even make it to the surface. If the sea surface temperatures (SSTs) are too warm, such as during an El Nino event, the intensity of an upwelling can be reduced by **stratification** caused by warming of the surface layers of the ocean. The people of Peru know this all too well. If the **upwelling** does not make it to the surface, the **nutrients** (also) do not make it up to the surface, which means less phytoplankton (less fish) and less absorption of atmospheric CO_2[2][3].

Q. If there are less nutrients, will there be less phytoplankton? Ans. [✓ Yes] [No] circle correct answer

---

[1] Adapted from: Basu, S. and Mackey, K. R. M. (2018). Phytoplankton as Key Mediators of the Biological Carbon Pump: Their Responses to a Changing Climate. *Sustainability, 10, 869 DOI:10.3390/su10030869*

[2] Lluch-Cota, S.E., Hoegh-Guldberg, P., Karl, D., Portner, H.O., Sundby, S. and Guttuzo, J.P. (2014). *Uncertain Trends in Major Upwelling Ecosystems*. In: IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Summaries, Frequently Asked Questions, and Cross-Chapter Boxes. A Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken,P.R. Mastrandrea, and L.L. White (eds.)]. World Meteorological Organization, Geneva, Switzerland, 190 pp. (in Arabic, Chinese, English, French, Russian, and Spanish). p.149-151.

[3] Winder, M. and Sommer, U. (2012). Phytoplankton response to a changing climate. *Hydrobiologica 698(1):5 -16. DOI: 10.1007/s10750-012-1149-2*

$CaCO_3$ Critters – Recognise that the type of carbonate ions and concentration of ions have an implication for the development of shell-forming and skeletal-forming organisms including hard corals (Scleractinia), coralline algae, molluscs, plankton and crustaceans T116

Name:

Date:

Tiny but tough

Coccolithophores are single-celled **phyto**plankton. They carry out photosynthesis and make armoured plates (coccoliths) out of $CaCO_3$[1]. They might be small, but coccolithophores are the most productive pelagic calcifiers on the planet (alongside forams)[2]. Coccolithophore blooms can be seen from space!

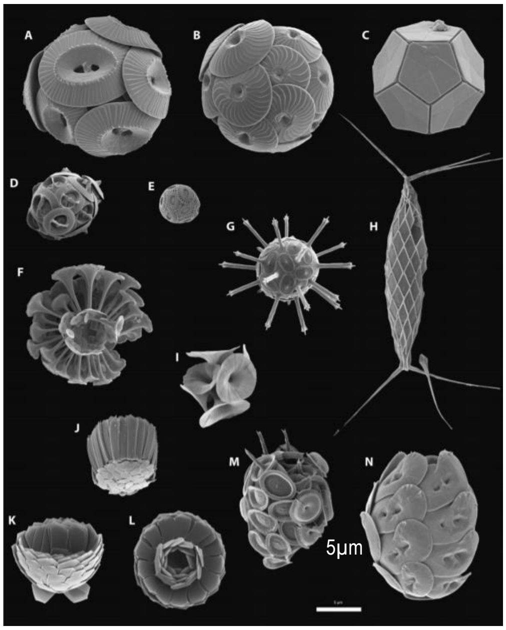


Fig. 1: Scanning electron micrographs of coccolithophores[2].

Fig. 2: A chalky, white coccolithophore bloom visible from space[5].

Activity: Revise the information on page 19

Coccolithophores are made of the *calcite* polymorph of calcium carbonate (*not* the aragonite version). Coccolithophores need lots of dissolved calcium and carbonate ions to make their $CaCO_3$ skeletons. Not enough results in reduced calcification rates (i.e. they can't make their bodies as fast or as strong). Notably, organisms made of calcite might cope with ocean acidification a little better than organisms made of aragonite (although that is still up for debate) because $\Omega_{calcite}$ is higher than $\Omega_{aragonite}$ (different Ksp). E.g. in locations where $\Omega_{aragonite}$ is 3-4, $\Omega_{calcite}$ is 5-6. Thus, aragonite is more soluble than calcite[3][4].

Activity: Complete the table below. Discuss how each will be affected by ocean acidification.

Organisms made of aragonite ($CaCO_3$)	Organisms made of calcite ($CaCO_3$)
Pteropods (the major planktonic producers of aragonite)	Foraminifera (forams)
Coral, halimeda	Coccolithophores, crustaceans, echinoderms

---

[1] Doney, S.C., Fabry, V.J., Feely, R.A. & Kleypas, J.A. (2009). Ocean Acidification: the other CO2 problem. *Annual Reviews. Washington Journal of Environmental Law and Policy. Vol. 6:2. DOI: 10.1146/annurev.marine.010908.163834*

[2] Reproduced with permission from: Monteiro, F.M., Back, L.T., Brownlee, C., Bown, P. Rickaby, R.E.M., Poulton, A.J., Tyrrell, T., Beaufort, L., Dutkiewicz, S., Gibbs, S., Gutowska, M.A., Lee, R., Riebesell, U., Young, J. and Ridgwell, A. (2016). Why marine phytoplankton calcify. *Science Advances 2(7). DOI: 10.1126/sciadv.1501822.*

[3] Kleypas, J.A., Buddemeier, R.W., Archer, D., Guttuso, J., Langdon, C. and Opdyke, B.N. (1999). Geochemical Consequences of Increased Atmospheric Carbon Dioxide on Coral Reefs. *Science 284 (5411), 118-120. DOI: 10.1126/science.284.5411.118*

[4] Orr, J.C., Fabry, V.J., Aumont, O., Bopp, L., Doney, S.C., Feely, R.A., Gnanadesikan, A., Gruber, N., Ishida, A., Foos, F., Key, R.M., Lindsay, K., Maier-Reimer, E., Matear, R., Monfray, P., Mouchet, A., Najjar, R.G., Plattner, G.K., Rodgers, K.B., Sabine, C.L., Sarmiento, J.L., Schlitzer, R., Slater, R.D., Totterdell, I.J., Weirig, M.F., Yamanaka, Y. and Yool, A. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature Articles. Vol. 437:29. DOI: 10.1038/nature04095*

[5] On June 15, 2004, the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite captured this image of a bloom off the coast of Brittany, France. The bloom had been developing for a few days before this image was taken. Image Credit: Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC. Accessed 03.07.2019 from: https://visibleearth.nasa.gov/view.php?id=71344

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Watching the Earth Breathe CO2 – Interpret trends in data in relation to the carbonate system and changes in pH

T117

Name:

Date:

Keeling Curve

Charles David Keeling (1928-2005) received funding in 1957 (at a time when the concentration of CO2 in the air was not well known) to design and build a CO2 monitoring station on Moana Loa in Hawaii. His rigorous measurements set the stage for today's profound concerns about climate change, now referred to as the *Keeling Curve* (Figure 1)[1].

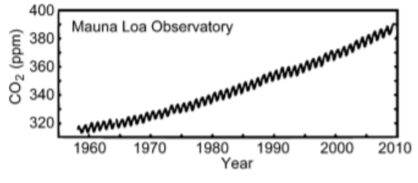

Figure 1: Keeling Curve[1]

Q. Why the zig zag pattern in Figure 1? Ans. (*hint:* see Fig. 3)

Seasonal variation (lower CO2 at *end* of growing season)

Commonly quoted as being the first time we could actually 'see' earth 'breathing'

Figure 2 shows hourly CO2 readings. Some readings were steady, whilst others varied (e.g. from volcanic burps). To enhance reliability, an average reading for a given day was only reported if there were at least 6 hours of steady data. Plus, Keeling rejected readings for any hour with >0.5ppm variability.

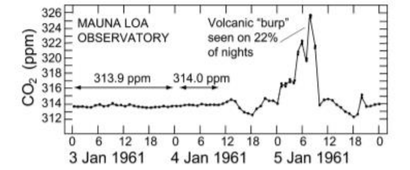

Figure 2. Hourly CO_2 readings. A daily average was reported only from periods of ≥6 h of constancy. Data from ref 3. [1]

Q. How did those decisions make his data more reliable? Ans.

It removed the *daily* CO2 variation (noise)

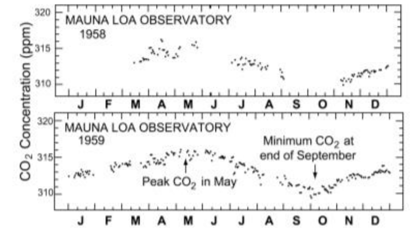

Figure 3. Daily CO_2 readings from the first two years of monitoring on Mauna Loa. Data from ref 3. [1]

Activity: Interpret trends in the data below

As atmospheric pCO2 concentrations increase, dissolved CO2 concentrations increase and pH and CO_3^{2-} concentrations decrease.
DIC increase (Fig. 4).
Note: DIC includes dissolved carbon dioxide + carbonic acid + bicarbonate ions + carbonate ions.

By the year 2100, pCO2 concentrations will be in the order of 750 µatm (RCP 6.0-8.5) and carbonate ion concentrations will have fallen to approximately 120µmol kg^{-1} (Fig. 4).

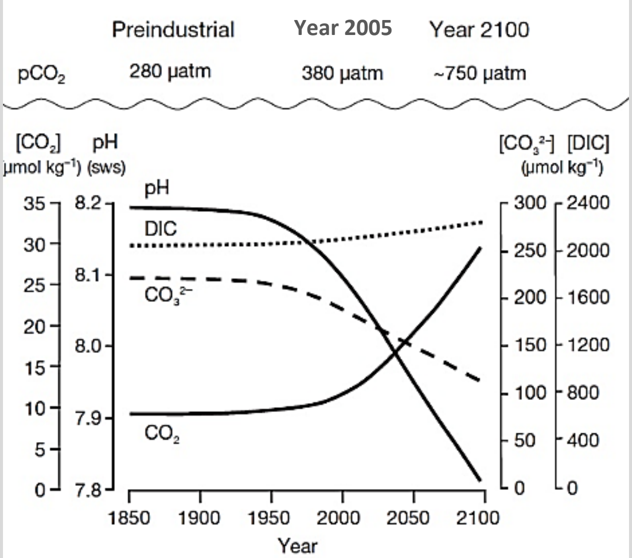

Figure 4: Changes in atmospheric carbon dioxide (pCO2), dissolved CO2, pH, carbonate ion concentrations (CO_3^{2-}) and DIC (dissolved inorganic carbon) over time[2]

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[1] Adapted with permission from: Harris, D. C. (2010). Charles David Keeling and the Story of Atmospheric CO2 Measurements. *Analytical Chemistry:Feature. 82, 7865-7870.* Accessed 30/03/2019 from: https://pubs.acs.org/doi/pdf/10.1021/ac1001492. Copyright (2010) American Chemical Society.

[2] Reprinted with permission from: Forus Na Mara Marine Institute (2005). *Nutrients and Ocean Acidification (OA).* Forus Na Mara Marine Institute. Ireland. Accessed 30/03/2019 from: https://www.marine.ie/Home/site-area/areas-activity/marine-environment/nutrients-and-ocean-acidification-oa

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Acid Test – Distinguish between laboratory-scale and field-based experiments and what they demonstrate about ocean acidification (OA) T118

Name:

Date:

- ❖ ***Laboratory-scale* experiments are conducted in the lab. *Field-based* experiments are conducted in the field (called '*in situ*')**
- ❖ **Ocean acidification experiments aim to lower the pH of seawater to simulate pH values predicted for the future.**
- ❖ **There is abundant evidence from laboratory experiments that OA causes reduced calcification in marine organisms[1][3]**

In the lab

Lab-scale OA experiments are highly controlled and can investigate the effect of changing pH levels on a single species in isolation. Methodologies used to reach the desired pH in tanks in the lab include the addition of strong acids and bases, or the addition of high-CO_2 seawater[1]. For example, in the aeration technique, a value opens or closes to deliver CO_2 gas to a tank whenever pH goes above or below a set value[2]. The beauty of a lab-scale experiment is that you can test a single variable (pH) in a highly controlled setting and identify a species pre-adapted sensitivity to increasing CO_2[1]. The problem with lab-scale experiments is that you are not simulating the high complexities of nature, and organisms may not react to stressors in a realistic way[5].

In the field

Field-based OA experiments are conducted in the field with lots of natural variability. Surprisingly, the pH on a reef flat changes a lot over the course of a day. The field-based experiment pictured in Figure 1[3] was able to mimic those changes whilst investigating the effects of ocean acidification on corals and algae. The device you can see sitting on the reef flat is called the cpFOCE. It has corals and algae inside. CO_2 was injected into the device to maintain a pH that was always 0.06 pH units lower than the surrounding seawater (e.g. if the pH went up or down, so did the pH in cpFOCE). A second device (not pictured) was maintained at 0.22 pH units lower than the surrounding seawater, while a third device was the control[3].

Figure 1: One of the three cpFOCE flumes underwater, with the wind-power generator and floating computer control system in the background. Image © David Kline[3]

Nature's lab

Environments that are naturally low in pH and Ω, such as CO_2-rich volcanic vent sites and submarine springs, serve as *natural* laboratories* that can be used to observe organisms over time scales long enough for **adaptation** or **acclimatization** to be observed (see next page)[4][6].

**Note:* problematic is when the water chemistry mimics high atmospheric CO_2 concentrations but does *not* mimic temperatures predicted for future global warming.

Activity: Distinguish between lab-scale experiments and field-based experiments and what they demonstrate about ocean acidification (OA).

Lab-scaled OA studies are highly controlled and can investigate the effect of changing pH levels on a single species in isolation. Field-based OA studies are conducted in the field with lots of natural variability. Both have demonstrated calcification rates declining with ocean acidification[1][4].

---

[1] Doney, S.C., Fabry, V.J., Feely, R.A. and Kleypas, J. (2009). Ocean Acidification: the other CO2 problem. *Annual Reviews. Washington Journal of Environmental Law and Policy. Vol. 1:169-192. DOI: 10.1146/annurev.marine.010908.163834*

[2] Riebesell, U., Fabry, V.J., Hansson, L. and Guttuso, J. (2010). *Guide to best practices for ocean acidification research and data reporting.* European Commission. DOI: 10.2777/66906.

[3] Adapted with permission from: Kline, D.I., Teneva, L., Schneider, K., Miard, T., Chai, A., Marker, M., Headley, K., Opdyke, B., Nash, M., Valetich, M., Caves, J.K., Russell, B.D., Connell, S.D., Kirkwood, B.J., Brewer, P., Peltzer, E., Silverman, J., Caldeira, K., Dunbar, R.B., Koseff, F.R., Monismith, S.G., Mitchell, B.G., Dove, S. and Hoegh-Guldberg, O. (2012). A short-term in situ CO2 enrichment experiment on Heron Island (GBR). *Nature. Scientific Reports. 2:413 DOI:10.1038/srep00413.*

[4] Crook, E.G., Cohen, A.L., Rebolledo-Vieyra, M., Hernandez, L. and Payten, A. (2013). Reduced calcification and lack of acclimatization by coral colonies growing in areas of persistent natural acidification. *PNAS Vol 110 no. 27. DOI: 10.1073/pnas.1301589110*

[5] Hoegh-Guldberg, O. (n.d.). *Science, solutions and the future: the Great Barrier Reef in a time of change. Final Synthesis Stakeholder Report. Qld Premier's Fellowship.* Accessed 02.04.2019 from: https://gci.uq.edu.au/filething/get/194/GCIQLDPremiersFellowshipReport.pdf

[6] Camp, E.F., Nitschke, M.R., Rodolfo-Metalpa, R., Houlbreque, F., Gardner, S.G., Smith, D.J., Zampighi, M. and Suggett, D.J. (2017). Reef-building corals thrive within hot-acidified and deoxygenated waters. Scientific Reports. Article number (7) 2434. DOI: 10.1038/s41598-017-02383-y

The Great Debate – Describe the potential consequences of ocean acidification for coral reef ecosystems

T119

Name:

Date:

Suggested Activity: Conduct a debate. Team 1 argues the potential consequence of ocean acidification is a looming death sentence for coral reef ecosystems. Team 2 argues there is still hope for coral reef ecosystems, owing to species adaptation and acclimatization. Both teams must do their research prior to the debate and base their arguments on science.

Note: Ocean acidification (OA) and coral bleaching are often discussed together. Even though OA and coral bleaching are two different types of disturbance (i.e. OA is a *ramp-type* disturbance, whereas, coral bleaching is an episodic *pulse-type* disturbance), they are both caused by quickly rising atmospheric CO_2 concentrations[1]. In addition, coral bleaching (if it does not kill the coral) reduces the fitness of coral (due to the coral starving from a lack of zooxanthellae). Whereby, a bleached coral lacks the energy needed to maintain its internal pH (see *pH up-regulation* next page) to maintain a rate of calcification that exceeds the rate of erosion. Thus, the question remains, will reef-building corals be able to avoid bleaching (see next page Figures 1 and 2), and then find ways to adapt and/or acclimatize to an increase in H^+ ions (drop in pH) from OA[8]? If so, which corals will be able to do this[2]? And, what is the role of the coral holobiont in making that possible[3][4][5]? And, could the corals that survive (*if* they survive) be the ones to 'seed' and aid recovery of damaged reefs in the future[6]?

Activity: In the space provided below, define the terms *adaptation** and *acclimatization***

- Adaptation refers to a long-term *genetic* response that allows an organism to tolerate a new environment.
- Acclimatization refers to a short-term *phenotypic* response that allows an organism to tolerate a new environment.

* **Adaptation** refers to a long-term *genetic* response that allows an organism to tolerate a new environment.
****Acclimatization** refers to a short-term *phenotypic* response that allows an organism to tolerate a new environment.
Note: when a phenotypic response is investigated *experimentally* (e.g. by manipulating a single environmental factor in the lab) it is termed ***acclimation***[7].

Activity: Describe the potential consequences of ocean acidification for coral reef ecosystems

Answers may vary. See references below and in other worksheets.

---

[1] Van Hooidonk, R., Maynard, J.A., Manzello, D. & Planes, S. (2014). Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. *Global Change Biology. 20, 103-112. DOI: 10.1111/gcb.12394.*

[2] De Carlo, T. M. (2019). Acclimatization of massive reef-building corals to consecutive heatwaves. *Proc. R. Soc. B. 286. DOI: 10.1098/rspb.2019.0235*. https://royalsocietypublishing.org/doi/full/10.1098/rspb.2019.0235

[3] Stat, M. & Gates, R. D. (2011). Clade D Symbiodinium in Scleractinian Corals: A 'Nugget' of Hope, a Selfish Opportunist, an Ominous Sign, or All of the Above? *Journal of Marine Biology. Vol. 2011, Review Article ID 730715. DOI: 10.1155/2011/730715* (Note: the nomenclature of zooxanthellae is currently under review; i.e. clades → Genus sp.)

[4] Thompson, J.R., Rivera, H.E., Closek, C.J. and Medina, M. (2015). Microbes in the coral holobiont: partners through evolution, development, and ecological interactions. *Front Cell Infect Microbiol Vol.4 Article 176. DOI:10.3389/fcimb.2014.00176*

[5] Torda, G., Donelson, J.M., Aranda, M., Barshis, D.J., Bay, L., Berumen, M.L., Bourne, D.G., Cantin, N., Foret, S., Matz, M., Miller, D.J., Moya, A., Putnam, H.M., Ravasi, T., Van Oppen, M.J.H., Thurber, R. V., Vidal-Dupiol, J., Voolstra, C.R., Watson, S.A., Whitelaw, E., Willis, B.L. & Munday, P.L. (2017). Rapid adaptive responses to climate change in corals. *Nature Climate Change, 7(9), 627-636. doi:10.1038/nclimate3374*

[6] Beyer, H.L., Kennedy, E.V., Beger, M., Allen Chen, C., Cinner, J., Darling, E.S., Eakin, C.M., Gates, R.D., Heron, S.F., Knowlton, N., Obura, D.P., Palumbi, S.R., Possingham, H.P., Puotinen, M., Runting, R.K., Skirving, W.J., Spalding, M., Wilson, K.A., Wood, S., Veron, J.E. & Hoegh-Guldberg, O. (2018). Risk-sensitive planning for conserving coral reefs under rapid climate change. *Conservation Letters. Volume 11, Issue 6. DOI: 10.1111/conl.12587*

[7] Edmunds, P.J. & Gates, R.D. (2008). Acclimatization in tropical coral reefs. *Marine Ecology Progress Series. Volume 361: 307-310. DOI: 10.3354/meps07556.*

[8] Camp, E.F., Nitschke, M.R., Rodolfo-Metalpa, R., Houlbreque, F., Gardner, S.G., Smith, D.J., Zampighi, M. and Suggett, D.J. (2017). Reef-building corals thrive within hot-acidified and deoxygenated waters. *Scientific Reports. Article number (7) 2434. DOI: 10.1038/s41598-017-02383-y*

Buying Time – Explain how resilience may partially offset ocean acidification (OA) responses in the short term T120

Name:

Date:

Building resilience

Removing the pressures on reefs builds resilience. Energy that would otherwise be used on surviving drivers of change such as climate change, pollution and overfishing, can instead be used for calcification.

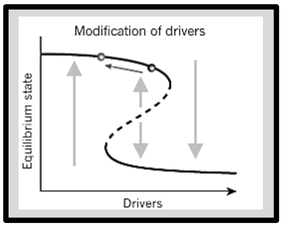

Figure 1: By reducing the relative strength of multiple drivers of change (i.e.stressors), the system moves away from a dangerous threshold (see black arrow). E.g. establish more marine parks, reduce pollution, and encourage shifts in social norms (the informal rules that shape people's attitudes and behaviours) to foster compliance[1].

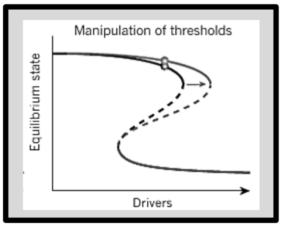

Figure 2: Thresholds are manipulated to allow the system to handle higher levels of drivers without collapsing. E.g. the impact of fishing is reduced by gear modifications, or by increasing the proportion of species that are more tolerant to escalating drivers (e.g. heat tolerant species)[1].

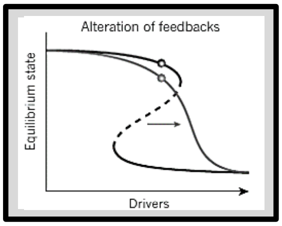

Figure 3: Multiple feedbacks (consequences) could be managed to flatten the slope of the equilibrium response curve, reducing the risk of surpassing a tipping point (or to eliminate it altogether). E.g. when fish stocks decline, fishers that do not have access to alternative livelihoods (and may increase their fishing efforts as a result) are given government-backed incentives to exit a fishery when stocks decline[1].

Activity: In Figure 1, draw the vertical arrows that represent resilience - whereby long arrows represent high resilience and short arrows represent low resilience (see p. 70).

pH up-regulation

Incredibly, scleractinian corals can actively pump H+ ions out of their calcifying fluid (cf) where calcification takes place (see page 27). This increases their **internal** pH (pHcf ~8.3-8.6) and **internal** (calcifying fluid) saturation state (Ωcf ~15-25) and therefore rate of calcification[2]. Pretty neat huh! Then, when seawater pH and Ωara decline with ocean acidification, the corals simply pump out more H+ ions! However, some do it better than others. And, to pump out H+ ions requires energy. Energy that comes from zooxanthellae. Further emphasizing the importance for corals to maintain their symbiotic relationship with zooxanthellae and avoid bleaching[2]. Importantly, bleaching is *not* limited to just thermal stress. It can also happen with excessive UV, aerial exposure, pollutant and toxin exposure, reduced salinity, and high sedimentation[3].

Q. How do scleractinian corals maintain calcification rates under OA conditions? Ans.

They actively pump H+ out of their calcifying fluid to lower their internal pH

Assisted Evolution

Assisted evolution aims to enhance the resilience of organisms to climate change. Whereby naturally occurring evolutionary processes, that would normally take a very long time to evolve, are accelerated. For example, exposing corals to stressful conditions to unlock (epigenetic) coping mechanisms and induce acclimatization; selectively breeding certain corals that possess desirable traits (and replanting them); subjecting zooxanthellae to stress hoping to elicit an adaptive response through selection or random somatic mutations; and actively modifying the community composition of coral-associated microbes (e.g. inoculating young corals with stress tolerant zooxanthellae), all aim to enhance resilience[4].

Q. What are your thoughts on Assisted Evolution for improving coral resilience[5]? Ans.

Answers will vary

---

[1] Adapted by permission from Springer Nature Customer Centre GmbH: *Nature Springer*. Coral Reefs in the Anthropocene, Hughes, T.P., Barnes, M.L., Bellwood, D.R., Cinner, J.E., Cumming, G.S., Jackson, J.B.C, Kleypas, J., Van de Leemput, I.A., Lough, J.M., Morrison, T.H., Palumbi, S.R., Van Nes, E.H. and Scheffer, M. © 2017. *Nature. 546(7656):82-90. DOI: 10.1038/nature22901.*

[2] McCulloch, M., Falter, J., Trotter, J. and Montagna, P. (2012). Coral resilience to ocean acidification and global warming through pH up-regulation. *Nature. Climate Change. 2(8). DOI: 10.1038/nclimate1473*

[3] Pratchett, M.S., Munday, P.L., Wilson, S.K., Graham, N.A.J., Cinner, J.E., Bellwood, D.R., Jones, G.P., Polunin, N.V.C. and McClanahan, T.R. (2008). Effects of Climate-Induced Coral Bleaching on Coral Reef Fishes – Ecological and Economical Consequences. *Oceanography and Marine Biology: An Annual Review (46) 251-296.*

[4] Van Oppen, M.J.H., Oliver, J.K., Putnam, H.M. and Gates, R. D. (2015). Building coral reef resilience through assisted evolution. *PNAS. Vol. 112 no. 8. DOI:10.1073/pnas.1422301112*

[5] Filbee-Dexter, K. and Smajdor, A. (2019). Ethics of Assisted Evolution in Marine Conservation. *Perspective Article: Frontiers of Marine Science. DOI: 10.3389/fmars.2019.00020*

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Mandatory Practical – Investigate the effects an altered ocean pH has on marine carbonate structures

T121

Name:

Date:

The aim of this experiment is to measure the dissolution rates of marine carbonate structures in various pH solutions

Dissolution means *to dissolve*. Dissolution rates increase as H^+ ion concentrations increase (pH decreases).

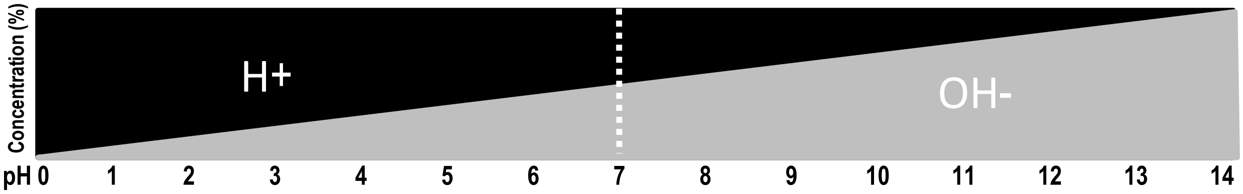


Figure 1: Each one-unit change in pH corresponds to a ten-fold change in H+ ion concentration. Acidic solutions have more H+ ions than OH$^-$ ions.

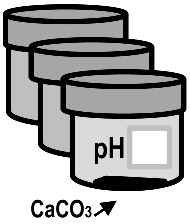
Experimental Design

An easy way to achieve the desired pH for each treatment is to add hydrochloric **acid** (HCl) to distilled water. The more you add, the stronger the solution. Alternatively, your teacher will prepare HCl solutions for you. Measure the pH and record below. Then, measure and record the dry weight of $CaCO_3$ before the experiment, and again after the experiment. The *dissolution rate* will be the (mean) change in mass over time.

Treatment 1

☐ % HCl

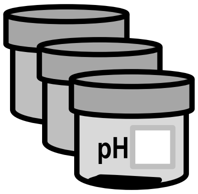
☐ % distilled water



Treatment 2

☐ % HCl

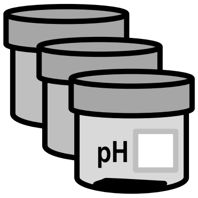
☐ % distilled water



Treatment 3

☐ % HCl

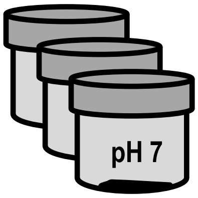
☐ % distilled water



Control

0 % HCl

100 % distilled water



Activity: Record and Discuss your Results below. Discuss how to improve the experiment.

Repeats ⇩	Treatment 1 (g)			Treatment 2 (g)			Treatment 3 (g)			Control (g)		
	Before	After	Change in mass	Before	After	Change in mass	Before	After	Change in mass	Before	After	Change in mass
1												
2												
3												
MEAN			☐			☐			☐			☐

Unit 4 Ocean issues and resource management

Topic 1:
Oceans of the future

Management and conservation
Future Scenarios

CoralWatch Survey, North West Island Lagoon, Capricorn Bunker Group, Great Barrier Reef.
Note: waterproof paper and pencils are available at Officeworks.

Marine Education

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Why Protect our Natural Assets? – Recall and use the arguments for preserving species and habitats (i.e. ecological, economic, aesthetic, ethical) through identifying their associated direct and indirect values in a given case study T122

Name:

Date:

Valuing Nature

- **Direct Use values** of coral reefs can be extractive or non-extractive (*in situ*), consumptive or non-consumptive. E.g. fisheries, tourism, aquarium trade, education, etc.
- **Indirect Use values** of coral reefs are the *functional* benefits of coral reefs that are enjoyed indirectly[1]. E.g. coast protection, fish nurseries, carbon storage, etc.
- **Non-use values** of coral reefs are the values assigned to coral reefs even if you never have, or never will, use it. E.g. potential value to future generations.

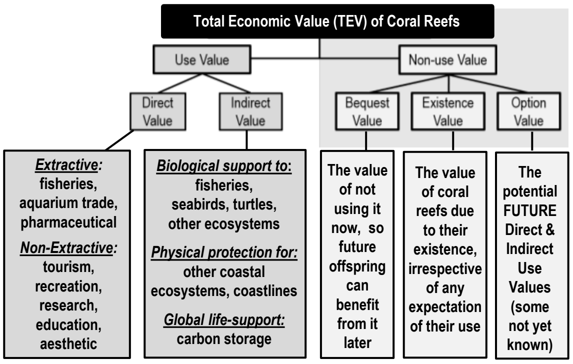

Figure 1: The Use (Direct and Indirect) and Non-Use Values of Coral Reefs[1][2]

Activity: Name one direct value of a coral reef: Fisheries, tourism, research…

Activity: Name one indirect value of a coral reef: Coast protection, fish nursery…

Historical Fight for the Reef

The Great Barrier Reef was not always protected. Figure 2 was published in 1971 by (the legendary) Isabelle Bennett[3]. It shows what 'could have been'.

Conservationist and poet, Judith Wright, tells of her fight to protect the reef in her book '*The Coral Battleground'* [4].

Q. What do you think Judith Wright might have said to the prime minister, politicians and trade unions in the 1970s to convince them to protect (and not mine) the reef? Ans.

Ecological: source of genetic diversity
Economic: ecotourism, recreation, yield
Ethical: bio rights and stewardship
Aesthetic: source of beauty, spiritual connection

Note: these answers are straight from the syllabus. Student answers may vary.

Note: The Great Barrier Reef Marine Park (GBRMP) was established in 1975. In 1981, an area including the GBRMP was inscribed on the World Heritage List as GBRWHA.

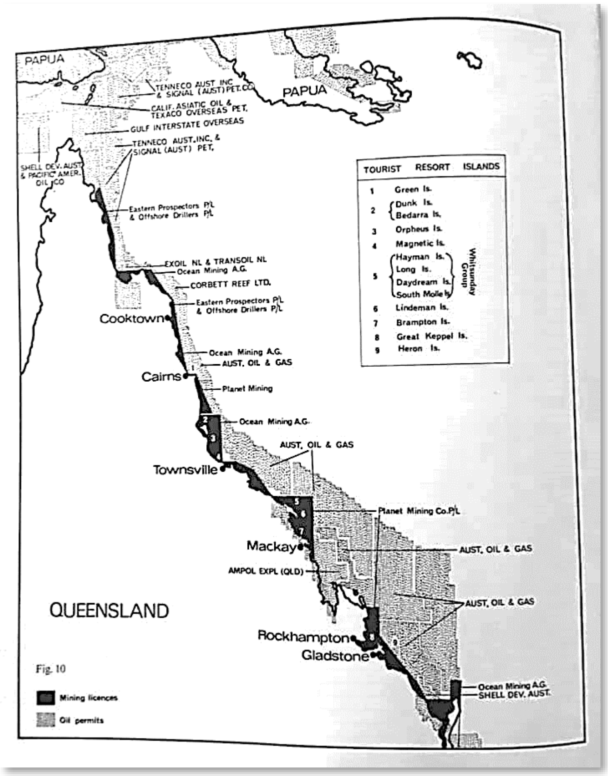

Figure 2: Mining licences (in black) and Oil permits (shaded areas) in 1971[3]

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[1] Adapted from: Mohamed, M. (2007). Economic valuation of coral reefs: a case study of the costs and benefits of improved management of Dhigali Haa, a marine protected area in Baa atoll, Maldives. Thesis. University of Canterbury NZ.

[2] Adapted from: TEEB (2010). *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the Approach, Conclusions and Recommendations of TEEB*. Accessed 16.04.2019 from: www.teebweb.org

[3] Bennett, I. (1971). *The Great Barrier Reef.* Lansdowne Press. Victoria. Australia. Page 176.

[4] Wright, J. (1977). *The Coral Battleground.* Thomas Nelson (Australia) Limited. Melbourne, Vic. Aust.

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Marine Education

How to Protect our Natural Assets? – Recall and explain the criteria (i.e. site selection, networking and connectivity, replication, spacing, size and coverage) used to design marine protected areas (MPAs) T123

Name:

Date:

How to design a marine reserve

Marine ***reserves**** provide protection from extractive and destructive activities[1]. Hence, there are rules. Thus, in order to be effective (and become powerful tools for conservation and management) they need to be designed well. When designing a marine reserve or marine reserve *network*, a few things need to be decided upon, such as where they should go (site selection, networking and connectivity), how big they need to be (size and coverage), how many there needs to be (replication), and how close together they need to be (spacing). As a rule of thumb, marine reserves should be at least **twice the size** of the home range of focal species for protection (in all directions), protect habitats critical to any stage of their life cycle (e.g. nursery grounds and spawning sites), and be spaced 10s to 100s of kilometres apart (depending on the larval dispersal distances of focal species) to allow for species replenishment[3].

*A 'marine reserve' is a type of MPA that usually offers a higher rate of protection for a designated area and its species (usually fish). E.g. no-take areas.

Q. How many fish species in Fig. 1 would be protected by a reserve with a 1km diameter? Ans. 19

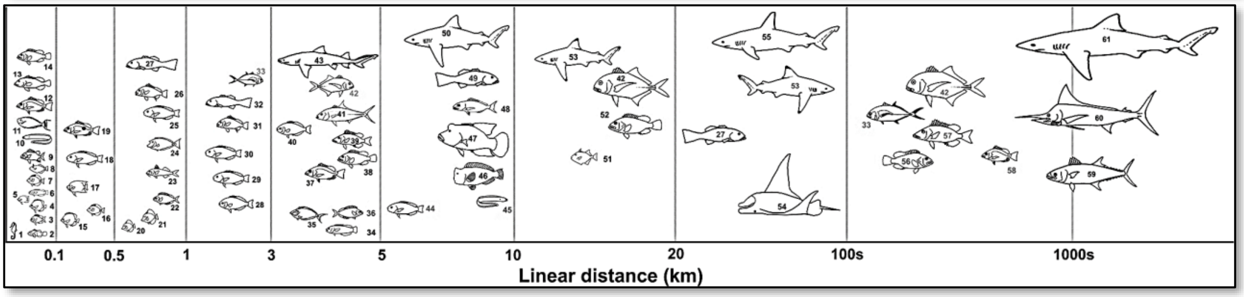

Figure 1: Linear scale of movement of coral reef and coastal pelagic fish species[1].

Note: the <u>home range</u> of a fish is the area in which an individual spends the majority of its time and engages in most of its routine activities including foraging and resting. Small-scale resident spawning aggregations are included in that home range. Larger scale movements to transient spawning aggregations are not[1].

Activity: Explain the following general recommendations for resilient MPA network design[2]

Criteria	Recommendation	**Explanation** (the reason for the recommendation)
Site selection, Networking and Connectivity (where they should go)	Put them in habitats critical to any stage of the focal species life cycle	Areas with high habitat connectivity improve reserve performance[1]
Size and Coverage (how big they need to be)	Be at least twice the size of the focal species home range	To ensure the reserve includes the entire home range of at least one individual, and will likely include many more with overlapping home ranges[1]
Spacing (how close together they need to be)	Be spaced 10s to 100s of kilometres apart	To allow for species replenishment[1]

Recommended Reading:

- The Nature Conservancy (2019). MPA Network Design for Fisheries, Climate Change and Biodiversity Objectives. Conservation Gateway. Accessed 05.07.2019 from: **http://nature.org/MPANetworkDesign**
- McLeod, E., Salm, R., Green, A., and Almany, J. (2008). Designing marine protected area networks to address the impacts of climate change. *Frontiers in Ecology and the Environment. Volume 7. Issue 7. DOI: 10.1890/070211.* https://www.researchgate.net/profile/Rodney_Salm/publication/303855892_Designing_marine_protected_area_networks_to_address_the_impacts_of_climate_change/links/57d079b508ae6399a389db6b/Designing-marine-protected-area-networks-to-address-the-impacts-of-climate-change.pdf
- Green, A. L., Fernandes, L., Almany, G., Abesamis, R., McLeod, E., Alino, P., White, A. T., Salm, R., Tanzer, J. and Pressey, R.L. (2014). Designing Marine Reserves for Fisheries Management, Biodiversity Conservation, and Climate Change Adaptation. *Coastal Management 42: 143-159. DOI: 10.1080/08920753.2014.877763.* https://www.researchgate.net/publication/260555735_Designing_Marine_Reserves_for_Fisheries_Management_Biodiversity_Conservation_and_Climate_Change_Adaptation

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[1] Reproduced with permission from: Green, A.L., Maypa, A.P., Almay, G.R., Rhodes, K.L., Weeks, R., Abesamis, R. A., Gleason, M., Mumby, P. and White, A.T. (2014). Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. *Biological Reviews. Volume 90. Issue 4. DOI: 10.1111/brv.12155.* CC BY-NC-ND 4.0

[3] Dr. Alison Green, personal communication (04.07.2019). *Note:* originally, the rule of thumb was to space marine reserves no more than 15km apart[1]. The science has recently changed with more empirical movement studies on more species. Therefore, now we say they should be spaced 10s or 100s of km apart, depending on larval dispersal distances of focal species[3].

In the Zone – Identify management strategies used to support marine ecosystem health (e.g. managing threats, zoning, permits, plans, longitudinal monitoring) T124

Name:

Date:

Zoning

Zoning is a management strategy that divides a Marine Park into zones, with different rules for each zone. It was initially applied to the Great Barrier Reef (GBR) in 1981 and is now widely regarded as the cornerstone of GBR management[1]. It is interesting to note that many of the original GBR zone names are colloquially known by their colour as depicted on a zoning map[1]. E.g. the *Marine National Park Zone* is called the green zone ('no-take' zone) and the *Preservation Park Zone* is called the pink zone ('no-go' zone)[2].

Activity: Download the 'Eye on the Reef' app and explore zonings in 'General Information'.

Activity: Complete the table below[2]

Activities Guide	General Use Zone (light Blue)	Habitat Protection Zone (Blue)	Conservation Park Zone (Yellow)	Buffer Zone (Brown)	Scientific Research Zone (Orange)	Marine National Park Zone (Green)	Preservation Park Zone (Pink)
Aquaculture	Permit	Permit	Permit	X	X	X	X
Bait Netting	✓	✓	✓	X	X	X	X
Boating, diving, photography	✓	✓	✓	✓	✓	✓	X
Crabbing (trapping)	✓	✓	✓	X	X	X	X
Harvest fishing for aquarium fish, coral and beachworm	Permit	Permit	Permit	X	X	X	X
Harvest fishing for sea cucumber, trochus, tropical rock lobster	Permit	Permit	X	X	X	X	X
Limited collecting	✓	✓	✓	X	X	X	X
Limited spearfishing (snorkel only)	✓	✓	✓	X	X	X	X
Line fishing	✓	✓	✓	X	X	X	X
Netting (other than bait netting)	✓	✓	X	X	X	X	X
Research (other than limited impact research)	Permit	Permit	Permit	Permit	Permit	Permit	Permit
Shipping (other than in a designated shipping area)	✓	Permit	Permit	Permit	Permit	Permit	X
Tourism programme	Permit	Permit	Permit	Permit	Permit	Permit	X
Traditional use of marine resources	✓	✓	✓	✓	✓	✓	X
Trawling	✓	X	X	X	X	X	X
Trolling	✓	✓	✓	✓	X	X	X

Reef 2050 Plan

The Australian and Qld. governments responded to increasing concerns about the health of the GBR[3] with the **Reef 2050 Plan** – an overarching framework for protecting and managing the reef until 2050[4].

Q. How often will the *Reef 2050 Plan* be reviewed? Ans. Every 5 years (starting 2020)

---

[1] Day, J. C. (2002). Zoning – lessons from the Great Barrier Reef Marine Park. *Ocean and Coastal Management. Volume 45. Issues 2-3. Pages 139-156. DOI: 10.1016/S0964-5691(02)00052-2*

[2] Adapted with permission from: Great Barrier Reef Marine Park Authority 2018, *Maps.* GBRMPA, Townsville. Accessed 18.04.2019 from: http://www.gbrmpa.gov.au/access-and-use/zoning/zoning-maps

[3] Great Barrier Reef Marine Park Authority 2014, *Great Barrier Reef Outlook Report 2014,* GBRMPA, Townsville. Accessed 06.07.2019 from: http://www.gbrmpa.gov.au/our-work/reef-strategies/great-barrier-reef-outlook-report

[4] Commonwealth of Australia (2018). *The Reef 2050 Plan.* The Australian Government: Department of Environment and Energy. Canberra. Accessed 18.04.2019 from: http://www.environment.gov.au/marine/gbr/long-term-sustainability-plan

Successful MPAs – Evaluate the success of a named protected marine area T125

Name:

Date:

Activity: In the space below, evaluate the success of a named protected marine area

For example:

- Kimbe Bay, Papua New Guinea[1]
- Apo Island, in the Philippines[2]
- Nguna-Pele Marine and Land Protected Area Network, Vanuatu[3]
- Great Barrier Reef Marine Park, Australia[4]

Recommended Readings

[1] Green, A., Smith, S.E., Lipsett-Moore, G., Groves, C., Peterson, N., Sheppard, S., Lokani, P., Hamilton, R., Almany, J., Aitsi, J. and Bualia, L. (2009). Designing a resilient network of marine protected areas for Kimbe Bay, Papua New Guinea. *Oryx. 43(04):488 – 498. DOI: 10.1017/S0030605309990342*

[2] Alcala, A. C. (2004). *Marine Reserves as Tools for Fishery Management and Biodiversity Conservation: Natural Experiments in the Central Philippines, 1974-2000*. Silliman University-Angelo King Center for Research and Environmental Management, Dumaguete city. Accessed 19.04.2019 from: https://www.cbd.int/doc/nbsap/fisheries/ALCALA.pdf

[3] United Nations Development Programme (2012). *Nguna-Pele Marine and Land Protected Area Network, Vanuatu.* Equator Initiative Case Study Series. New York, NY. Accessed 19/04.2019 from: https://www.equatorinitiative.org/wp-content/uploads/2017/05/case_1348163605.pdf

[4] Craik, AM. W. (2017). *Review of Governance of the Great Barrier Reef Marine Park Authority*. Report. Canberra: Department of the Environment and Energy. Accessed 19.04.2019 from: http://www.environment.gov.au/system/files/resources/6a038c9a-34dd-42cb-a0b4-a688bd284658/files/final-report-review-governance-gbrmpa.pdf

Government and NGO Roles – Compare the roles of government and non-government organisations in the management and restoration of ecosystems and their relative abilities to respond (e.g. speed, diplomatic constraints, political influence, enforceability) T126

Name:

Date:

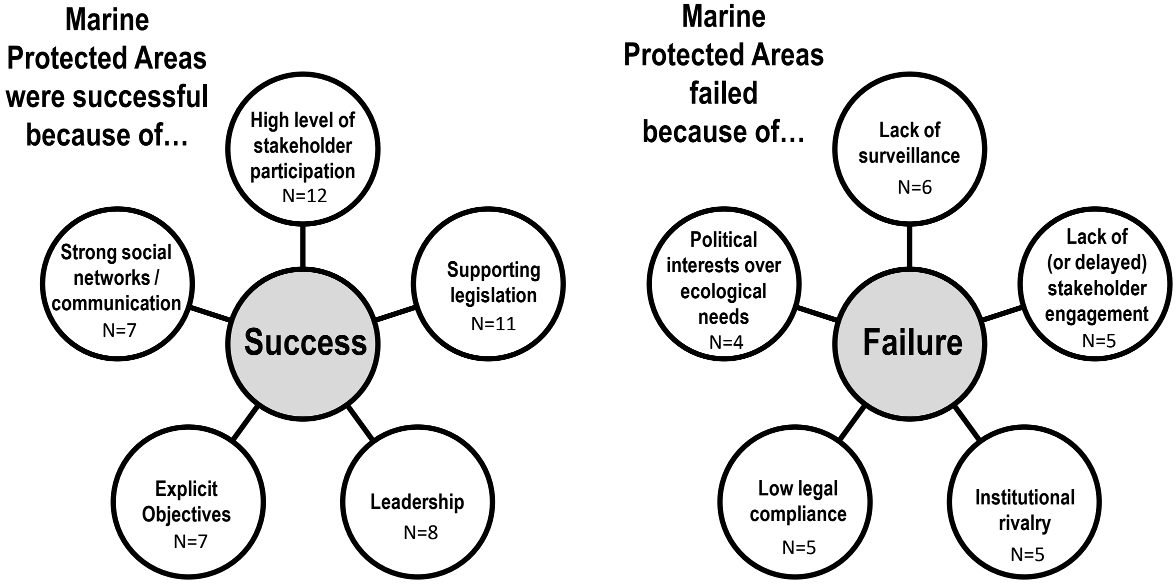

Figure 1: Top 5 factors determining the success of 16 MPAs (left) and the failure of 11 MPAs (right) around the world, according to expert judgement[1].

Copyright © 2018 Giakoumi, McGowan, Mills, Beger, Bustamante, Charles, Christie, Fox, Garcia-Borboroglu, Gelcich, Guidetti, Mackelworth, Maina, McCook, Micheli, Morgan, Mumby, Reyes, White, Grorud-Colvert and Possingham.

Q. How can a government organisation help turn a failed MPA into a successful one? Ans.

Include in your answer a comment on the **speed** of their ability to respond, **diplomatic constraints**, **political influence** and **enforceability**.

Increase stakeholder engagement and participation (e.g. outreach to forge relationships with key individuals), demonstrate leadership, provide supporting legislation with explicit objectives, put ecological needs before political interests, actively work towards eliminating any institutional rivalry, and increase funding for surveillance.

- Speed can be slow (must follow a process) with diplomatic constraints.
- Governments generally have lots of political influence and enforceability.

Q. How can a non-government organisation (NGO) help turn a failed MPA into a successful one?

Include in your answer a comment on the **speed** of their ability to respond, **diplomatic constraints**, **political influence** and **enforceability**.

Through advocacy (by drawing attention to it, lobbying, rallying support, etc.);
By providing scientific data and expertise (e.g. citizen science initiatives increasing stakeholder engagement and participation); By taking on a management role (habitat restoration, co-management with government); By being a watchdog (monitoring for compliance and publicizing infractions), and; By being an enabler (fundraising, networking, stakeholder engagement)[2][3].

- Speed, diplomatic constraints and political influence largely depend on existing community beliefs and values. Enforceability can be limited to shaming.

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[1] Adapted with permission from: Giakoumi, S., McGowen, J., Mills, M., Beger, M., Bustamante, R.H., Charles, A., Christie, P., Fox, M., Garcia-Borboroglu, P., Gelcich, S., Guidetti, P., Mackelworth, P., Maina, J., McCook, L., Micheli, F., Morgan, L.E., Mumby, P., Reyes, L.M., White, A., Grorud-Colvert, K. and Possingham, H.R. (2018). Revisiting "Success" and "Failure" of Marine Protected Areas: A Conservation Scientist Perspective. *Frontiers in Marine Science. Volume 5. Article 223. DOI: 10.3389/fmars.2018.00223*

[2] Brumbaugh, D. R. (2017). *Co-Management of Marine Protected Areas: A suggested framework for The Bahamas*. Report to the Nature Conservancy, Northern Caribbean Program, Nassau, Bahamas. 32pp. Accessed 20.04.2019 from: file:///C:/Users/riche/Downloads/Co-Management-Framework-Final2.pdf

[3] Crosman, K. M. (2013). *The roles of non-governmental organizations in marine conservation.* Thesis. University of Michigan. Accessed 20.04.2019 from: https://deepblue.lib.umich.edu/bitstream/handle/2027.42/99557/Crosman_Roles_of_NGOs_in_Marine_Conservation_Final.pdf?sequence=1

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Marine Education

Future Scenarios – Evaluate future scenarios for a named marine system through the analysis of different atmospheric condition datasets T127

Name:

Date:

Activity: Describe the atmospheric conditions (e.g.W/m^2, CO_2, °C) **in 2100 for each of the RCPs. Then, evaluate the future of a named marine system for each of the RCPs.** *Hint*: see pages 89 & 27.

Name of Marine System:

RCP8.5

Atmospheric Conditions

- Radiative Forcing 8.5W/m^2. CO_2e 1370ppm. CO_2 936ppm (p.89).
- More unlikely than likely the temperature will stay below 4°C (p.89).

Future of Coral Reefs

- Not dominated by coral (p.27).
- Annual bleaching (p.89).
- Global sea level rise will be ~0.75m (IPCC WG1 AR5 Chapter 13. p.1181).

RCP6.0

Atmospheric Conditions

- Radiative Forcing 6.0W/m^2. CO_2e 850ppm. CO_2 670ppm (p.89).
- More unlikely than likely the temperature will stay below 3°C (p.89).

Future of Coral Reefs

- Not dominated by coral (p.27).
- Annual bleaching (p.89).
- Global sea level rise will be ~0.55m (IPCC WG1 AR5 Chapter 13, p.1181).

RCP4.5

Atmospheric Conditions

- Radiative Forcing 4.5W/m^2. CO_2e 650ppm. CO_2 538ppm (p.89).
- More unlikely than likely the temperature will stay below 2°C (p.89).

Future of Coral Reefs

- Not dominated by coral (p.27).
- Annual bleaching (p.89).
- Global sea level rise will be ~0.525m (IPCC WG1 AR5 Chapter 13, p.1181).

RCP2.6

Atmospheric Conditions

- Radiative Forcing 2.6W/m^2. CO_2e <490ppm. CO_2 421ppm (p.89).
- More unlikely than likely the temperature will stay below 1.5°C (p.89).

Future of Coral Reefs

- 10-30% of reefs might be saved (p.89).
- Global sea level rise will be ~0.45m (IPCC WG1 AR5 Chapter 13, p.1181).

Trends through Time – Compare historical geological data (e.g. of coral cores) with changes in land use practices and global carbon dioxide and temperature levels T128

Name:

Date:

Porites coral cores

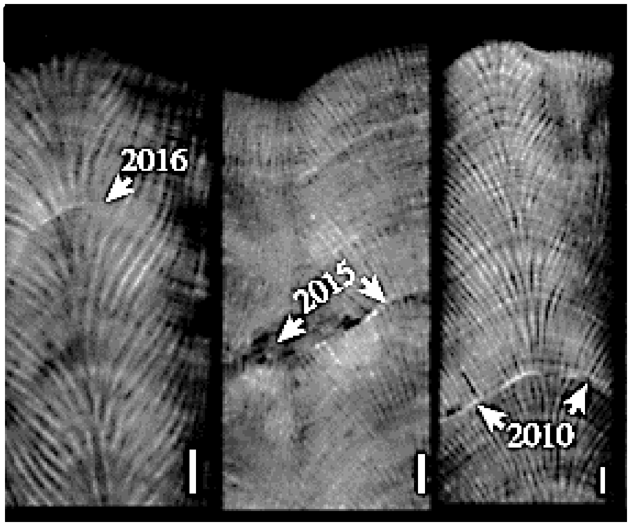


Figure 1: Stress bands on *Porites* coral cores from the Great Barrier Reef[1]

Global reefs exposed to ≥4DHW

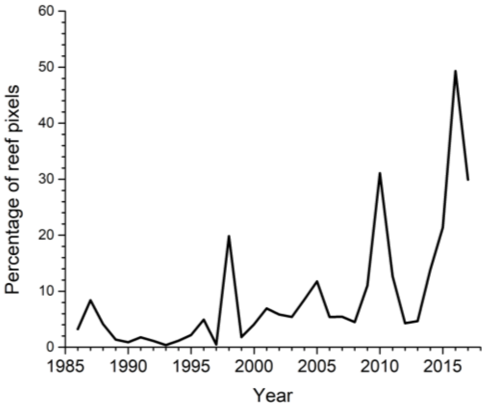


Figure 2: Percentage of global reefs exposed to bleaching-level heat stress of ≥4 Degree Heating Weeks (DHW). Note the peaks in 1998, 2010, 2015, 2016 and 2017, which were all considered to be global bleaching events in terms of extent. Graph courtesy of Dr. William J. Skirving[2].

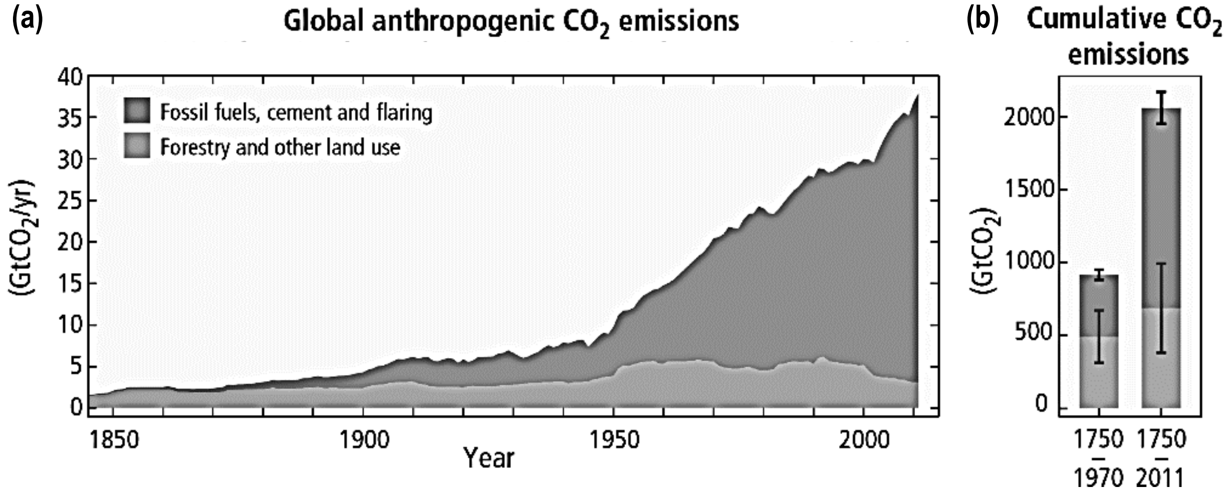


Figure 3: (a) Global anthropogenic CO2 emissions from burning fossil fuels, cement production and flaring, as well as from forestry and other land uses; (b) *Cumulative* emissions of CO2 from these sources, and their uncertainties[3].

Activity: Below, identify any obvious trends, patterns or relationships between Figures 1-3

CO2 emissions, the number of reefs exposed to ≥4DHWs (globally), and coral stress events all increase over time. Figure 3 clearly shows the steep climb in CO2 emissions since 1950 (compared to the relatively slow increases prior to 1950). The temperature spikes in Figure 2 correspond to the coral stress bands in *Porites* coral cores in Figure 1.

---

[1] Adapted with permission from: De Carlo, T.M., Harrison, H.B., Gajdzik, L., Alaguarda, D., Rodolfo-Metalpa, R., D'Olivo, J., Liu, G., Patalwala, D. and McCulloch, M.T. (2019). Acclimatization of massive reef-building corals to consecutive heatwaves. *Proc. R. Soc. B. 286. DOI: 10.1098/rspb.2019.0235*

[2] Adapted with permission from: Skirving, W.J., Heron, S.F., Marsh, B.L., Liu, G., De La Cour, J.L., Geiger, E.F. and Eakin, C.M. (2019). The relentless march of mass coral bleaching: a global perspective of changing heat stress. *Coral Reefs. Report. DOI: 10.1007/s00338-019-01799-4*

[3] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Shell Shock – Recognise that ocean acidification has indirect consequences on the ocean and its uses T129

Name:

Date:

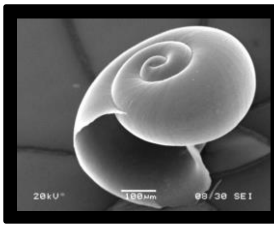
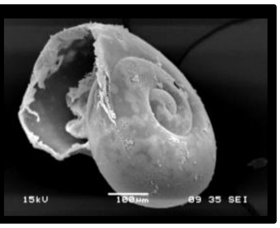


Figure 1 (left): A pteropod shell taken from ambient seawater with supersaturated conditions for omega typically has a smooth, sleek shell surface[1].

Figure 2 (right): Progressive roughening of the shell surface induced by dissolution. Shell integrity is lost and prone to fragmentation and increased frailness[1].



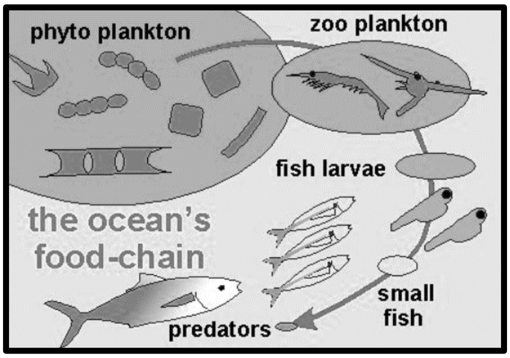
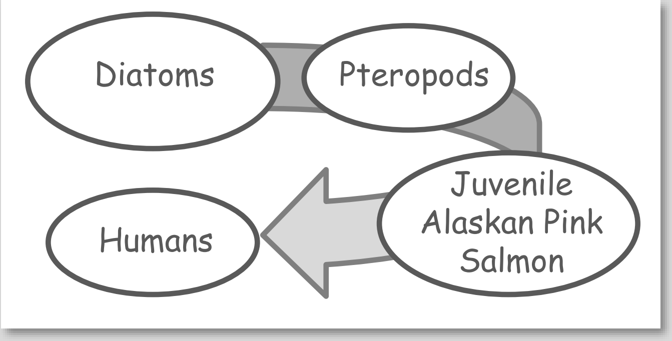


Figure 3: In the ocean, all creatures depend on the supply of plankton (tiny plants and animals) at the bottom of the food chain[2]. Many of which are made of calcium carbonate ($CaCO_3$). E.g. coccolithophores and pteropods are both made of $CaCO_3$.



Activity: Draw a food *chain* featuring a Pteropod
(*hint:* Juvenile Alaskan Pink Salmon eat Pteropods)

Activity: Find Figure 3 in Williamson & Turley (2012)[3]. Fill in the blanks below.

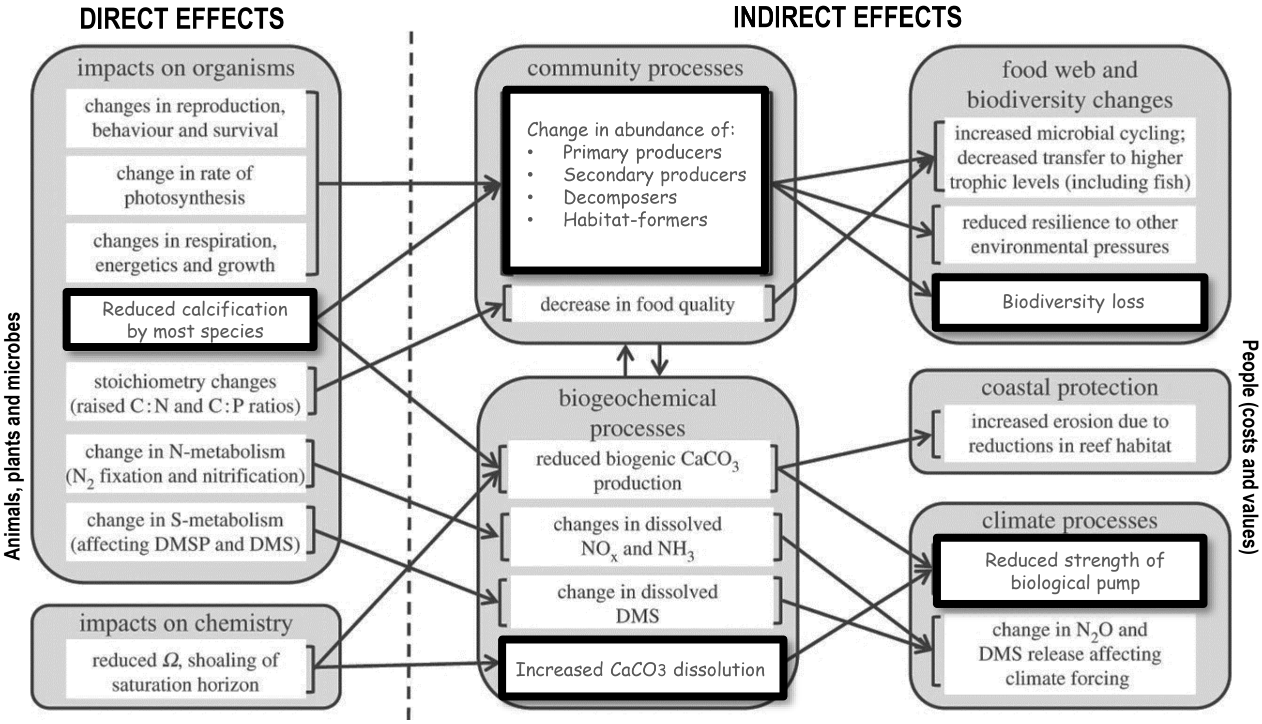


Figure 4: Conceptual representation of possible future ocean acidification direct effects on organisms and chemistry, and indirect effects on ecosystems and ecosystem services[3].

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[1] Adapted with permission from: Bednarsek, N., Tarling, G.A., Bakker, D.C.E., Fielding, S., Cohen, A., Kuzirian, A., McCorkle, D., Leze, B. and Montagna, R.(2012). Description and quantification of pteropod shell dissolution: a sensitive bioindicator of ocean acidification. *Global Change Biology. Volume 18. Issue 7. Pages 2378-2388. DOI: 10.1111/j.1365-2486.2012.02668.x*

[2] Adapted with permission from: Climate Kids (2019). *What is happening in the ocean?* NASA. Accessed 20.04.2019 from: https://climatekids.nasa.gov/ocean/. Courtesy NASA/JPL-Caltech.

[3] Adapted with permission from: Williamson, P. and Turley, C. (2012). Ocean acidification in a geoengineering context. *Philosophical Transactions of the Royal Society. 370, 4317-4342. DOI:10.1098/rsta.2012.0167*

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The Way the Wind Blows – Identify the factors between the atmosphere and the oceans that drive weather patterns and climate (e.g. temperature, wind speed and direction, rainfall, breezes and barometric pressure) T130

Name:

Date:

Weather or Climate?

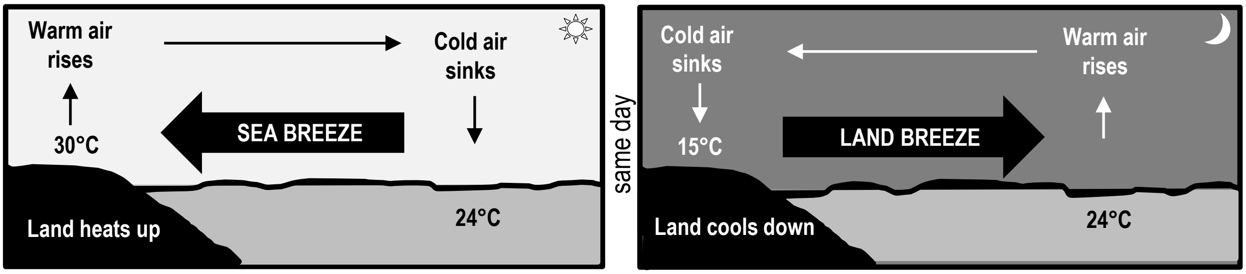
Weather and climate are not the same thing. Weather is short-term. Climate is long-term. Weather is what you see outside. Climate is the pattern of many weather events over a long period of time. As Dr. J. Marshall Shepherd[1] explains, '*weather is your mood and climate is your personality*'.

Q. What is climate? Ans. Long term average of weather events in one location

---

[1] Shepherd, J. M. (2019). *3 kinds of bias that shapes your worldview.* TedxUGA on YouTube. Accessed 21.04.2019 from: https://www.youtube.com/watch?v=LcNvkhS4UYg

Sea Breeze



Q. What time of day is a sea breeze usually at its strongest? Ans. Midday → mid afternoon

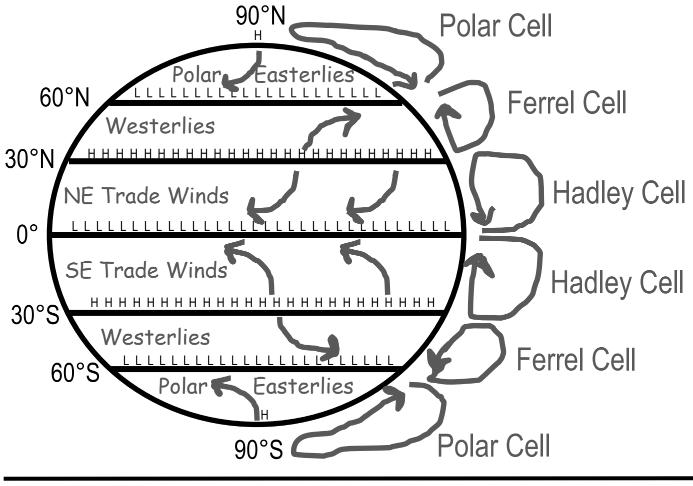
Q. Which one has the highest *heat capacity*....the ocean or the land? Ans. the ocean

Q. If you are in a boat, far away from land, and your barometer is reading 2008 hPa and falling fast, what sort of weather is headed your way? Ans. Bad weather!!!!

Global Atmospheric Circulation Patterns

Activity: Draw and label the following on the diagram below left: Hadley Cell, Ferrel Cell, Polar Cell, South-east Trade Winds, North-east Trade Winds, Westerlies, Polar Easterlies (incl. arrows)

Remember: wind always blows from a high (H) to a low (L). And, the Coriolis Effect steers wind to the left in the southern hemisphere and to the right in the northern hemisphere.



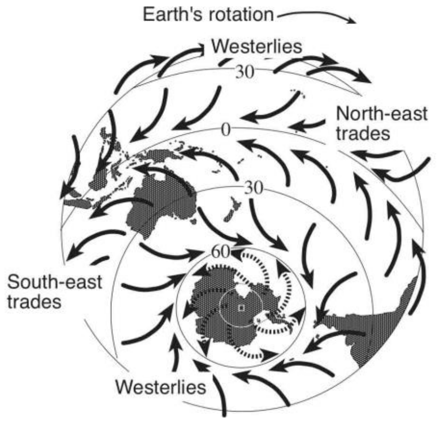


Figure 1: Prevailing wind directions influenced by Earth's rotation.
https://dumielauxepices.net/drawn-ocean/drawn-ocean-southern

Our Changing Climate in a Nutshell –

Understand that average global temperature increases impact on marine environments by altering thermal regimes and changing physical and chemical parameters of the ocean (e.g. aragonite saturation levels and rising sea levels) T131

Name:

Date:

Activity: In the space below, draw a mind map to consolidate your understanding of the impact of increasing CO2 on the physical, chemical and biological parameters of the ocean

Physical

Chemical and Biological

CO_2 increases at an alarming rate, mainly from burning fossil fuels for energy

CO_2 is absorbed by the ocean

Carbonate buffer system overwhelmed by *rate* of CO_2 input

Greenhouse Effect intensifies

Sea surface temperatures (SSTs) increase

pH and aragonite and calcite saturation states (Ω) decline (ocean acidification)

Bleaching occurs

Calcification rates decline

Severe weather events intensify in severity and frequency

Loss of Plankton (Pteropods, Forams and some Coccolithophores)

Sea levels rise (from melting ice and thermal expansion)

Thermohaline circulation slows (?)

Shallowing of CCD and ACD

Loss of habitat (phase shifts, reef erosion exceeds reef accretion)

Loss of Biodiversity (nature's workforce)

Loss of ecosystem services

Unit 4 Ocean issues and resource management

Topic 2:
Managing fisheries

Fisheries and population dynamics
Australia's fisheries management
Aquaculture

Above: Fishermen in the Maldives, pole and line fishing for Skipjack Tuna (*Katsuwonus pelamis*). This fishing method is regarded as a more sustainable way to catch tuna. Only fish of a certain size are caught, leaving juveniles to grow to spawning age. Small bait fish are thrown over the side of the boat to lure the tuna to the water surface. The fishermen use the acceleration of the fish as they race to get their prey, hook them and fling them onto the ship's flat deck[1]. Photograph © Paul Hilton. Reprinted with permission[2].

[1] ABC News Rural. (2017). *Pole and Line Fishing for Tuna.* ABC News Rural. Accessed 08.06.2019 from: https://www.abc.net.au/news/rural/2017-12-22/pole-and-line-fishing-for-tuna/9279282

[2] Paul Hilton is a conservation photojournalist and wildlife trade consultant. Visit:**paulhiltonphotography.com** or donate and follow Paul's work at **https://www.patreon.com/paulhilton**

Gone Fish'n – Understand that the term fishery has a variety of meanings and that there are three main types (i.e. artisanal, recreational and commercial) T132

Name:

Date:

For Survival

Artisanal/subsistence fishing

Figure 1: Vanuatu.
Photograph © 2009 Gail Riches

For Fun

Recreational fishing

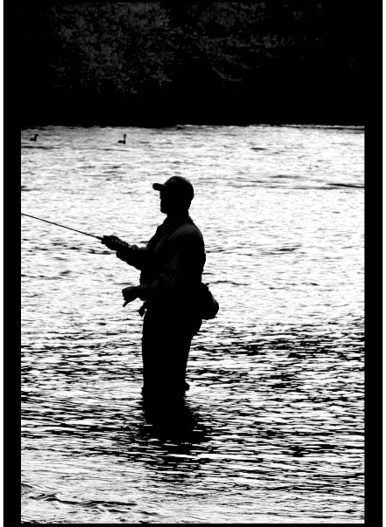


Figure 2: Fly fishing. Photograph: © 2019 West Virginia State Parks. www.stateparks.com/

For Big Profits

Commercial fishing

Figure 3: Crab fishing.
Photograph © SAGA www.fv-saga.com/

Q. What are the three main types of fishery? Ans.

Artisanal/subsistence

Recreational

Commercial

Fishing for Names

A *fishery* can be named after many things. E.g. it can be named after a *target* species (e.g. Northern *Prawn* Fishery). It can be named after a place of fishing (e.g. The *Coral Sea* Fishery). It can even be named after a *method* of fishing (e.g. Offshore *Net and Line* Fishery). Or any combination of these!

Activity: Below, name at least 10 Fisheries (*hint:* explore the AFMA website: www.afma.gov.au/).

For example,

1. Southern and Eastern Scalefish and Shark Fishery
2. Southern Squid Jig Fishery
3. Torres Strait Fisheries
4. Western Deepwater Trawl Fishery
5. Bass Strait Central Zone Scallop Fishery
6. Eastern Tuna and Billfish Fishery
7. The Southern Bluefin Tuna Fishery
8. Macquarie Island Toothfish Fishery
9. Norfolk Island Fishery
10. North West Slope Trawl Fishery

QUITE A CATCH:
ESTIMATING GLOBAL FISH STOCKS

Name:

Date:

The art of counting fish

Fish live underwater and can swim out of sight making them very difficult to count. But we need to know how many there are, so we know how many we can take. The FAO (Food and Agriculture Organization of the United Nations) uses various sources to estimate global fish stocks and trends as accurately as possible. The results are published every 2 years in the SOFIA report[1]. Below shows you how they do it[2].

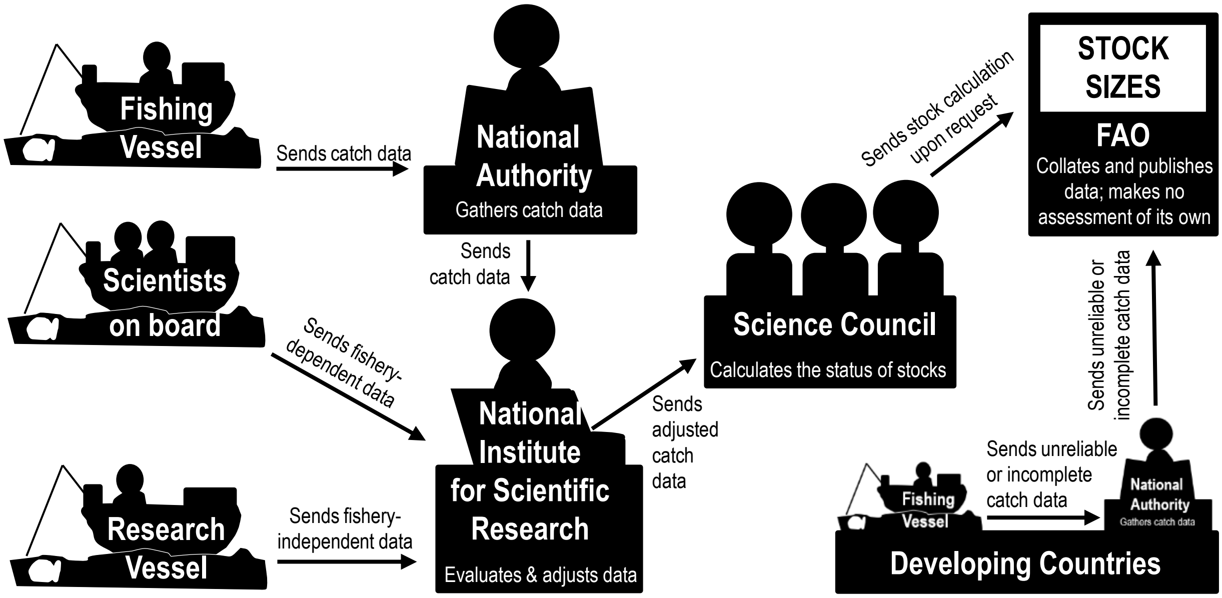


Figure 1: Global estimates of fish abundance. Data on the status of fish stocks is provided by fisheries and scientists[2].

Q. What is the latest estimate of wild fish stocks in millions of tonnes[1]? Ans. 90.9 (2016)
excluding aquaculture

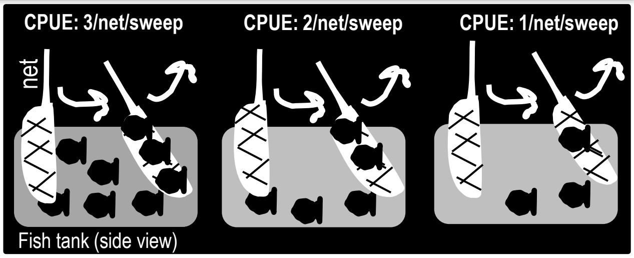
CPUE: Fishing Vessel log book catch data

Fishermen's log books record how many fish were caught, what gear was used, and how much effort it took for the fishermen to catch those fish (e.g. time spent fishing). That information gives a 'catch rate', or CPUE (catch per unit effort) which is then used to estimate the *abundance* of the unit stock.
For example, if more fish are caught (per same unit of effort) there must be more fish in the sea, right?!

Q. What does CPUE estimate? Ans. Abundance of the unit stock (population)

Suggested Practical[2]

1. Fill a fish tank with lots of small fish (count them)
2. Use a net and make one sweep across the tank
3. Do *not* put them back in the same tank
4. Count the number of fish caught (per unit effort)
5. Repeat steps 2-4 using the same unit of effort.



Q. Does CPUE increase or decrease when abundance declines? Ans. decrease

---

[1] Fisheries and Aquaculture Department (2018). *The State of World Fisheries and Aquaculture (SOFIA).* FAO. Accessed 29.04.2019 from: http://www.fao.org/fishery/sofia/en

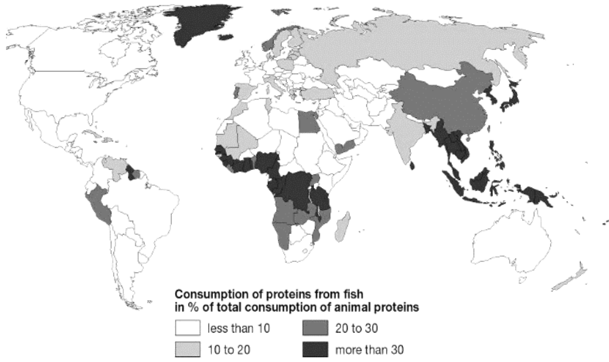
[2] Adapted with permission from Jan Lehmköster, World Ocean Review (2013). *2 The Future of Fish – The Fisheries of the Future.* Maribus gGmbH. Pg. 44/45. Accessed 24.04.2019 from: https://worldoceanreview.com/en/

[3] Adapted from: Fishwell Consulting (2013). *Fisheries Stock Assessment Modelling Video 07 - Catch Per Unit Effort.* YouTube. Accessed 03.08.2019 from: https://www.youtube.com/channel/UC90sh0piBbxe3iXwlPOZtig

Packets of Protein – Understand the significance of wild caught fish as the major source of protein globally T133

Name:

Date:



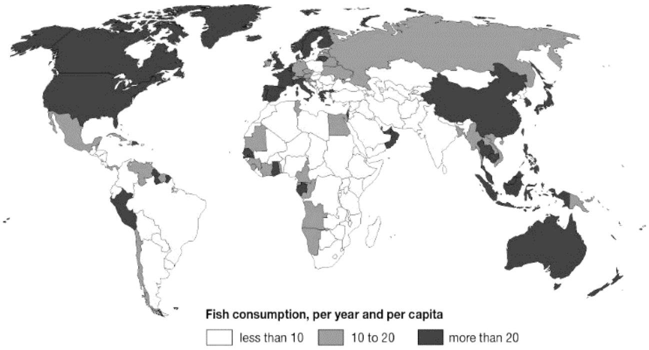


Figure 1: Consumption of proteins from fish in % of total consumption of animal proteins. Image © Cartographer: Philippe Rekacewicz, February 2006. Source: www.grida.no/resources/5620

Figure 2: Fish protein intake in kilograms per year (average 2001-2003). Image © Cartographer: Philippe Rekacewicz, February 2006. Source: www.grida.no/resources/5637

Q. In Figure 1, what % of total animal protein consumed in Australia was fish? Ans. <10%

Q. On average, how much fish (kg) did an Australian eat every year in Figure 2? Ans. >20 kg

Fish % of Animal Protein

While fish provide a significant percentage of animal protein globally, this percentage can be higher in communities by the sea. For example, fish comprise 76.1% of the animal protein intake of people in the island nation of the Maldives (Figure 3)*.

Q. What does fish contain that makes it so good for you? Ans.

Protein, omega-3, Vit. A, I, Fe, Ca, Zn, etc.

Q. What is a health benefit to eating fish? Ans.

Lowers risk of heart disease

Q. What is the daily recommended dietary intake of protein (not just fish) per day? Ans.

0.8 grams of protein per kg. of body weight (E.g. 100kg person = 80g protein)

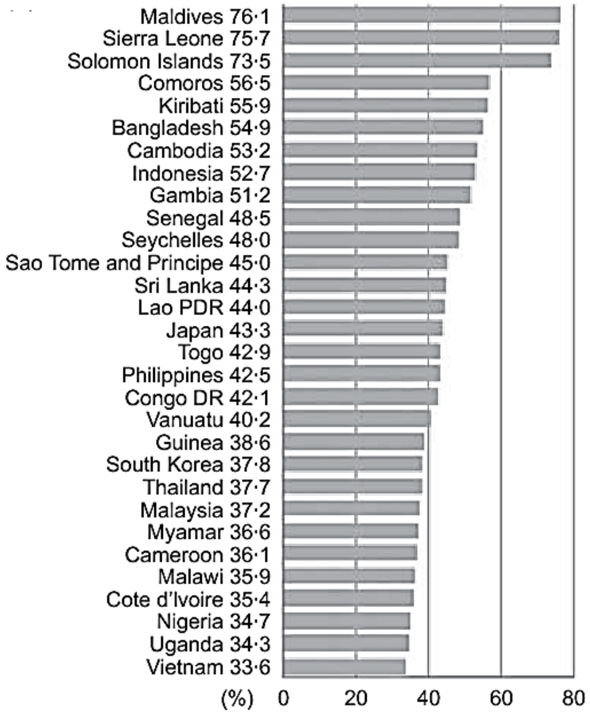


Figure 3: Fish protein as a percentage of animal protein consumption (%) in 30 countries with the highest proportion of fish in the animal-based part of their diet[1][2]. Calculated from FAO Food Balance Sheets.

* *Note:* The sources of fish supply in Figure 3 include wild-caught fisheries as well as aquaculture fisheries and land-locked freshwater fisheries.

[1] Adapted from: Allison, E. H. (2011). *Aquaculture, Fisheries, Poverty and Food Security*. The WorldFish Centre. Penang. Malaysia. Page 19.

[2] Adapted with permission from: Kawarazuka, N. and Bene, C. (2011). The potential role of small fish species in improving macronutrient deficiencies in developing countries: building evidence. *Public health Nutrition. 14(11): 1927-1938. DOI: 10.1017/S1368980011000814*

Gone OverFish'n – Understand that the world's fisheries are in decline T134

Name:

Date:

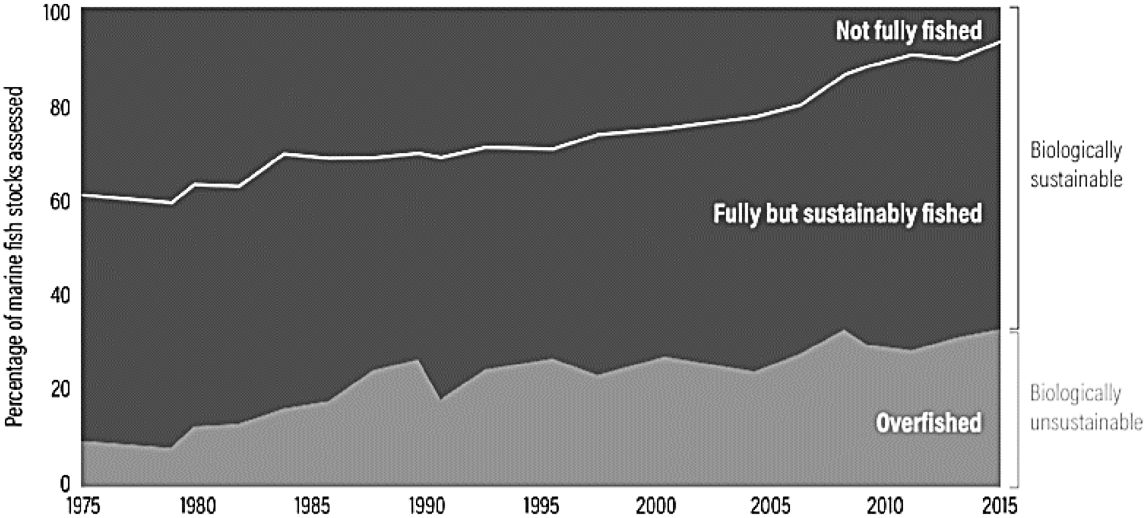


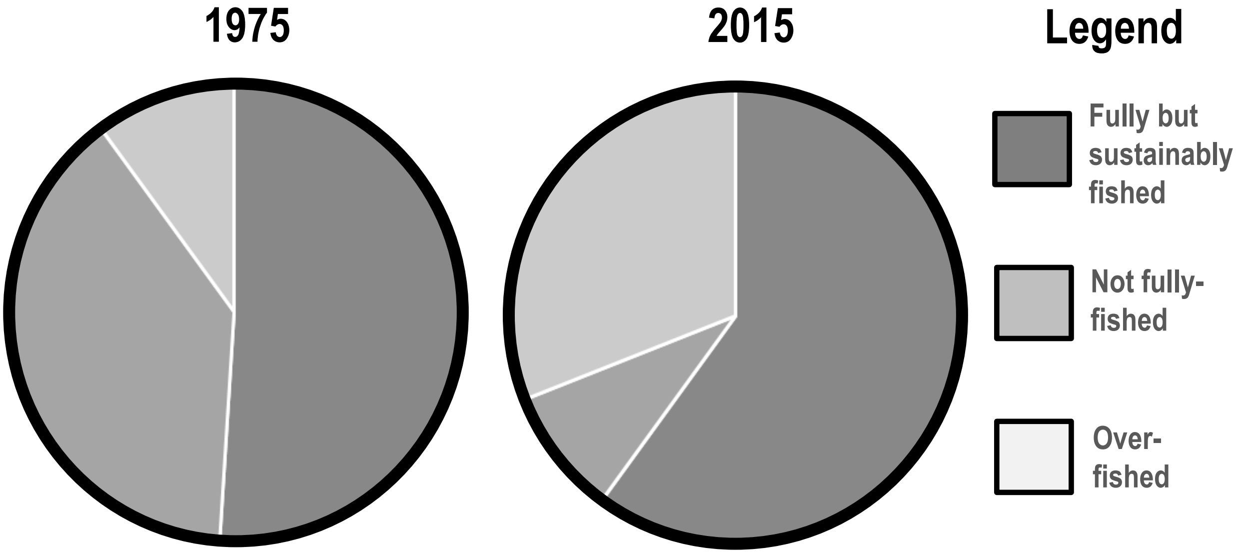
Figure 1: Global trends in the state of world marine fish stocks, 1974-2015. The percentage of overfished stocks (in grey) is increasing[1][2].

Q. What percentage of global fish stocks were 'overfished' in 1975? Ans. ~10%

Q. What percentage of global fish stocks were 'overfished' in 2015? Ans. ~30%

Activity: Draw a PIE CHART and LEGEND to illustrate Figure 1 data for 1975 (left) and 2015 (right)

Note: if you want to know how many degrees of the circle equals the percentage of a piece of the pie, simply divide 360 (the number of degrees in a circle) by 100 to get 3.6 (thus 3.6° equals 1% of the pie), and then multiply the percentage of a piece of the pie by 3.6 (e.g. if the percentage is 50%, 50 x 3.6 = 180°).



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[1] FAO. 2020. The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome. https://doi.org/10.4060/ca9229en Licence: CC BY-NC-SA 3.0 IGO.

[2] Searchinger, T., Waite, R., Hanson, C. and Ranganathan, J. (2018). World Resources Report: Creating a Sustainable Food Future. A Menu of Solutions to Feed Nearly 10 Billion People by 2050. World Resources Institute. Washington DC. USA. p.9 https://www.wri.org/our-work/project/world-resources-report/world-resources-report-creating-sustainable-food-future

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Fertilizing the Ocean – Explain how distribution of fish populations are determined by temperature, primary productivity and nutrient dispersal, and these are influenced by currents, upwelling and seasonal factors T135

Name:

Date:

Nutrients = Primary Productivity = FISH!

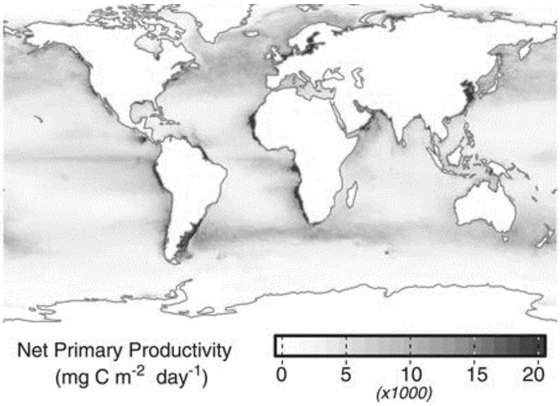

Figure 1: Global patterns of average annual NPP (expressed as milligrams of carbon uptake per square meter per day)[1]

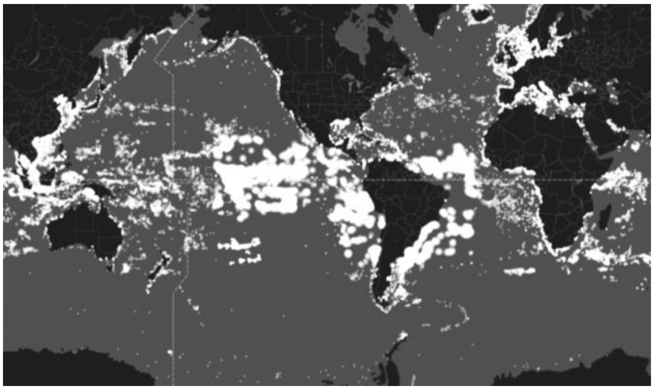

Figure 2: The location of 9,387,301 vessels tracked by Global Fishing Watch[2] on Thursday 9th May 2019.

Fishing Hotspots

Fishing hotspots are commonly found in areas with high chlorophyll-a concentrations (the green pigment in plants commonly used to indicate phytoplankton abundance) resulting from oceanographic processes such as upwellings, cyclonic gyres and eddies[3]. The sea surface temperature (SST) of hotspots is often **cold**, from the surfacing of deep-water masses (*from* below the pycnocline) that deliver nutrients to the surface[3].

Activity: Indicate the regions of upwelling that are well-known fishing hotspots, listed 1-11 below

Four major western boundary upwellings: (1) Canary (2) Benguela (3) California and (4) Peru currents. Equatorial upwelling regions: (5) Equatorial Pacific (6) Equatorial Atlantic. Others: (7) Somalia Coast (8) Yucatan Shelf (9) Cabo Frio, Brazil (10) Samalga, Alaska and (11) Costa Rica Dome.

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[1] From Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N.A., Boerder, K., Ferretti, F., Wilson, A., Bergman, B., White, T.D., Block, G.A., Woods, P., Sullivan, B., Costello, C. and Worm, B. (2018). Tracking the global footprint of fisheries. *Science. Vol.359. Issue 6378. P. 904-908. DOI: 10.1126/science.aao5646.* Reprinted with permission from AAAS.

[2] Global Fishing Watch (2016-2019). *Global Fishing Watch.* Accessed 09.05.2019 from: https://globalfishingwatch.org/map/

[3] Valavanis, V.D, Kapantagakis, A., & Katara, I. and Palialexis, A. (2004). Critical regions: A GIS-based model of marine productivity hotspots. *Aquatic Sciences 66(1): 139-148. DOI: 10.1007/s00027-003-0669-2.*

Rugosity Rocks – Assess rugosity data and link this to fish diversity T136

Name:

Date:

Activity: Measure and record the rugosity (C) and fish diversity (SDI) of Sites 1 & 2 below.

Hint: The formula for rugosity is C=a/b. Use a ruler to measure the length of b. Then, use a piece of string to follow the contours of the chain (a) to measure its length.

Site 1

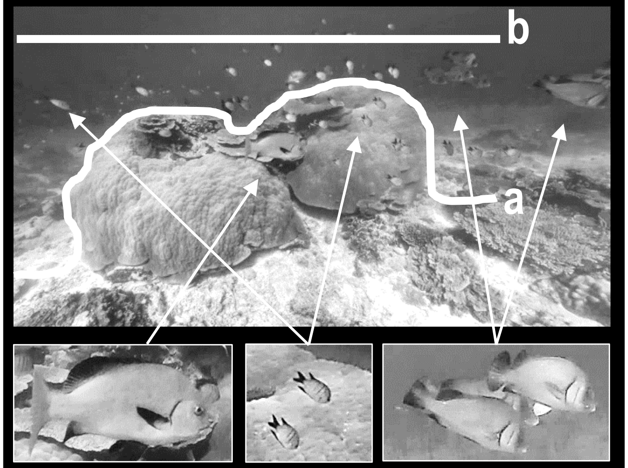


Figure 1: Image (of Lady Elliot Island) sourced from the XL Catlin Global Reef Record.
© Underwater Earth / XL Catlin Seaview Survey

Site 2

No fish!

Figure 2: Image (of Lady Elliot Island) sourced from the XL Catlin Global Reef Record.
© Underwater Earth / XL Catlin Seaview Survey

Site 1		
RUGOSITY (C):	C=10cm/7cm=1.43	
IDENTIFY	COUNT	STATS
Species Name	**n**	**n(n -1)**
Lutjanus rivulatus	1	0
Abudefduf sp.	30	870
Plectorhinchus gibbosus	10	90
Total	**N** 41	$\sum n(n-1)$ 960
Simpson's Diversity Index (SDI) = $1-\left[\frac{\sum n(n-1)}{N(N-1)}\right]$ N = total number of organisms of all species n = number of organisms of one species	N(N-1)= 1640	SDI = 0.41

Site 2		
RUGOSITY (C):	C=7.5cm/5.5cm=1.36	
IDENTIFY	COUNT	STATS
Species Name	**n**	**n(n -1)**
Total	**N**	$\sum n(n-1)$
What does it mean? 0: no diversity 1: infinite diversity **SDI =**	N(N-1)=	**SDI =** **0**

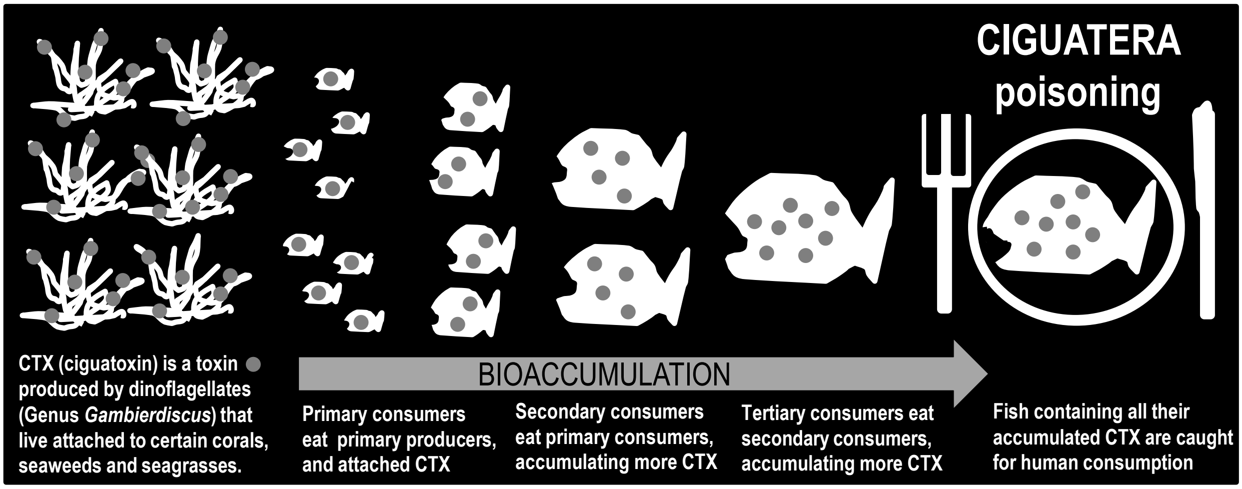
Activity: Explain how habitat complexity (rugosity), established by corals, effects fish diversity

Page 65: Healthy, thriving, busy, city-like coral reefs, with high rugosity, provide more organisms with more places to live, and more places to hide than unhealthy, struggling, desert-like coral rubble banks with low rugosity. Reefs that are structurally complex have more surface area for larval settlement, more refuge for prey species, more vertical relief and more microhabitat variability for more species to live in (i.e. fish)!

We are what we eat – Assess the impact of bioaccumulation through the food web into edible seafood T137

Name:

Date:



CTX (ciguatoxin) is a toxin ● produced by dinoflagellates (Genus *Gambierdiscus*) that live attached to certain corals, seaweeds and seagrasses.

Primary consumers eat primary producers, and attached CTX

Secondary consumers eat primary consumers, accumulating more CTX

Tertiary consumers eat secondary consumers, accumulating more CTX

Fish containing all their accumulated CTX are caught for human consumption

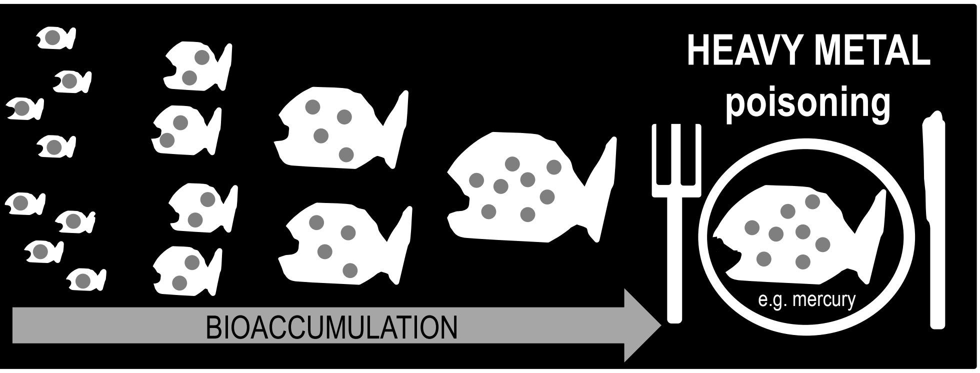
Q. What is the source of the toxin CTX? Ans. Dinoflagellate *Gambierdiscus sp.*

Q. What could happen to you if you ate an extra-large tropical fish? Ans.

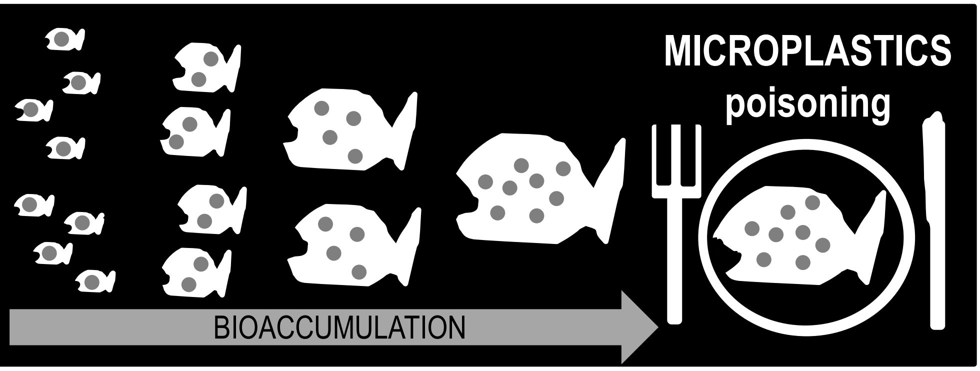
You could get ciguatera poisoning. Apart from the usual gastrointestinal symptoms that indicate food poisoning (vomiting, diarrhea, muscle pain) the nervous system starts doing strange things, such as the mouth, lips and extremities start to feel numb, you feel dizzy, and anything that is cold feels hot and vice versa. It takes months to get better and symptoms return whenever you eat seafood again.

Activity: Identify 2 SOURCES of HEAVY METALS and MICROPLASTICS in the spaces below left.

- Industrial waste (e.g. waste water from a factory or mine)
- Extended flooding



- Cosmetic industry
- Fishing industry
- Packaging
- Single-use plastics
- Plastic Bags



Fishy Futures – Explain how the alteration of thermal regimes caused by climate change is affecting the distribution of fish populations T138

Name:

Date:

Fish need to move

The alteration of thermal regimes caused by climate change is affecting the distribution of fish populations in a number of ways. On one hand, some warm water species have been able to extend their distribution into waters previously too cold[1]. On the other hand, not all species have been able to do so. For example, when temperatures get too warm and start to exceed the thermal thresholds of ectothermic animals, such as fishes, their metabolisms slow down. That slows down their reproduction and growth rates, movements and behaviors and consequently their fitness and survival[1]. They get sluggish. To make matters worse, there is less oxygen in warmer water. Which means even less energy to swim, forage, evade predators or relocate[1].

Q. What happens to fish when temperatures exceed their thermal threshold? Ans.

They get sluggish. Their metabolisms slow down. Which slows down their reproduction and growth rates, movements and behaviors and consequently their fitness and survival.

Fish need a home

Even *with* enough energy to relocate, fish still need to find a place in which to relocate to!

Mass Bleaching = Coral Loss = Habitat Loss = Fish Loss

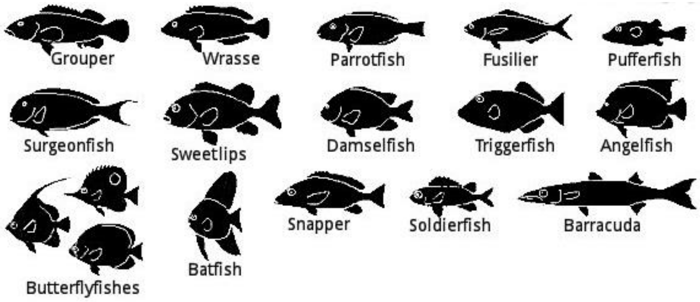


Figure 1: Common reef fish that rely on coral for habitat and food[2].

Q. What happens to coral-dependent fish when large areas of reef suffer consecutive mass bleaching events? Ans.

They lose their habitat.
Mass bleaching = coral loss = habitat loss = fish loss

Fish also need FOOD

Currents carry nutrients. More nutrients, more phytoplankton, more productivity, more food, more fish.
Currents (surface currents and deep-water currents) are expected to change with climate change[3][4].

Activity: Complete the sentence below

Less Nutrients = Less Phytoplankton = Less Food = Less Fish

---

[1] Scott, M., Heupel, M., Tobin, A. and Pratchett, M. (2017). A large predatory reef fish species moderates feeding and activity patterns in response to seasonal and latitudinal temperature variation. *Nature. Scientific Reports Volume 7, Article number: 12966. DOI: 10.1038/s41598-017-13277-4*

[2] Redang Island Rendezcous (1998-2003). *Marine Life: Identifying Fishes: How to identify fishes*. Redang Island. Accessed 27.04.2019 from: https://www.redang.org/fishid.htm

[3] Winder, M. and Sommer, U. (2012). Phytoplankton response to a changing climate. *Hydrobiologica 698(1):5 -16. DOI: 10.1007/s10750-012-1149-2*

[4] Brierley, A S. and Kingsford, M. J. (2009). Impacts of Climate Change on Marine Organisms and Ecosystems. *Current Biology, 19, R602-R614. DOI: 10.1016/j.cub.2009.05.046*

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Fish Management Highs and Lows – Compare a case study of a fish population in decline with a case study of a fish population that is in recovery in relation to fisheries management practices T139

Name:

Date:

> ***"Fisheries management is about managing people, not fish stocks"***
>
> Dr. Michael King[1]

Q. What is the meaning of this quote? Ans.

Fisheries management is just as much a social science, as it is a biological one. Measures put in place to manage a fishery are about managing people, not fish.

> ***"I believe that the cod fishery, the herring fishery, pilchard fishery, the mackerel fishery, and probably all the great sea fisheries are inexhaustible: that is to say that nothing we do seriously affects the numbers of fish. And any attempt to regulate these fisheries seems consequently, from the nature of the case, to be useless".***
>
> Thomas. H. Huxley, Inaugural Address. Fisheries Exhibition, London (1883)[1][2]

The words of Thomas M. Huxley in 1883 may seem naïve to us today. However back then, fishing boats still used sails, there were no large international fishing fleets, and the world population was less than one third of what it is today[1].

Activity: Research the decline of Atlantic Cod (*Gadus morhua*)

Activity: In the space provided below, LIST the factors that contributed to its decline

Overfishing

- Improvements to equipment and technology (sounders, navigation gear, etc.) made it easier to find and catch the fish.
- The arrival of large factory trawlers in the late 50's meant they were able to harvest cod offshore in winter months and fish new areas.
- Large catch amounts by factory trawlers caused an *overestimation* of stock.
- Increased bycatch amounts included prey species of the cod – capelin

Activity: Research the recovery of Coral Trout (*Plectropomus leopardus)*

Note: Coral Trout is a primary target species of the *Coral Reef Fin Fish Fishery* (CRFFF) on the Great Barrier Reef.

Activity: In the space provided below, LIST the factors that contributed to its recovery[3]

Reduced Fishing

- The fishery was restructured in 2004, introducing a (reduced) TACC (total allowable commercial catch) limit of 1288 tonnes managed through Individual Transferable Quotas (ITQ), as well as spawning closures.
- Stakeholder involvement in decision-making.
- The Great Barrier Reef Marine Park was rezoned in 2004, closing more areas to fishing.

---

[1] Reproduced with permission from: King, M. (2007). Fisheri*es Biology, Assessment and Management.* Blackwell Publishing. Victoria Australia. Preface Page xii.

[2] Thomas H. Huxley, Inaugural Address for the Fisheries Exhibition, London (June 18,1883), available at https://mathcs.clarku.edu/huxley/SM5/fish.html

[3] Leigh, G.M., Campbell, A.B., Lunow, C.P. and O'Neill, M.F. (2014). *Stock assessment of the Queensland east coast common coral trout (Plectropomus leopardus) fishery.* The State of Queensland. Accessed 29.04.2019 from: http://era.daf.qld.gov.au/id/eprint/4547/1/CoralTroutStockAssessment2014.pdf

Capture and Recapture – Interpret fish population data using the Lincoln index (capture–recapture method) and identify the reliability of this data to inform fisheries management decision-making on quota and total allowable catch

T140

Name:

Date:

Total Allowable Catch (TAC): The total allowable fish catch or fishing effort allowed in a fishery for a particular species or stock over a fishing season[1].
Quotas: The allocation of a share of the fish catch or fishing effort allowed in a fishery[1].

Note: In fisheries biology, sometimes the word 'stock' is used instead of 'population'. A **population** is a group of individuals belonging to the same species in the same place at the same time[2]. A **stock** is a distinct, reproductively isolated population which exists within a defined spatial range[2].

Estimating Stock Size using the Lincoln Index (capture-recapture)

One way to estimate stock size in a given area is to catch a bunch of fish, tag them, let them go again (hope they don't die), wait for them to swim about and mix in with the other fish, before catching some more (using the same unit of effort as before) and counting how many are tagged.
Then apply a simple formula (**N=Mn/m**) to estimate the size of the stock.
The assumption is that the ratio of tagged fish (M) in the stock (N) is equal to the ratio of recaptured tagged fish (m) in the second catch (n). Whereby, M/N=m/n is rearranged to become **N=Mn/m**.

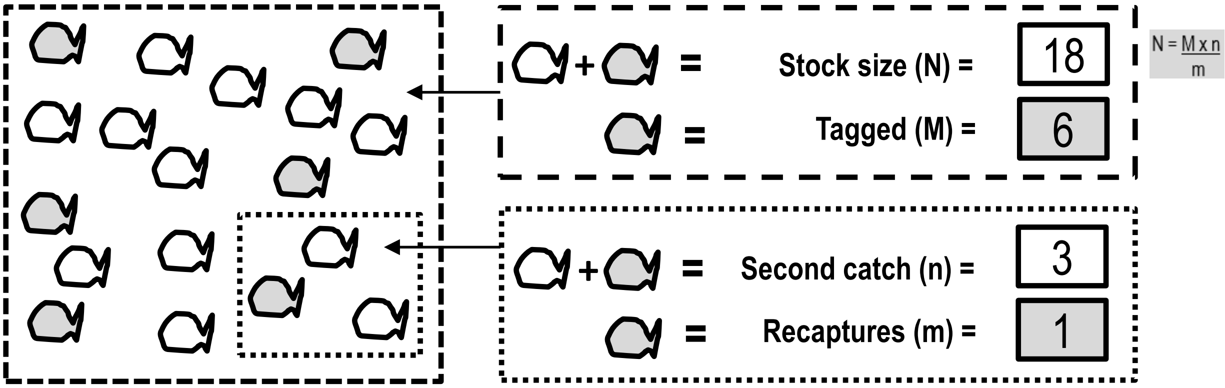

Figure 1: The large rectangle on the left represents a unit stock of fish with a total of six tagged fish (shaded). The small box inside the large rectangle represents the second catch of three fish, whereby one has a tag[2].

Activity: Model the capture-recapture method by following the steps below

Step 1: Take a small unknown quantity of A4 paper (not too much – we want to save trees!).
Step 2: Cut them into small squares of equal size. Put them in a box and close the lid. Shake the box.
Step 3: Ask a student to put their hand in the box and pull out a square one by one. Stop after 20 seconds.
Step 4: Ask the student to mark every piece of paper they pulled out of the box (i.e. the 'tagging' process).
Step 5: Count the number of marked pieces of paper. This is the value for 'M'.
Step 6: Return all marked pieces of paper back into the box. Shake the box.
Step 7: Repeat Step 3 (*note:* student *is not* allowed to peak in the box to see which square to pick)
Step 8: Count the number of pieces of paper the student pulled out of the box. This is the value for 'n'.
Step 9: Count the number of MARKED pieces of paper the student pulled out of the box. This is the value for 'm'.
Step 10: Apply the formula: Population size **(N) = M x n / n** to estimate population size (number of squares)
Step 11: Count the total number of squares in the box. How close was your population size estimate?!

M	
n	
m	
N $= \frac{M \times n}{m}$	

Q. How reliable was this method for estimating population size (&, later, safe catch limits)? Ans.

answers may vary
Note: assumptions that are made when using this method are that no individuals die between tagging events, and that tagged individuals are no easier nor harder to catch (each has an equal chance of being recaptured).

---

[1] Australian Fisheries Management Authority (2018). *What is Fishing Quota?* AFMA. Accessed 29.04.2019 from: https://www.afma.gov.au/what-fishing-quota
[2] Adapted with permission from: King, M., Blanc, M., Desurmont, A., Sharp, M. and Barre, C. (2014). *Guide to Teachers' Resource Sheets on Fisheries for the Cook Islands.* Secretariat of the Pacific Community (SPC) Coastal Fisheries Programme. New Caledonia. Accessed 29.07.2019 from: https://coastfish.spc.int/en/publications/technical-manuals/education/421-teachers-resource-kit-on-fisheries

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Fishing for Data – Identify the factors (e.g. sampling techniques, fish behaviour, temporal and spatial movement, life history) that determine the reliability of fisheries population data and consider the limitations of these factors T141

Name:

Date:

Sampling techniques: see below under 'Data Collection'.
Fish behaviours: schooling, spawning aggregations, diel vertical migrations, learned trap avoidance, feeding behaviours, etc.
Temporal and spatial movement: Movement over time (temporal) and space (spatial).
Life history: r-strategists (short-lived, boom and bust life history) or K-strategists (long-lived, slow-to-grow and slow-to reproduce life history) including information about rates of growth, natural mortality, sexual maturity, reproduction, and fecundity (number of offspring per adult fish).

Single-species stock assessment

It is important to know how many fish there are, to know how many fish to catch. Data is collected from fishers, scientists and market places etc., to measure a population in a stock assessment. Whereby, the maximum number of fish that can be caught (e.g. MSY) is calculated. Then, management controls are enforced to contain fishing (input controls), protect the environment, and restrict the catch (output controls).

Data Collection

Data from the Fishers

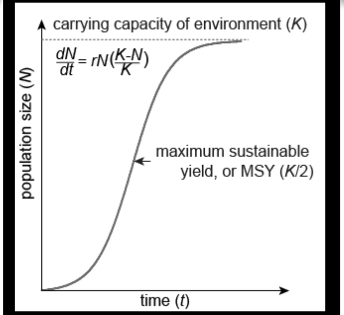
- Log books (including catch and effort details)
- Vessel tracking systems (usually mandatory)
- Catch disposal records
- e-monitoring (e.g. mandatory cameras on board)
- Telephone Survey data (recreational fishing)
- Portside sampling data (e.g. creel surveys)

Data from the Scientists

- On-board sampling (e.g. capture-recapture method, underwater visual census, acoustic method, egg production methods, depletion method, etc.).
- Portside sampling (e.g. otoliths, fish frames)

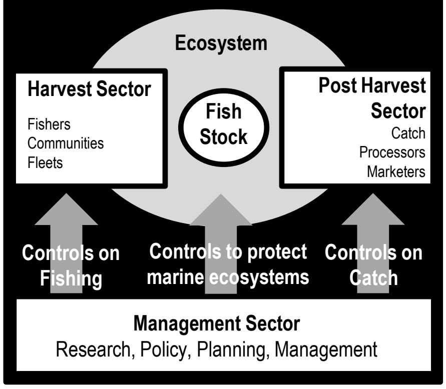
Data from the market place

Stock Assessment



Maximum sustainable yield (MSY)
The maximum number of fish that can be caught without long-term depletion (supposedly).

Management[1]



Activity: The table below features factors that determine the reliability of fisheries population data. Complete the table using the Southern Bluefin Tuna (*Thannus maccoyii*) Fishery as a case study to (i) provide examples for each factor (*hint:* see top of page) **and (ii) identify the limitations of each example.**

Factors	Examples (using the SBT Fishery as a case study)	Limitations (of each example)
Sampling Techniques	Creel survey – asking recreational anglers questions about their fishing trip and catch (*note:* the name comes from the creel or woven wooden basket that anglers used to hold fish).	Anglers may not have been targeting SBT. Costly and time consuming. Inconsistencies in reporting from a non-scientific survey method. Small sample size reduces the reliability of the predicted population.
Fish Behaviours and Temporal and Spatial movements	High-level apex predator. Opportunistic feeder. Migratory species (travels long distances). Gather at spawning grounds. Post spawning, females move south. Swims in both shallow and deep water.	Difficult to count over large areas, across more than one jurisdiction, and when spatial variability (both laterally and vertically) is so high. Risk overestimating population size when they are altogether to spawn. Localised collection of data - problematic.
Life History	Warm blooded. K-strategist. Sexually mature ~11-12 yrs. Live for 40+ yrs. Females release ~50million eggs/spawning event.	Difficult to count how many of the ~50 million eggs survive to become reproducing adults 11-12 years later. Age of the dataset is too small.

---

[1] Adapted with permission by John Wiley and Sons from: King, M. (2007). Fisheri*es Biology, Assessment and Management.* Blackwell Publishing. Victoria, Australia. Page 297.

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Marine Education

Fish with No Borders – Recognise an international agreement that is used to manage migratory pelagic species T142

Name:

Date:

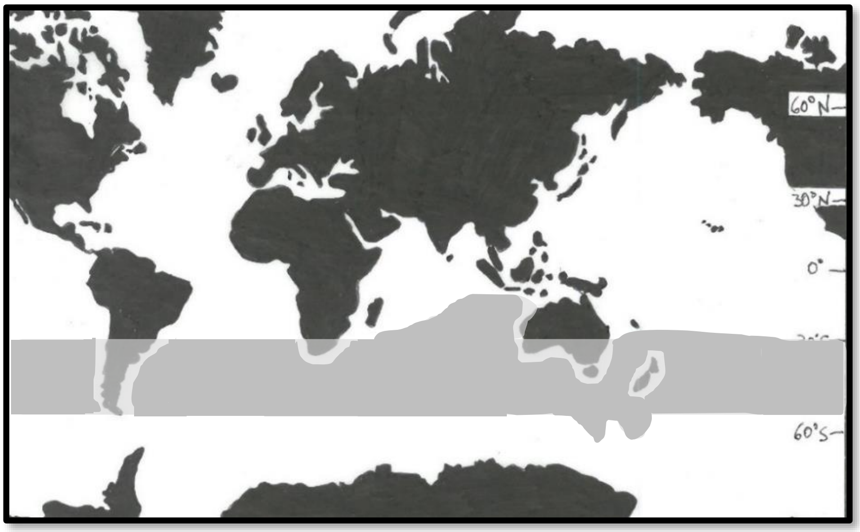
The High Seas

Almost two thirds of the ocean is High Seas[1]. There are no official laws in the high seas (yet). Only agreements between countries. Agreements that are more-or-less hand-shake deals, formalised by the signing of a convention, that usually prompt the creation of a commission or organization (e.g. Regional Fisheries Management Organizations) that set catch limits for species swimming between jurisdictions.

Q. How are the high seas managed? Ans.

Through regional fisheries management organizations (RFMOs) that are born from international agreements (formalised by the signing of a convention).

Activity: Shade the distribution of *Thannus maccoyii.* Darken any areas in the '*High Seas*'.



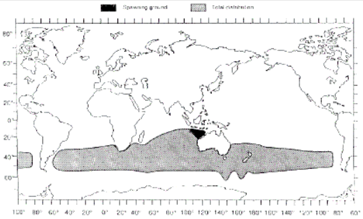


Figure 1: Spawning ground (black) and total distribution (grey) of Southern Bluefin Tuna[2]

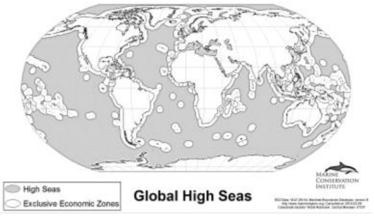


Figure 2: High Seas (dark) and EEZs (light). MPAtlas.org. [Current 07/2019][3].

Q. What is the conservation status of *Thannus maccoyii*? Ans. Critically endangered

Convention for the Conservation of Southern Bluefin Tuna (CCSBT)

In the 1980s, Japan, Australia and New Zealand began applying quotas to Southern Bluefin Tuna Fisheries in efforts to conserve stocks for the future. The voluntary arrangements were later formalised with the signing of the Convention for the Conservation of Southern Bluefin Tuna (CCSBT) which came into force in May 1994. Additional countries have since signed the convention[4].

Activity: What was the purpose of creating a convention for the conservation of *T. maccoyii*?

To reduce fishing pressure on Southern Bluefin Tuna and conserve stocks for the future.

---

[1] IUCN (2008). *10 Principles for High Sea Governance.* IUCN. Accessed 16.06.2019 from: https://www.iucn.org/downloads/10_principles_for_high_seas_governance___final.pdf

[2] Caton, A. E. (1994). *Review of aspects of southern bluefin tuna biology, population, and fisheries.* FAO. Accessed 04.05.2019 from: http://www.fao.org/3/t1817e/T1817E15.htm

[3] Adapted from: MPAtlas (2019). *High Seas.* Atlas of Marine Protection. Marine Conservation Institute. Accessed 04.05.2019 from: http://www.mpatlas.org/data/map-gallery/

[4] CCSBT (2019). *Origins of the Convention*. Commission for the Conservation of Southern Bluefin Tuna. Accessed 05.05.2019 from: https://www.ccsbt.org/en/content/home

What's the Catch? – Appraise the use of maximum sustainable yields and maximum economic yields T143

Name:

Date:

Maximum Sustainable Yield (MSY)

MSY is the largest average catch (or yield) that can be continuously taken from a stock under existing environmental conditions[1]. MSY was originally set at *half* the carrying capacity by Milner Schaefer in 1954[1].

Note: Initially, a population starts out small (e.g. after a major disturbance or when new habitat becomes available). The growth rate of the population (G) is also small because only a small number of individuals can reproduce. But, as time goes by, more offspring are born. And, if the environment can sustain ('carry') all the newborns, which later grow into reproducing adults, the growth rate of the population (G) will keep increasing at a rate of **G=rN** (Figure 1). The maximum growth rate of a population occurs at half the carrying capacity (see 'MSY' in Figures 1 and 2). *After* that point, the growth rate slows down. It eventually *stops* when the number of individuals added to the population *equals* the number of individuals removed from the population. They are removed (i.e. die) because the population has reached the maximum number of individuals that the environment can carry, called its carrying capacity (K). Which is also the max. size a population can grow to. Environmental factors that restrict population growth are called limiting factors, denoted as **(K-N)/K.**

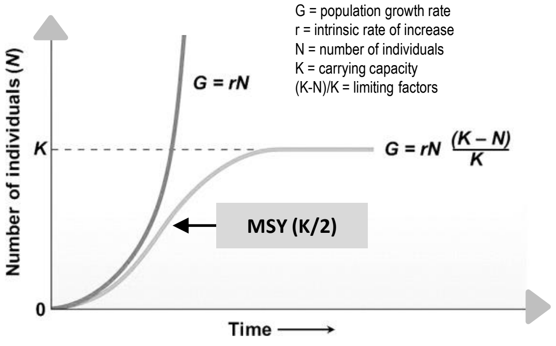
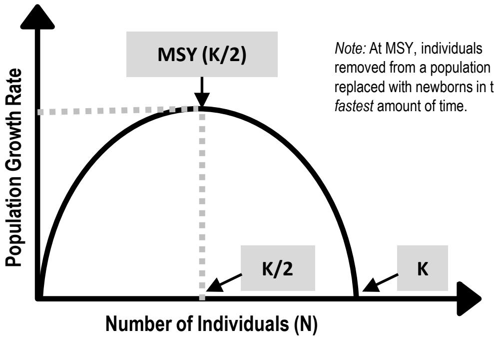


Figure 1: The exponential growth model (G=rN), the logistic growth model (G=rN(K-N)/K, and the location of MSY (K/2). *Note*: If the environmental conditions deteriorate, the carrying capacity (K) can drop[1].



Note: At MSY, individuals removed from a population are replaced with newborns in the *fastest* amount of time.

Figure 2: At K/2, the population growth rate (the rate that removed stocks are replaced) is at its maximum. Hence, the maximum sustainable yield (MSY) was set at K/2[2][3].

Q. Why was Maximum Sustainable Yield (MSY) set at half the carrying capacity (K/2)? Ans.

At K/2, the population growth rate is at its maximum.

Maximum Economic Yield (MEY)

- MEY is the amount of catch (or yield) that gives a fishery maximum economic return (assuming the cost of fishing is directly proportional to fishing effort).
- A fishery (as a whole) makes money (economic rent) when the revenue (the $ made on fish sold at market) is more than the cost of fishing (i.e. fuel, labour, etc.).
- A fishery makes its *most* money at MEY, when revenue and cost are the greatest distance apart (longest dotted line in Figure 3).
- Notably, MEY requires less fishing effort than MSY.

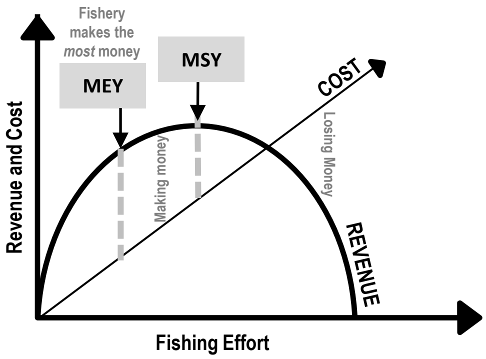


Figure 3: The curve is revenue (price of fish x number of fish). A fishery performs best at MEY (the longest dotted line)[3][4]. *Note:* the x-axis has been flipped with K at coordinate (0,0)

Q. Which requires less fishing effort AND costs less?….MEY or MSY? Ans. MEY

---

[1] Adapted from: Campbell, N. A., Reece, J.B., Taylor, M.R. and Simon, E.J. (2008). *Biology: Concepts and Connections: Fifth Edition.* Pearson Education Inc. San Francisco, CA 94111. Page 730.

[2] Tsikliras, A. C. and Froese, R. (2018). *Maximum sustainable yield.* In book: Reference Module in Earth Systems and Environmental Sciences. DOI:10.1016/B978-0-12-409548-9.10601-3

[3] Adapted from: World Bank (2017). *The Sunken Billions Revisited: Progress and Challenges in Global Marine Fisheries*. Washington, DC: World Bank. Environment and Sustainable Development series. DOI:10.1596/978-1-4648-0919-4. License: Creative Commons Attribution CC BY 3.0 IGO.

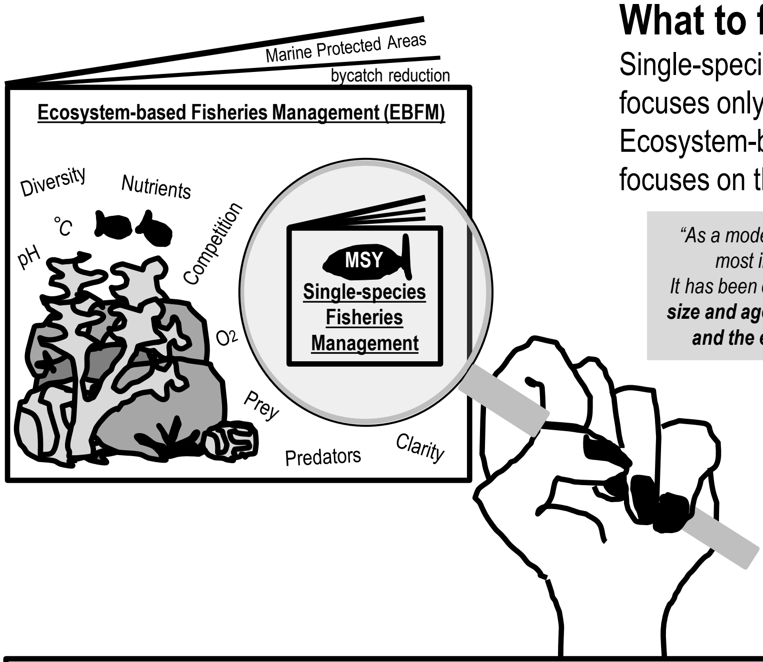
[4] Allison, E. H. (2011). *Aquaculture, Fisheries, Poverty and Food Security.* The WorldFish Centre. Penang. Malaysia. Page 27.

The Bigger Picture – Recognise that fisheries management has shifted from single species maximum sustainable yield towards ecosystem-based fisheries management

T144

Name:

Date:



What to focus on?

Single-species fisheries management (SSFM) focuses only on the target species (magnifying glass). Ecosystem-based fisheries management (EBFM) focuses on the ecosystem that supports the fishery.

> *"As a model, maximum sustainable yield (MSY) has been one of the most influential concepts to inform fish stock management. It has been criticized as a fisheries management tool as **it ignores the size and age of the animal being harvested, its reproductive status and the effects of fishing on the ecosystem more broadly**"*[1].

> *"The aim (of EBFM) is to sustain healthy marine ecosystems and the fisheries they support by addressing some of the **unintended consequences of fishing**, such as **habitat destruction**, incidental mortality of non-target species (i.e. **bycatch**) and changes in the structure and function of ecosystems. An ecosystem approach to fisheries requires that fisheries should be managed to limit their impact on the ecosystem to the extent possible"*[2].

Q. What is the difference between single-species fisheries management (SSFM) and EBFM? Ans.

Single-species fisheries management focuses only on the target species. EBFM focuses on the ecosystem that supports the fishery.

Q. What do MSY models in single-species fisheries management (SSFM) ignore? Ans. (*hint*: see bold)

The size and age of the animal being harvested, its reproductive status and the effects of fishing on the ecosystem more broadly[1].

Q. What are the unintended consequences of fishing that MSY models fail to address? Ans.

Habitat destruction and bycatch. As well as any serious deterioration in trophic levels and ecosystem structure by removing top predators with unpredicted consequences at bottom trophic levels[2].

EBFM tools in action

EBFM tools are often context-specific, matching local goals for management[3].
Two common EBFM tools include **Marine Protected Areas** and **bycatch reduction.**

Activity: Name 2 EBFM tools: Marine Protected Areas and bycatch reduction

---

[1] QCAA (2018). Marine Science 2019 v1.2: General Senior Syllubus. QCAA. Accessed 13.04.2019 from: https://www.qcaa.qld.edu.au/senior/senior-subjects/sciences/marine-science/syllabus

[2] Zhou, S., Smith, A.D.M., Punt, A., Richardson, A.J., Gibbs, M., Fulton, E.A., Pascoe, S., Bulman, C., Bayliss, P. and Sainsbury, K. (2010). Ecosystem-based fisheries management requires a change to the selective fishing philosophy. *PNAS 107(21):9485-9 DOI: 10.1073/pnas.0912771107*

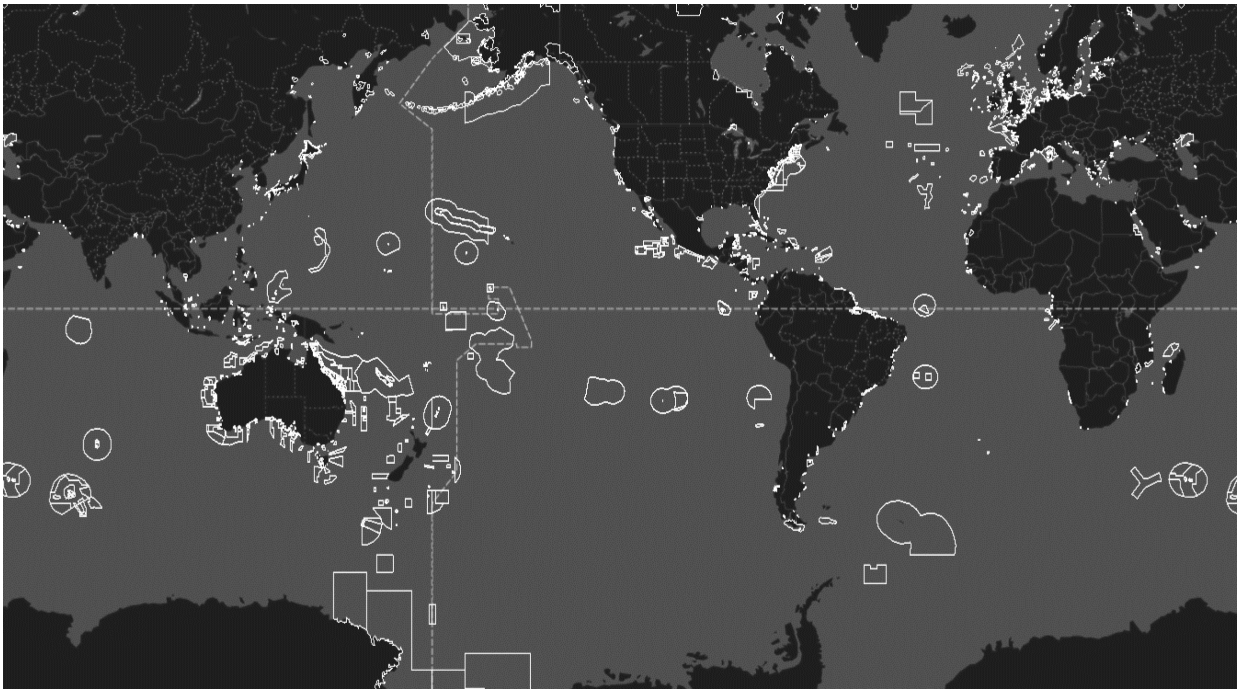
[3] Trochta, J.T., Pons, M., Rudd, M.B., Krigbaum, M., Tanz, A. and Hilborn, R. (2018). Ecosystem-based fisheries management: Perception on definitions, implementations, and aspirations. *PLoS ONE 13(1):e0190468. DOI: 10.1371/journal.pone.0190467*

MPAs – Understand the value of marine protected areas including estuarine and open-water environments to fisheries sustainability T145

Name:

Date:

These are all the marine protected areas (MPAs) around the world in July 2021[1].

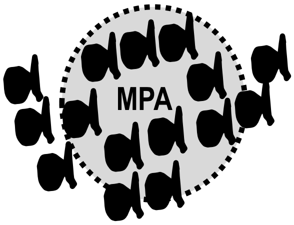


This is a picture of 19.015 MPAs, covering 7.65% of the ocean, protecting a total area of 27,730,122km^2. This is a ten-fold increase from the year 2000 when MPAs only covered ~2,000,000km^2. National waters comprise 39% (protects 17.9%). The high seas comprise 61% (but only protect 1.18% of the high seas)[2].

Q. How many MPAs exist today? [2] Ans.

MPA formula for more fish!

“Spill-over” effects



- ✓ Protect specific life stage (e.g. nursery ground, spawning season)
- ✓ Protect critical functions (e.g. feeding grounds and spawning grounds)
- ✓ Protect dispersion centers for the supply of larvae to a fishery
- ✓ Protect critical environmental requirements for fished species
- ✓ Protect ecosystem services (provisional, cultural, supporting, regulating)

Q. How are MPAs of value to fisheries sustainability? Ans.

Any of the above

---

[1] Global Fishing Watch (2016-2019). *Global Fishing Watch.* Accessed 01.07.2021 from: https://globalfishingwatch.org/map/

[2] Protected Planet (2014-2021). Explore the World’s Marine Protected Areas. UNEP-WCMC. Accessed 01/07/2021 from: https://www.protectedplanet.net/marine

Mandatory Practical – Apply the Lincoln Index in a modelled capture-recapture scenario T146

Name:

Date:

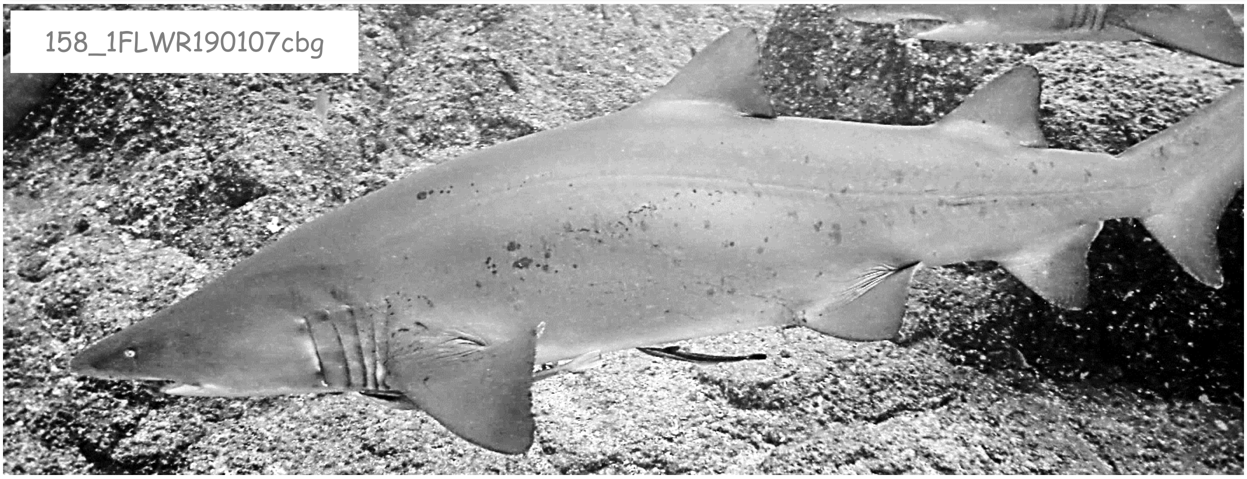
BEFORE GOING ANY FURTHER, REVISE CONCEPTS INTRODUCED ON PAGE 134 TITLED, 'CAPTURE AND RECAPTURE'

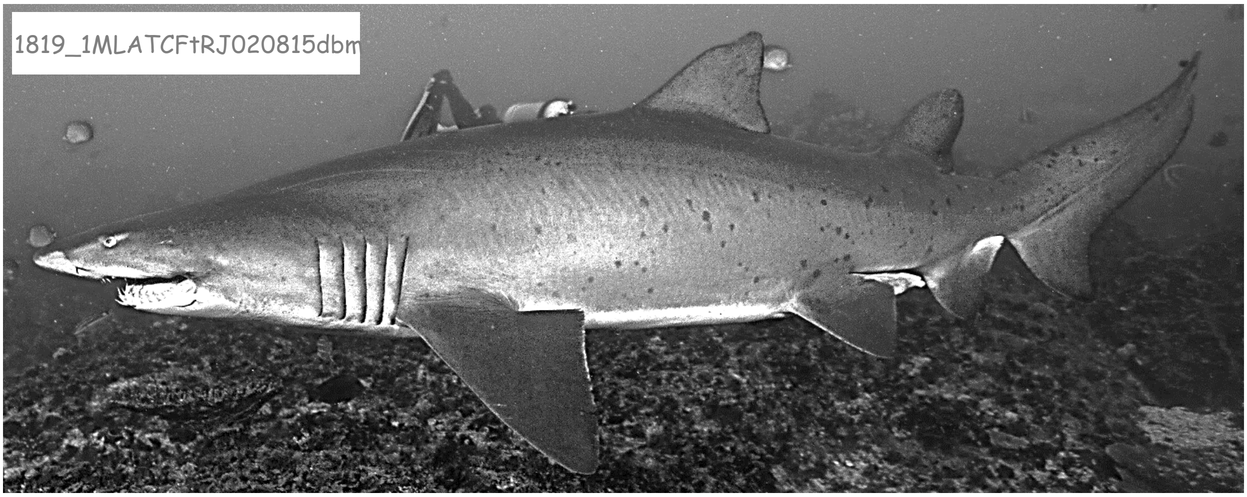
Natural Tags on Grey Nurse Sharks (*Carcharias taurus*)

Below are pictures that were kindly donated by Grey Nurse Shark Watch (GNSW), a community Grey Nurse Shark photographic identification program[1]. The Australian east coast sub-population of Grey Nurse Shark were hunted almost to extinction in the 1950's. They are now **critically endangered.**
The Grey Nurse Shark Watch program tags each shark by giving it a name. Each shark is recognizable from the unique arrangement of spots on the side of its body that act as a 'natural tag'. Once a shark has been photographed, it is named or matched to a previous photograph. *Note:* the sharks often swim in a circuit-like configuration, allowing divers to sit in one spot and wait for the sharks to predictably swim past (usually very close) and have their picture taken. The sharks only 'look' dangerous because they can not cover their teeth (another common name is 'ragged-tooth shark'). They are not dangerous at all.

Activity: 'Tag' each shark by giving it a name (write the name in the empty box provided).

***Note:* for a closer look, you can view all original colour photos at marineeducation.com.au**





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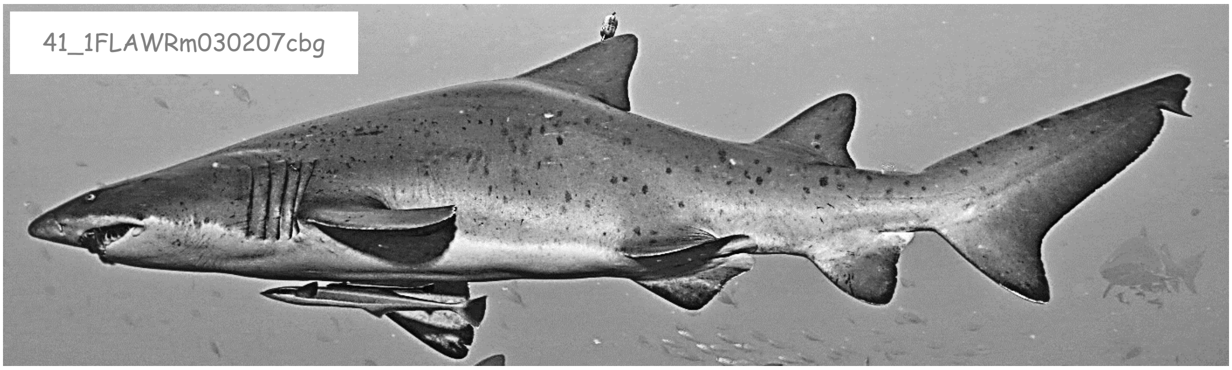
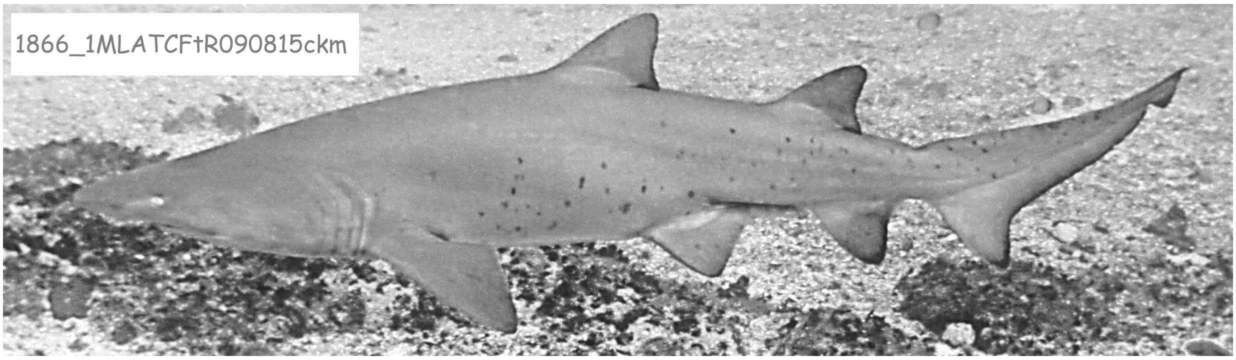
[1] Photographs © Dr. Carley Kilpatrick from Grey Nurse Shark Watch - Reef Check Australia at https://www.reefcheckaustralia.org/grey_nurse_shark_watch

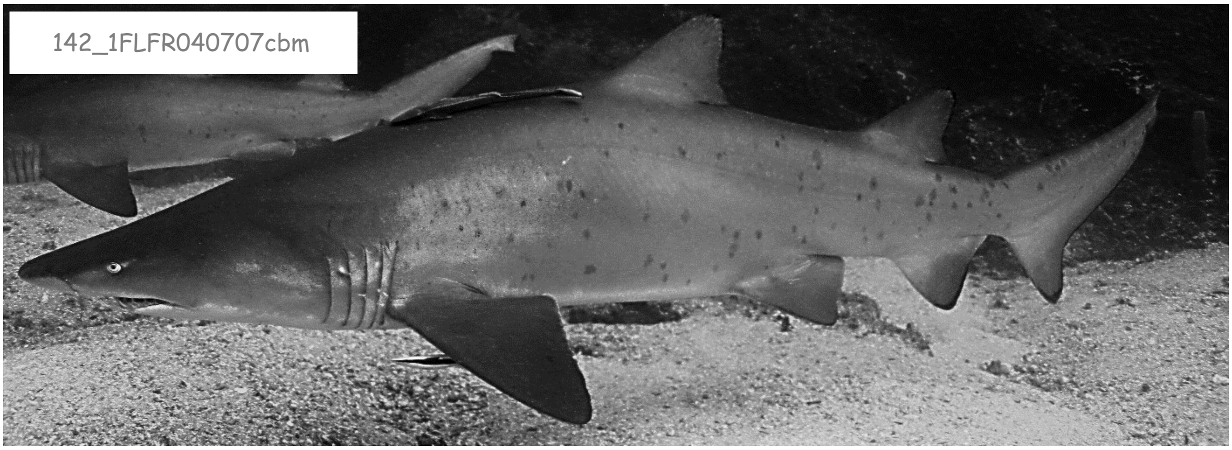
First Catch (tagging)

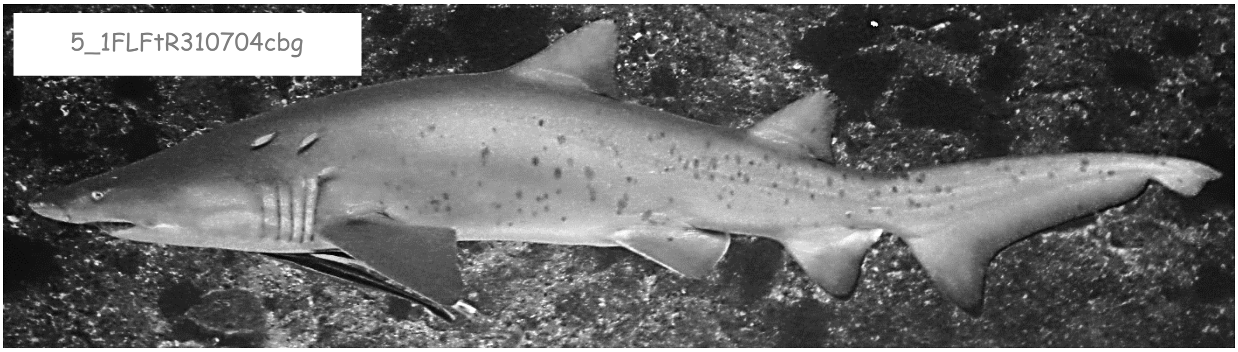
Name:

Date:







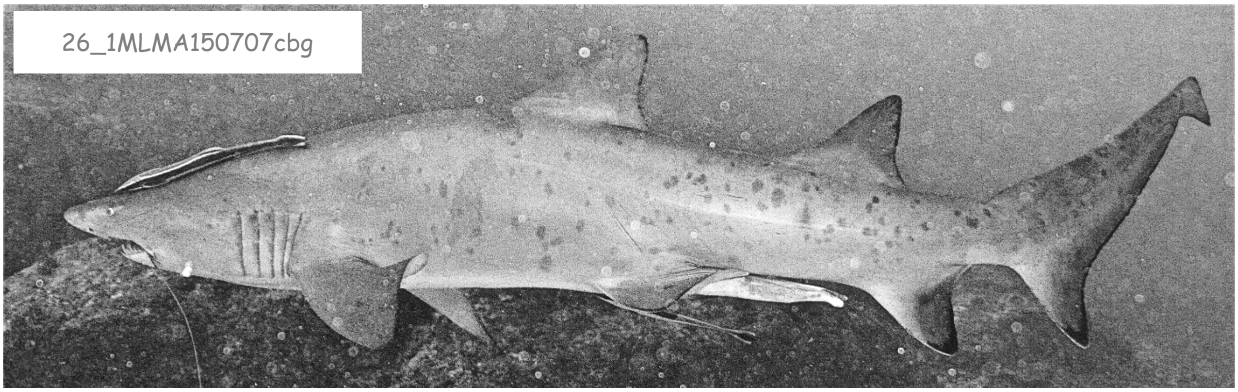


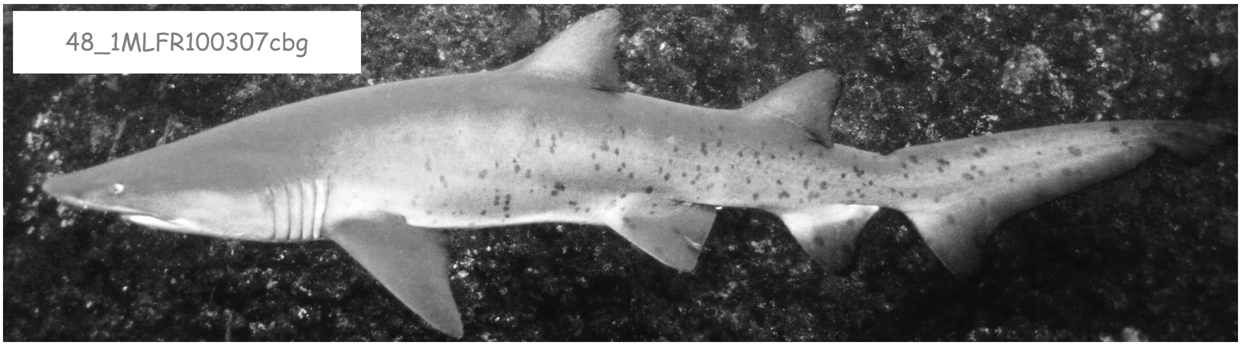
[1] Photographs © Dr. Carley Kilpatrick from Grey Nurse Shark Watch - Reef Check Australia at https://www.reefcheckaustralia.org/grey_nurse_shark_watch

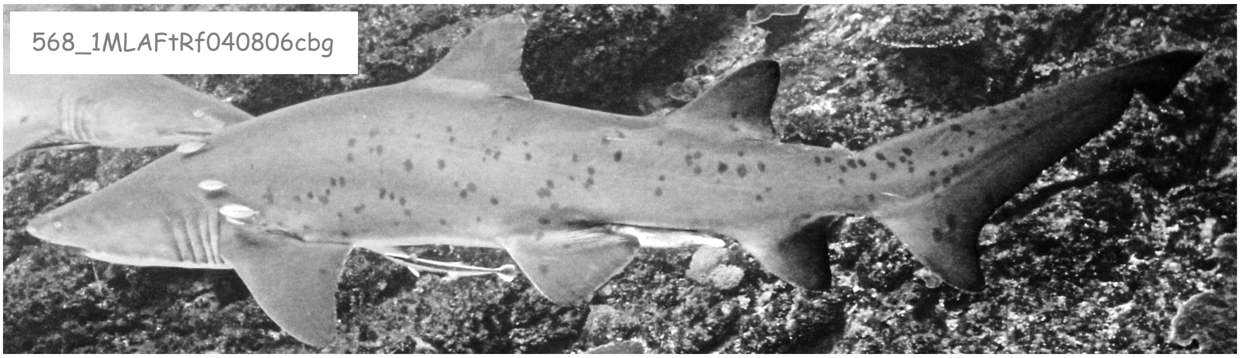
First Catch (tagging)

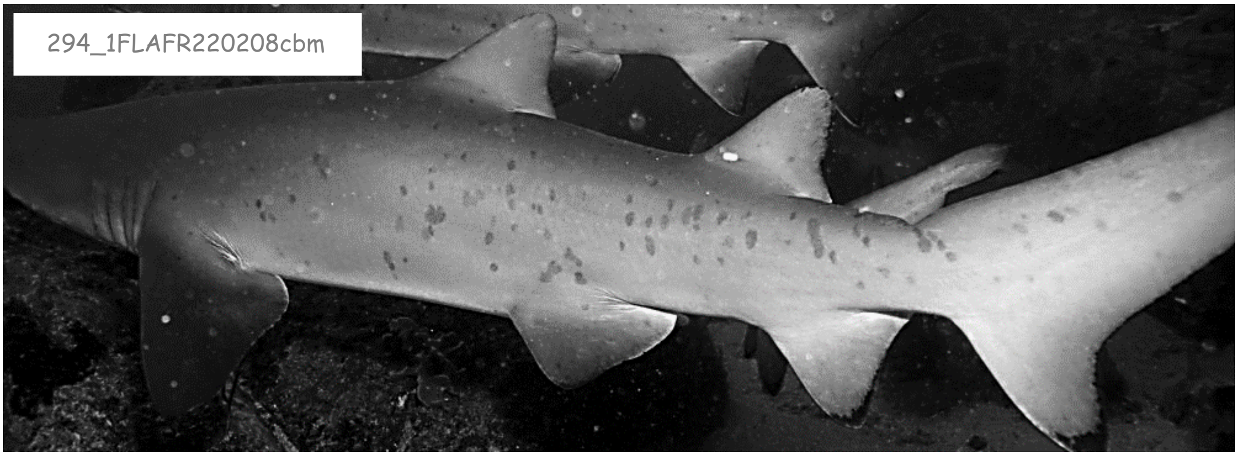
Name:

Date:









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[1] Photographs © Dr. Carley Kilpatrick from Grey Nurse Shark Watch - Reef Check Australia at https://www.reefcheckaustralia.org/grey_nurse_shark_watch

Second Catch (recapture)

Name:

Date:

Activity: This ‘second catch’ also includes 10 sharks. Identify the sharks that you already named (tagged) in the first catch. If it is a new shark, give it a new name in the box provided.

***Note:* for a closer look, you can view all original colour photos at marineeducation.com.au**

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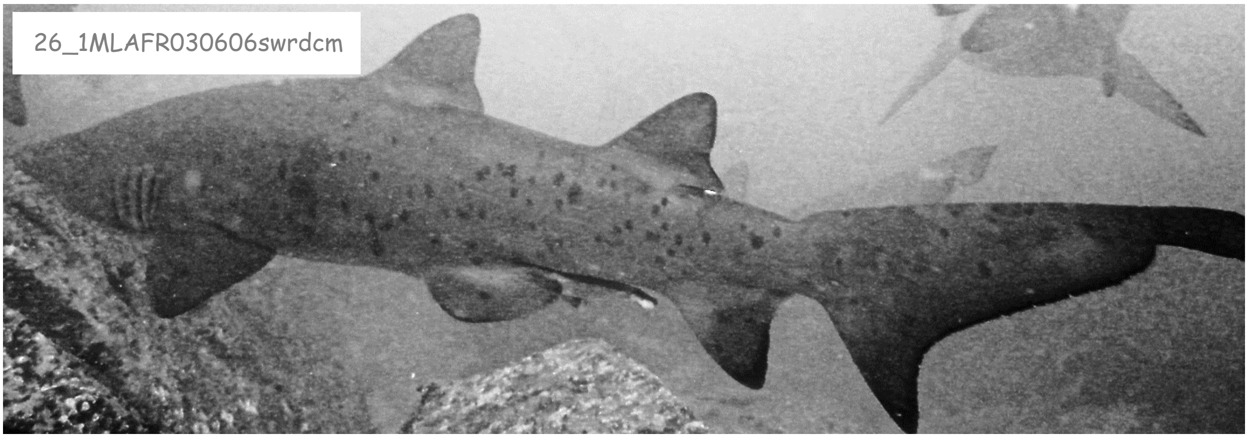
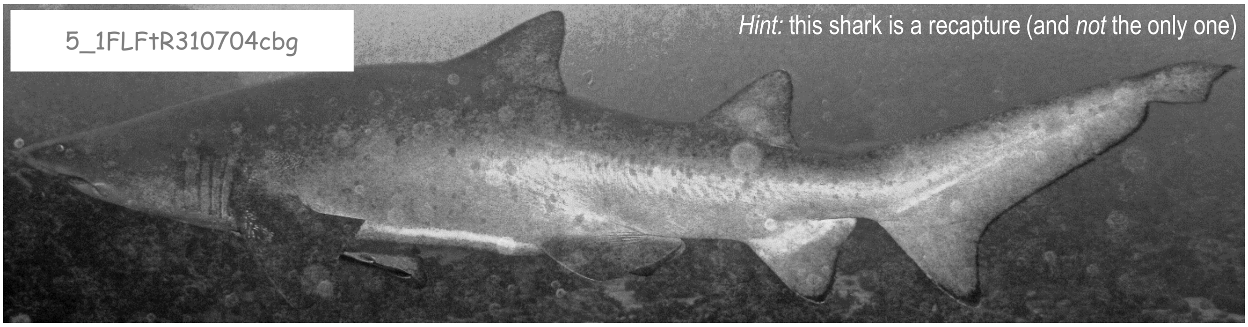


26_1MLAFR030606swrdcm



5_1FLFtR310704cbg

Hint: this shark is a recapture (and *not* the only one)

---

[1] Photographs © Dr. Carley Kilpatrick from Grey Nurse Shark Watch - Reef Check Australia at https://www.reefcheckaustralia.org/grey_nurse_shark_watch

Second Catch (recapture)

Name:

Date:


172_1FLAMAj090307cbg


31_1MLAPFj120208cbm


48_1MLJFRfj230208cbg

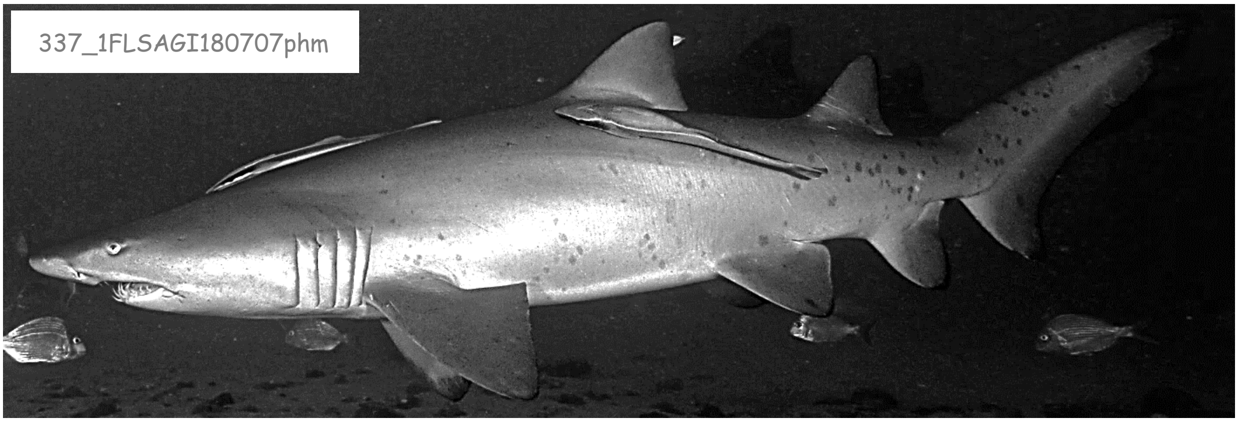

621_1MLSAFRfj230208cbm

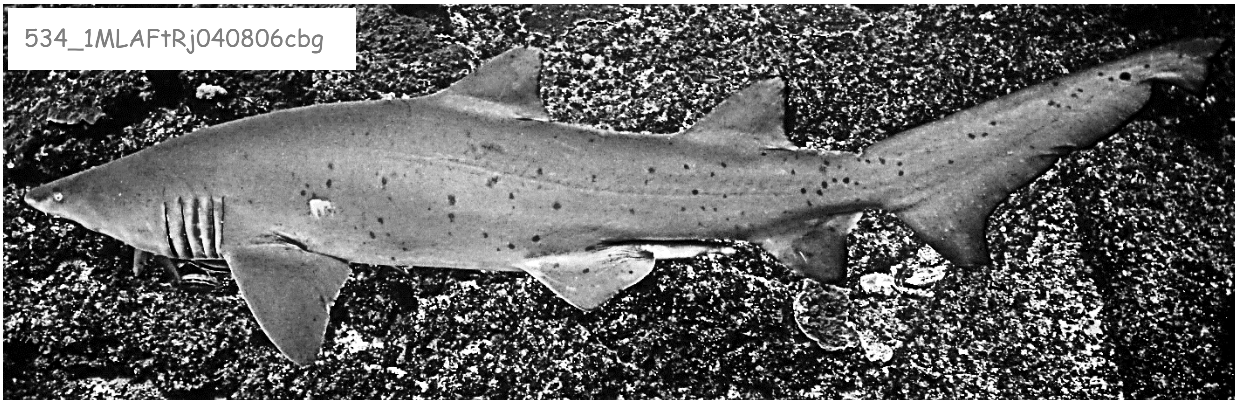
[1] Photographs © Dr. Carley Kilpatrick from Grey Nurse Shark Watch - Reef Check Australia at https://www.reefcheckaustralia.org/grey_nurse_shark_watch

Second Catch (recapture)

Name:

Date:





Total number of sharks in the first catch	**M**	**10**
Total number of sharks in the second catch	**n**	**10**
Number of recaptures in the second catch (how many already had a name?)	**m**	3
Estimated population size (to the nearest whole number) $N = \frac{M \times n}{m}$	**N**	33

[1] Photographs © Dr. Carley Kilpatrick from Grey Nurse Shark Watch - Reef Check Australia at https://www.reefcheckaustralia.org/grey_nurse_shark_watch

FOOD FOR THOUGHT

Name:

Date:

Activity: Refer to Figure 1 (below) to check your estimate of the population.

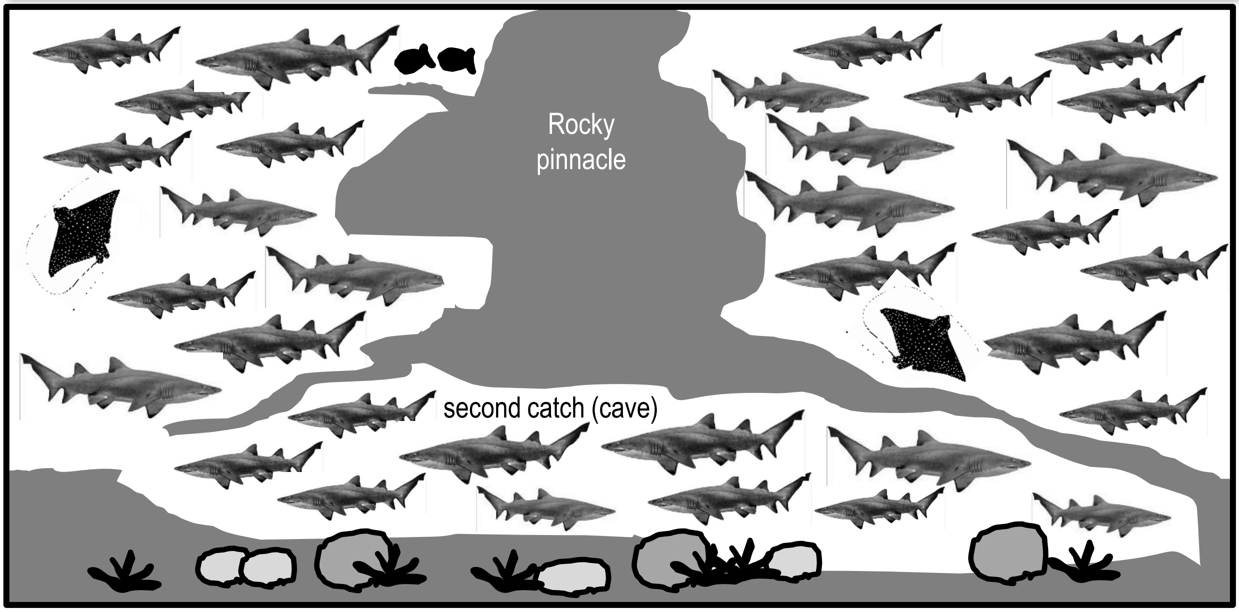


Figure 1: All the sharks in the first catch are pointing to the right. All the sharks in the second catch (recaptures) are in the cave (although, they may *not* have been photographed whilst in a cave; and the size of the sharks in Figure 1 are not representative of the size of the sharks in the photographs).

Activity: Discuss the assumptions that are made when estimating population size using this method.

Code Names

Grey Nurse Shark Watch use a code to name their sharks. The code goes like this: the first number is the unique ID number for that shark. Underscore. The photo number for that individual shark on that day and at one site. Then, the gender of the shark, whereby males have claspers (**M**ale/**F**emale/**U**nknown). Then, the side of the shark that the photograph was taken (**L**eft/**R**ight). Followed by the maturity of the shark (**A**dult/**S**ub-**A**dult/**J**uvenile). Then, the site code (*note:* these sharks often aggregate at a particular site at a particular time of year, e.g. **S**olitary **I**slands, **W**olf **R**ock, **F**lat **R**ock, **J**ulian **R**ocks). If applicable, any other information such as fishing gear (f) jaw injury (j) mating scars (m) pregnant (p) tag or tag tether present (t). Lastly the date, the initials of the photographer and the photo quality (**g**ood, **m**edium, **p**oor)[2].

Q. Is the following shark male or female? 1_3FRSAWRjp100815jgm **Ans.** Female

Combing through the Grey Nurse Shark database to find a match for a photograph of a shark is quite the task.

The code names make it a little easier to narrow it down. But a software program would make it a lot easier!

You just tried to find a match for 10 sharks. Imagine trying to find a match for hundreds of sharks!

If you would like to donate to Grey Nurse Shark Watch to help them raise money for a shark matching software program, or if you want to volunteer to match sharks, or take photographs of grey nurse sharks in the wild to upload to the database, visit their website at *https://www.reefcheckaustralia.org/grey_nurse_shark_watch*

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[1] Department of Environment (2014). *Recovery Plan for the Grey Nurse Shark (Carcharius taurus).* Commonweath of Australia. Accessed 12.05.2019 from: https://www.environment.gov.au/resource/recovery-plan-grey-nurse-shark-carcharias-taurus

[2] Methodology © Dr. Carley Kilpatrick from Grey Nurse Shark Watch - Reef Check Australia at https://www.reefcheckaustralia.org/grey_nurse_shark_watch

Australian Fishing Zone – Identify the Australian Fishing Zone (AFZ) T147

Name:

Date:

The **Australian Fishing Zone** is defined as follows in the **Fisheries Management Act 1991**[1]

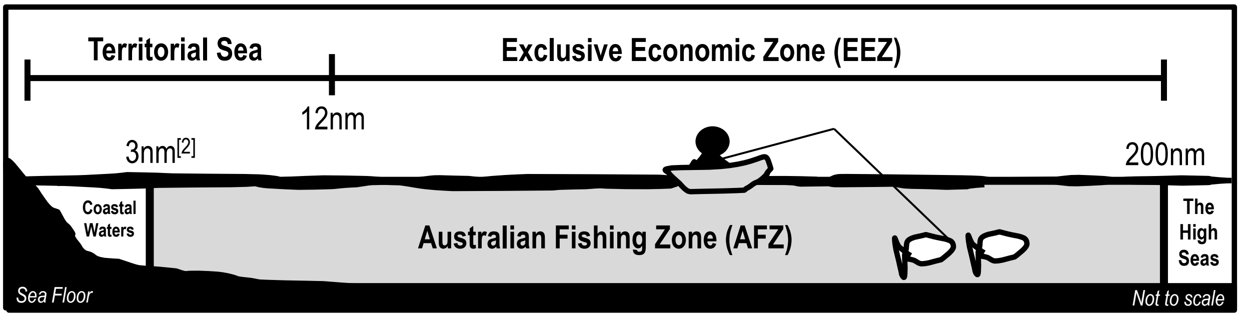
(a) the waters adjacent to Australia within the outer limits of the **exclusive economic zone** adjacent to the coast of Australia; and

(b) the waters adjacent to each external territory within the outer limits of the exclusive economic zone adjacent to the coast of the external Territory;

but does **not** include:

(c) **coastal waters** of, or waters within the limits of, a State or internal Territory; or

(d) waters that are excepted waters (specified by Proclamation under section 11)



Q. How many nautical miles offshore does the AFZ (usually) start and finish? Ans.

The AFC (usually) starts at 3nm and finishes at 200nm.

The Cannon Shot Rule to UNCLOS

In the seventeenth century, nations began to defend their coastlines with the use of cannons. A cannon shot could reach 3 nautical miles (nm). Hence, the *territorial sea* of a country (where a country has full sovereignty) was declared at 3nm (dubbed the 'cannon shot rule'). But, by the 1900s, tensions arose when countries started extending their jurisdictions out to 4, 6, 10 and 12nm. It was not until 1982 that countries finally agreed that their territorial seas would stop at 12nm, but each could have exclusive economic *rights* over a 200nm zone along its shore (EEZ). These decisions were part of a monumental piece of international legislation called the **U**nited **N**ations **C**onvention on the **L**aw **o**f the **S**ea[3].

Q. What does UNCLOS stand for? Ans.

The United Nations Convention on the Law of the Sea

Q. True or False? 'Illegal fishing' is when foreign vessels fish for stocks within the AFZ with*out* authorisation from the relevant Australian authorities (e.g. AFMA). Ans.

True

---

[1] Federal Register of Legislation (2017). *Fisheries Management Act No. 162 of 1991 as amended, taking into account amendments up to Fisheries Legislation Amendment (Representation) Act 2017.* Australian Government. Accessed 18.05.2019 from: https://www.legislation.gov.au/Details/C2017C00363

[2] *Note:* in some places, *coastal waters* stretch out further than 3 nautical miles, but never more than 12 nautical miles.

[3] Oceans and the Law of the Sea (2018). *The United Nations Convention on the Law of the Sea (A historical perspective).* United Nations. Accessed: 18.05.2019 from: https://www.un.org/Depts/los/index.htm

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Aussie Aussie Aussie – Infer that the status of Australian fisheries is due to science-based management, the rule of law and good governance

T148

Name:

Date:

Infer: Derive or conclude something from evidence and reasoning, rather than from explicit statements; listen or read beyond what has been literally expressed; imply or hint at.

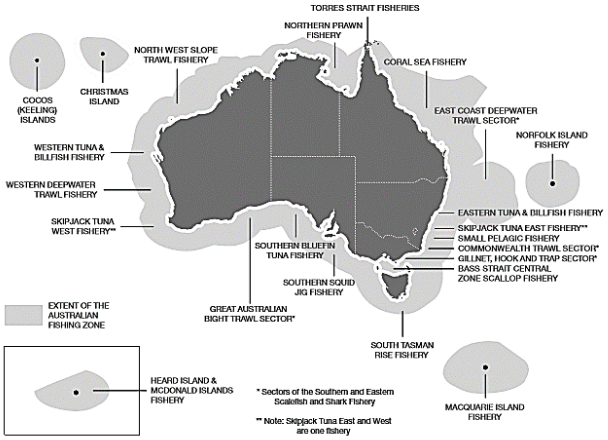

Figure 1: Major fisheries in the AFZ managed by the Australian Fisheries Management Authority (AFMA)[1].

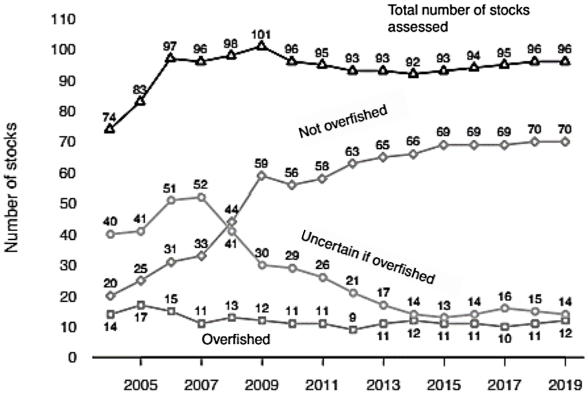

Figure 2: The biomass status of 96 fish stocks across 22 fisheries managed solely or jointly by the Australian government from 2004 to 2019[2]

Q. What percentage of fish stocks in Figure 2 were *not overfished* in 2019? Ans. 73% (70/96)

Activity: Download the following app to your phone: SAFS Sustainable Fish Stocks

A product of the FRDC: the status of Australian Fish Stocks (& a much larger suite of assessments from a range of Australian fisheries)

Scroll through the A-Z list.

Red is overfished and depleted. Yellow is depleting. Orange is recovering. Green is sustainable. Grey is undefined. White is negligible.

Q. What is your assessment of the status of Australian Fisheries? Ans.

Answers may vary

Activity: Infer that the status of Australian fisheries is due to science-based management, the rule of law and good governance

Suggested Activity: Compare Australia to another country's sustainability reporting
(for example, https://www.fisheries.noaa.gov/national/2018-report-congress-status-us-fisheries)

Suggested Activity: Compare *Top-down Governance* to *Bottom-up Governance*
(recall from Year 11 workbook, Unit 2, Topic 2).

Suggested Activity: Discuss the importance of (and access to) *funding* towards compliance
Q. Are people more likely to comply to the rules, when they know the rule of law is informed by science?
Q. Does every country have enough money to fund science-based management?
Q. Does top-down governance work in countries with little money?
Q. In wealthy countries, are attempts to maintain scientifically robust information to inform the public easily overridden by emotive information? (refer to *worldviews*: Year 11 workbook Unit 2, Topic 2)
Q. Can a fishery still be sustainable without scientific information (i.e. without a stock assessment)?

Suggested Activity: Comment on how many *fisheries* versus how many *stocks* are assessed

Activity: Observe boat activity on the AFZ border at www.globalfishingwatch.org/map/

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[1] Graphic kindly provided by Natalie Jorna of the Australian Fisheries Management Authority, 23rd July 2019.

[2] Adapted from ABARES (2020). *Fishery status reports 2020,* Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. Page 11. Accessed 01/.07.2021 from: https://daff.ent.sirsidynix.net.au/client/en_AU/search/asset/1030781/0 CC BY 4.0.

Exports and Imports – Identify an example of a major Australian edible seafood export product and an import product

T149

Name:

Date:

Activity: Identify an example of a major Australian edible seafood EXPORT product

Australia exports around half of its annual fisheries and aquaculture production by value, specialising in high unit value products for the Asian market (i.e. prawns, tuna, salmonids, rock lobster and abalone)[2]. COVID has caused some disruption to Australia's usual trade, particularly for products such as rock lobster and abalone[1]. Sporadic commodity-focused trade issues with China have posed additional challenges for exporters, especially for those exposed to and concentrated on Chinese markets[2].

[1] China accounted for around 91% of Australian rock lobster exports in 2019 and 2020 and the resumption of rock lobster exports to China is the key uncertainty for the forward projections. COVID-19 led to the cancellation of abalone orders in early 2020 and it is unclear when export markets will recover[2].

[2] Adapted from ABARES (2021). Australian Fisheries and Aquaculture Outlook. ABARES. Accessed 01.07.2021 from: https://www.agriculture.gov.au/abares/research-topics/fisheries/fisheries-economics/fisheries-forecasts#australian-exports

Activity: Identify an example of a major Australian edible seafood IMPORT product

Australia's seafood imports consist largely of lower value products such as frozen fillets (61%), frozen prawns (18%) and canned fish[3].

For example,

- Frozen and thawed basa (catfish) come from farms in Vietnam[3]
- Canned skipjack tuna come from Thailand (no significant canning of tuna has taken place in Australia since May 2010, when the tuna cannery in Port Lincoln closed)[3]
- White-fleshed fish species such as snapper and blue grenadier (hoki) come from New Zealand[3]
- Barramundi (an iconic Australian fish) come from Vietnam[4]
- Bright yellow-dyed smoked cod come from South Africa[4]
- Frozen prawns, squid and octopus come from China, Taiwan, Thailand, Malaysia and Vietnam[3][4]

[3] Department of Agriculture (2015). *Australia's Seafood Trade*. Commonwealth of Australia. Accessed 20.05.2019 from: http://www.agriculture.gov.au/SiteCollectionDocuments/fisheries/aus-seafood-trade.pdf
[4] Australian Marine Conservation Society (2019). *Australia's Sustainable Seafood Guide: Australian Seafood Overview*. AMCS. Accessed 20.05.2019 from: https://www.sustainableseafood.org.au/pages/.html

Fish flying in and out – Examine the factors that lead to a higher proportion of the seafood consumed in Australia being imported T150

Name:

Date:

Australians eat on average 3.1 meals a week with seafood in it[1]

>60% of our seafood is IMPORTED[1]

TOP 5 seafoods Aussies love to eat[1]

1st PRAWNS

Imported farmed prawns come from Thailand, Vietnam and China[2]

2nd Canned Tuna

No significant canning of tuna has taken place in Australia since May 2010, when the tuna cannery closed in Port Lincoln, South Australia[2]

3rd Crumbed and Battered Fish

Imported white-fleshed fish species such as snapper and blue grenadier (hoki) come from New Zealand[2]

4th Squid (calamari)

Imported squid come from China, Taiwan, Thailand and Malaysia[2]

5th Fresh Salmon

Imported farmed salmon come from New Zealand[3]

- **Exports** are dominated by high unit value products such as rock lobster, tuna and abalone[2].
- **Imports** are dominated by low unit value products such as frozen and canned fish and frozen prawns[2].
- Australia's apparent consumption of seafood increased, on average, at an annual rate of 1.1 % between 2005-6 and 2015-16. Over the same period, domestic seafood supply remained steady, whilst imports increased at an average rate of 1.7 % per year[2].
- Australian waters are nutrient poor with low levels of primary production (compared to other countries).

> ***…when each yellowfin tuna can weigh 70kg, and when the finest yellowfin can command 3000 yen a kilo (~$32/kilo) at the Japanese fish markets, a good day can be lucrative. "One tonne a day keeps the bank away," Pavo Walker says laughing[4]***

Q. What are the factors that lead to a higher proportion of the seafood consumed in Australia being imported? Ans.

Answers may vary.

E.g. Social Factors, Economic Factors ($), Environmental Factors

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[1] Mobsby, D. and Koduah, A. (2017). *Australian fisheries and aquaculture statistics 2016.* Fisheries Research and Development Corporation project 2017-095. ABARES, Canberra, December. CC BY 4.0. Accessed 20.05.2019 from: http://www.frdc.com.au/Services/Australian-Fisheries-Statistics

[2] Department of Agriculture (2015). *Australia's Seafood Trade.* Commonwealth of Australia. Accessed 20.05.2019 from: http://www.agriculture.gov.au/SiteCollectionDocuments/fisheries/aus-seafood-trade.pdf

[3] Australian Marine Conservation Society (2019). *Australia's Sustainable Seafood Guide: Seafood Search.* AMCS. Accessed 20.05.2019 from: https://www.sustainableseafood.org.au/fish.php

[4] The Australian – by Sarah Elks (2015). *Walker Seafoods Australia earns Marine Stewardship Council certification*. Walker Seafoods Australia. Accessed 25.05.2019 from: https://www.walkerseafoods.com.au/

Ecological Economics – Recall that Australian Fisheries have an economic value T151

Name:

Date:

Revenue - Cost

The value of Australia's commercial fisheries and aquaculture industry reached 3.18 billion in 2017-18[1]. The direct use value is usually calculated as the **revenue** (yield x fish price) **minus** the **costs** (the cost of fuel, labour, repairs, bait, capital, maintenance, administration, opportunity costs, etc.)[2].

Q. How is the direct use value of a commercial fishery usually calculated? Ans. (*hint:* see bold)

Revenue (yield x fish price) – cost (e.g. fuel, labour, repairs, bait, capital, etc.)

> ***'Fishing (in anything other than a subsistence-based economy) is an economic activity. The species that fisheries target, the level of exploitation, and the gear that they use are all influenced by the benefits they receive (i.e. the revenue) and the costs they incur'…***
>
> ***…'Fisheries management change the set of incentives facing fishers, and in doing so change their behaviour'***
>
> **Dr. Sean Pascoe. Marine Resource Economist[3]**

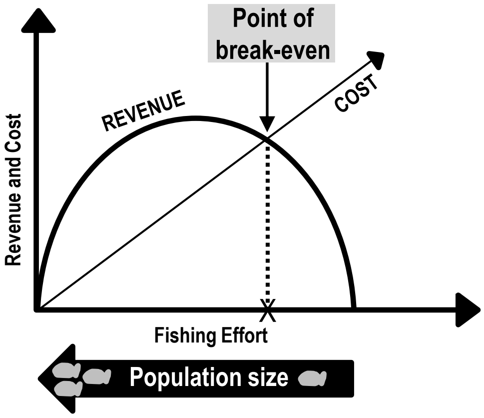

Figure 2: Population size (X) at the point of break-even when revenue EQUALS cost (assuming costs are directly proportional to fishing effort)[4].

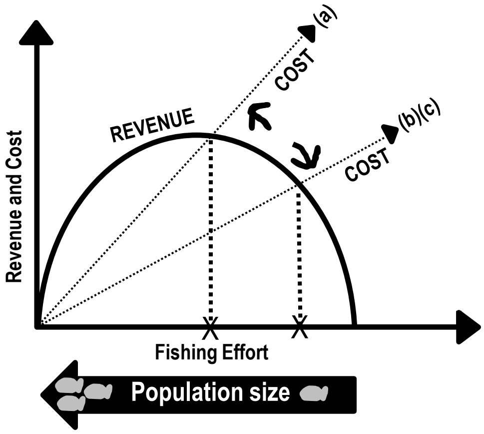

Figure 3: (a) Management impose costs to reduce fishing effort.
(b) Management subsidise costs to avoid bankruptcy.
(c) New technology reduce costs (increases fishing effort that can lead to stock collapse, such as the Atlantic northwest cod fishery)[5].

Q. Does fishing effort go <u>up</u> or <u>down</u> when costs are reduced in open access fisheries? Ans. UP

COSTS that do *not* have a clear dollar value, such as the cost of habitat damage, biodiversity loss and bycatch, can easily be overlooked. As a result, the cost of fishing can be underestimated.

Q. Does fishing effort go <u>up</u> or <u>down</u> when the cost of fishing is underestimated? Ans. UP

---

[1] ABARES (2020). Australian fisheries and aquaculture statistics 2018. ABARES, Canberra, April. CC BY 4.0. Accessed 01.07.2021 from: https://www.frdc.com.au/services/abares-annual-australian-fisheries-and-aquaculture-statistics-reports.

[2] Adapted with permission from: King, M., Blanc, M., Desurmont, A., Sharp, M. and Barre, C. (2014). *Guide to Teachers' Resource Sheets on Fisheries for the Cook Islands*. Secretariat of the Pacific Community (SPC) Coastal Fisheries Programme. New Caledonia. Accessed 29.07.2019 from: https://coastfish.spc.int/en/publications/technical-manuals/education/421-teachers-resource-kit-on-fisheries

[3] Pasco, S. (2006). Economics, fisheries, and the marine environment. *ICES Journal of Marine Science. Volume 63, Issue 1, Pages 1-3. DOI: 10.1016/j.icesjms.2005.11.001*

[4] Adapted with permission by John Wiley and Sons from: King, M. (2007). Fisheries Biology, Assessment and Management. Blackwell Publishing. Victoria, Australia. Page 276.

[5] Adapted from: Berkes, F., Mahon, R., McConney, P., Pollnac, R. and Pomery, R. (2001). Managing Small-scale Fisheries. International Development Research Centre. Canada. ISBN 0-88936-943-7. Accessed 07.08.2019 from: https://www.idrc.ca/sites/default/files/openebooks/310-3/index.html

Sharing Pieces of the Fish Pie – Explain monitoring and control of total allowable catch (TAC) and fixed quotas T152

Name:

Date:

Sharing the Total Allowable Catch

The Total Allowable Catch (TAC) is commonly divided into quota units to stop people 'racing' to catch fish. Instead of all the fishers fighting over who gets what, management decides! E.g. if a fishery has a TAC of 4 fish, management can decide to give all 4 fish to one fisher, or, split it between 4 fishers* (Figure 1).

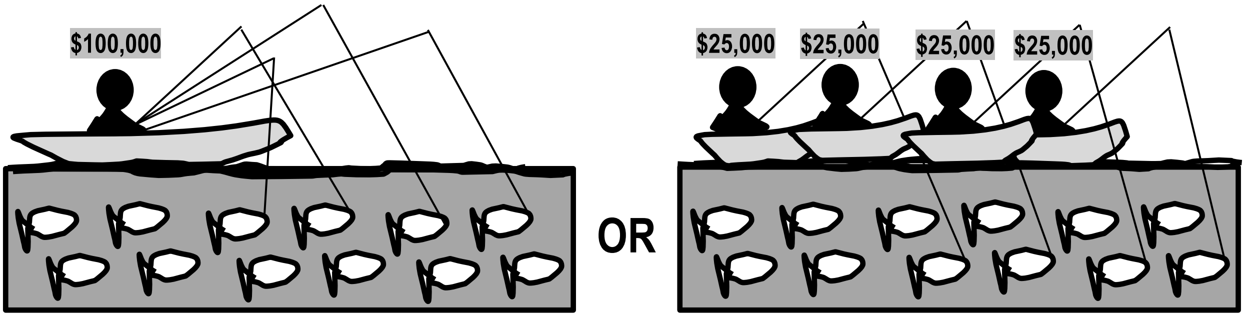

Figure 1: Left: one individual fisher has been allocated a fixed quota of 100% of the TAC (worth $100,000); Right: each fisher has been allocated a fixed quota of 25% of the TAC (worth $25,000 each).

Q. How much money is each fish worth in Figure 1? Ans. $25,000

Having fewer quota units makes it easier to monitor and control who is catching what. But at what price?

Activity: Discuss which is better….
(a) one large operator or (b) lots of small family-owned operators?

ITQs

Individual Transferable Quotas (ITQs) give fishers permission to catch a certain percentage of the TAC**. ITQs can sometimes be quite expensive (e.g. abalone are worth lots of money, thus, so are their quotas). However, whilst ITQs may be expensive, they are transferrable (can be sold or leased). Hence the word '*Transferable*' in the name. *Note:* additional restrictions may also apply (e.g. size limits to protect spawning biomass). And, heavy penalties apply for non-compliance.

Q. What purpose do ITQs serve? Ans. Stop people 'racing' to catch fish

Activity: Explain monitoring and control of total allowable catch (TAC) and fixed quotas

TAC is an output control (vs an input control) that limits the number of individuals that can be caught. TAC is commonly divided into quota units to stop people 'racing' to catch fish. Quotas give fishers permission to catch a certain percentage of the TAC**. ITQs are sometimes quite expensive, but also transferrable (can be sold or leased). The performance of a fish stock is closely monitored by fishers, scientists, markets and other stakeholders. Notably, TAC may change from year to year or from season to season, to ensure there are still enough fish to catch in the future.

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* Alternatively, management decide on the number of quotas available. Then, fishers bid $ to buy the quotas at an auction.

** or; TACC (Total Allowable Commercial Catch).

Dynamic Management Tools – Describe dynamic spatial zoning fish management (including e-monitoring) as a fish management technique in terms of ecosystem-based management in relation to a case study T153

Name:

Date:

Dynamic spatial zoning fish management: a management tool used to restrict fisher access to predicted dynamic habitats of protected species
e-monitoring: electronic monitoring (e.g. cameras, GPS) that collect catch data on fishing vessels to verify fisher logbook reports.
Bycatch: species that physically interact with fishing vessels and/or fishing gear and are not usually kept by commercial fishers[1].
Discards: Any part of the catch which is returned to the sea, dead or alive[1].

Dynamic Spatial Zoning Fish Management

What is dynamic spatial zoning fish management? Let's look at each word individually….
Dynamic means constantly changing. **Spatial** means relating to or occupying space (e.g. location). **Zoning** outlines activities *not* allowed in an MPA. **Fish,** in this case, refers to protected species. **Management,** in this case, refers to ecosystem-based management (not single species management).

Activity: Revise information on Pages 114, 115, 135 and 138

A dynamic tool to reduce bycatch

Sometimes non-target species are caught by accident, called **bycatch**. Managers try to reduce the amount of bycatch as much as possible. Particularly for protected species (e.g. turtles, dugongs).
A management strategy to reduce bycatch is to limit fishing access along the migratory pathways and hotspots of protected species. **Importantly, the migratory pathways and hotspots of protected species vary from season to season.** Therefore, zones (that prohibit activities in an area) must be *dynamic* (not *static*). Management use 'habitat models' to predict the whereabouts of a protected species (or species of interest) at any given time. Management then draw lines on a map (across a certain distance, and down to a certain depth) that tell fishers where they can and cannot fish. As the species move (predicted by the models and reported by the fishers), the boundaries of the zones move too. Surveillance systems (e.g. e-monitoring) monitor fishing activity and promote compliance to the rules[2].

Activity: Describe dynamic spatial zoning fish management (including e-monitoring) as a fish management technique in terms of ecosystem-based management in relation to a case study.

Suggestions include TurtleWatch (NOAA Fisheries), eCatch, and the East Australian Longline Fishery avoiding Southern Bluefin Tuna as bycatch[3].

answers may vary

---

[1] AFMA. (2019). Bycatch and Discarding. Australian Fisheries Management Authority. Accessed 14.06.2019 from: https://www.afma.gov.au/sustainability-environment/bycatch-discarding

[2] AFMA. (2019). E-monitoring requirements. Australian Fisheries Management Authority. Access 14.06.2019 from: https://www.afma.gov.au/fisheries-services/e-monitoring-requirements

[3] Hobday, A.J., Hartog, J.R., Timmiss, T. and Fielding, H. (2010). Dynamic spatial zoning to manage southern bluefin tuna *(Thannus maccoyii)* capture in a multi-species longline fishery. *Fisheries oceanography. 19:3, 243-253. DOI: 10.1111/j.1365-2419.2010.00540.x*

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The preCAUTIONary Principle – Describe the use of the precautionary principle as applied to ecosystem management

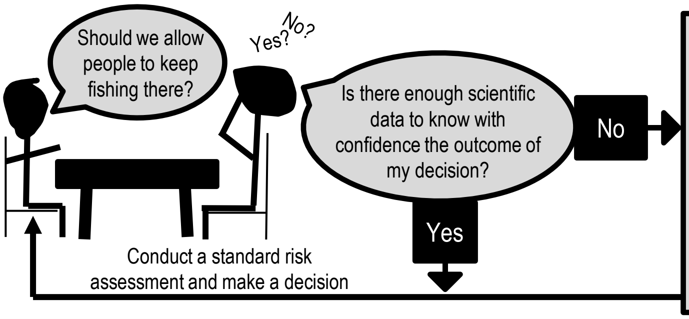
T154

Name:

Date:

Principle decisions

When management are busy making decisions, if they believe a decision has the potential to put the environment (or human health) at risk, but there's not enough scientific data to know with confidence the outcome of their decision (and it will take too long to find out), but they still need to make a decision regardless, then the **precautionary principle** applies.



Precautionary Principle applies

- ☐ Say **No**

(Your reason? When scientific data does not permit a complete evaluation of the risk, recourse to the principle may, for example, be used to decline the application)

- ☐ Say **Yes**, but modify or safeguard the activity
- ☐ Suggest alternative/s

Q. When does the precautionary principle apply? Ans.

When decision-makers believe a decision has the potential to put the environment (or human health) at risk, but there is *not* enough scientific data to know with confidence the outcome of their decision.

Exercising CAUTION

Fisheries managers constantly make management decisions. These decisions require careful consideration before implementation, as the wrong decisions may have negative consequences or impacts on the environment putting many species, including humans, at risk. The potential danger arises when there is insufficient scientific data known about an area, population or species, to support, with a high degree of confidence, the outcomes of their proposed management decisions. To avoid any negative outcomes, the Precautionary Principle is applied. Examples of precautionary measures which have been implemented in fisheries management include **bycatch reduction devices, size and bag limits, marine protected areas, closures, licensing, gear restrictions** and **protected species.**

Activity: Below is a list of questions. Assume the answer to each question is 'Yes', but there is not enough scientific data to know with confidence the outcome of that decision. Name a precautionary measure that could modify or safeguard the activity (*hint*: suggestions above).

Question	Decision	Precautionary Measure
Q1. Can people keep fishing where turtles are being caught as bycatch?	**Ans.** Yes, but only if…	they use a bycatch reduction device
Q2. Can people keep fishing *WHEN* coral reef fin fish aggregate to spawn?	**Ans.** Yes, but only if…	there are closures
Q3. Can people keep collecting oysters from the rocky shore?	**Ans.** Yes, but only if…	they have bag limits

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The Blue Revolution – Recognise why the current state of aquaculture in the world cannot address food security T155

Name:

Date:

Aquaculture BOOM!

Capture fishery production has been relatively static since the late 1980s. Aquaculture has since been responsible for continued growth in the supply of fish for human consumption (Figure 1)[1].

The term '*Blue Revolution*' is used in literature to reference the potential for aquaculture to address food security, and to describe the recent boom in aquaculture production. Previous 'revolutions' include 'the *Green Revolution*' – the agricultural boom, and the '*White Revolution*' – the dairy boom (i.e. in India).

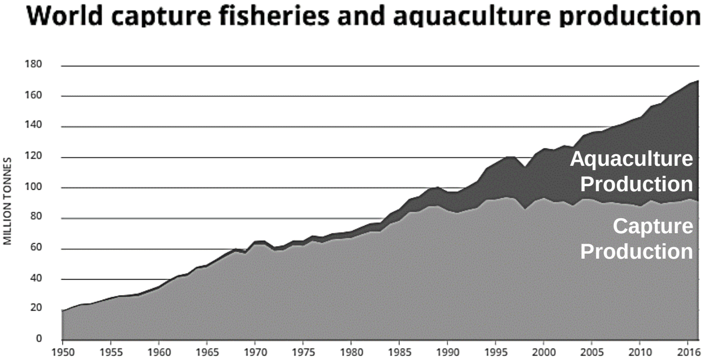

Figure 1: Aquaculture represented 47% of the total global fish production in 2016, most of which is derived from China[1].

Note: the term 'fish' indicates fish, molluscs and other aquatic animals, but excludes aquatic mammals, crocodiles, caimans, seaweeds and other aquatic plants[1].

Q. What is the 'Blue Revolution'? Ans.

The 'Blue Revolution' is a term used in literature to reference the potential for aquaculture to address food security, and to describe the recent boom in aquaculture production.

The 5 S's of Food Security

Food security requires aquatic food supplies to be **S**ufficient, **S**afe, **S**ustainable, **S**hock-proof and **S**ound (Fig. 1).

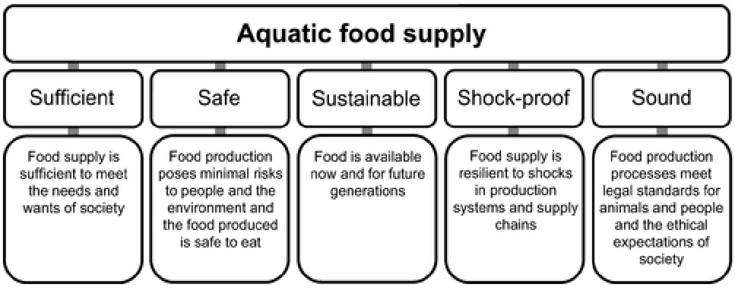

Figure 2: Critical elements of food security. In general terms, an aquatic food supply contributes to food security when the food supply is sufficient, safe, sustainable, shockproof and sound[2].

Activity: EVALUATE the claim below:

'the current state of aquaculture in the world cannot address food security'

Research, analyse and interpret secondary evidence from scientific texts[2][3][4] to form the basis for a justified conclusion about the claim.

STATE YOUR CONCLUSION BELOW

The current state of aquaculture in the world cannot address all 5 Ss[2]. The aquaculture sector requires an additional $150-300 billion in capital investment to expand production infrastructure to meet projected demand growth for 2030[4]. Also refer to page 59 of the QCAA Marine Science Syllabus V1.2 under 'guidance'.

[1] FAO (2018). The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals. Rome. Page 3. Licence: CC BY-NC-SA 3.0 IGO.

[2] Jennings, S., Stentiford, G.D, Leocardio, A.M., Jeffery, K.R., Metcalfe, J.D., Katsiadaki, J., Auchterlonie, N.A., Mangi, S.C., Pinnegar, J.K., Ellis, T., Peeler, E.J., Luisetti, T., Baker-Austin, C., Brown, M., Catchpole, T.L., Clyne, F.J., Dye, S.R., Edmonds, N.J., Hyder, K., Lee, J., Lees, D.N., Morgan, O.C., O'Brien, C.M., Oidtmann, B., Posen, P.E., Santos, A.R., Taylor, N.G.H., Turner, A.D., Townhill, B.L., Verner-Jeffreys, D.W. (2016). Aquatic food security: insights into challenges and solutions from analysis of interactions between fisheries, aquaculture, food safety, human health, fish and human welfare, economy and environment. *Fish and Fisheries. 17, 893-938.* CC by 4.0.

[3] Costa-Pierce, B. (2002). The 'Blue Revolution' – Aquaculture Must Go Green. *World Aquaculture 33(4).*

[4] O'Shea, T., Jones, R., Markham, A., Norell, E., Scott, J., Theuerkauf, S.,and Waters, T. (2019) *Towards a Blue Revolution: Catalyzing Private Investment in Sustainable Aquaculture Production Systems*. The Nature Conservancy and Encourage Capital, Arlington, Virginia, USA.

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Marine Education

ABARES – Analyse Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) fisheries reports to determine changes in fisheries practices over the past 10 years, including: economic contribution of aquaculture to wild catch; the top five aquaculture species in Australia by volume and value T156

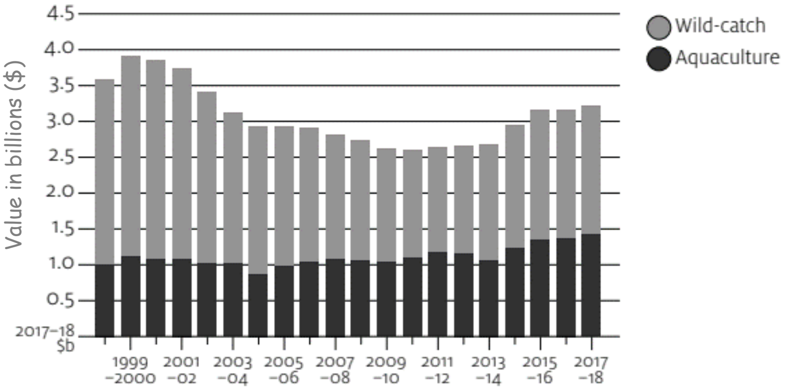
Name:

Date:

Activity: Download the latest ABARES fisheries *and aquaculture* report[1]

Activity: Identify the economic contribution of aquaculture to wild catch in Australia

FIGURE 1 Wild-catch and aquaculture GVP, 1998–99 to 2017–18

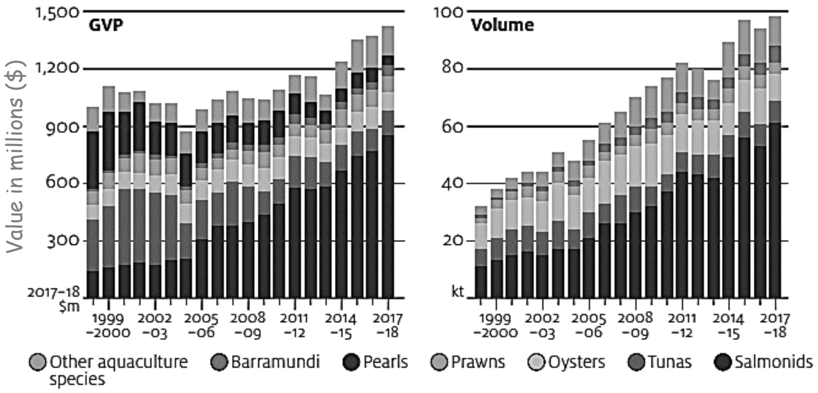


Source: ABARES

Note: GVP = Gross Value of Production

Activity: Identify the top 5 *aquaculture* species in Australia by volume and value

FIGURE 3 Aquaculture GVP and volume by major species group, 1998–99 to 2017–18



Note: Pearl production volume is unavailable.
Source: ABARES

TOP 5 (2017-18)

1. Salmonids ($855 million)
2. Tunas ($126 million)
3. Oysters ($102 million)
4. Prawns ($80.5 million)
5. Barramundi ($54 million)

Activity: PREDICT the effect of COVID on the future of Australian Fisheries

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[1] ABARES (2020). Australian fisheries and aquaculture statistics 2018. ABARES, Canberra, April. CC BY 4.0. Accessed 01.07.2021 from: https://www.frdc.com.au/services/abares-annual-australian-fisheries-and-aquaculture-statistics-reports

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Marine Education

Fishing for Information – Identify attributes (e.g. resilience, fast growth rate, low-feed conversion ratio) of an aquaculture species detailing its life cycle, adaptations, requirements and marketability that would make a species desirable to farm T157

Name:

Date:

Activity: Pretend you know a farmer who wants to begin an aquaculture farm. Below is a list of criteria, that was made by a family member of the farmer, to help the farmer decide on what species to farm.
As a friend of the farmer, your task is to select 3 species for the farmer to choose from (write them below). For each species that you suggest, you must also provide the farmer with details of its life cycle, adaptations, requirements and marketability, so the farmer can make an informed decision.

- ☑ **They are nutritious, tasty, marketable**
- ☑ **They grow fast**
- ☑ **Their food is cheap and accessible**
- ☑ **You can grow them from larvae**
- ☑ **They do not die easy**
- ☑ **They do not care if it is crowded!**
- ☑ **They do not care if the water quality is not the best**
- ☑ **They are resistant to disease**
- ☑ **They have a low-feed conversion ratio or FCR[1]**

1

Suggestions from the syllabus
bluefin tuna (*Thunnus maccoyii*), salmon (*Oncorhynchus spp.*), barramundi (*Lates calcarifer*), freshwater fish including eels (*Anguilla spp.*), abalone (*Haliotidae*), oysters (mainly *Crassostreas gigas, Saccostrea glomerata*), prawns (*Penaeus spp., Fenneropenaeus merguiensis*), yabbies (*Cherax destructor*), redclaw crayfish (*Cherax quadricarinatus*), silver perch (*Bidyanus bidyanus*) or Murray cod (*Maccullochella peelii peelii*).

2

Recommended Reading
Queensland Government *Business Queensland* website www.business.qld.gov.au/ (Home > Industries > Farms, Fishing and Forestry > Fishing and Aquaculture > Aquaculture > Aquaculture species).

Suggested Practical (syllabus)
Investigate factors that affect the growth rate of an aquaculture species

3

What is the 'feed conversion ratio'? FCR is the weight of feed administered over the lifetime of an animal (i.e. kg of feed) divided by weight gained (i.e. kg of edible biomass). This ratio measures how efficiently a kilogram of animal feed is converted into animal weight or biomass[1].
For example, the FCR of fish is lower (and therefore more efficient at converting food to biomass) than the FCR of, say, a cow or a sheep[1].

Q. Is the list of criteria realistic (can the farmer realistically tick all those boxes)? WHY? Ans.

answers may vary. E.g. No – unrealistic Or, Yes – suggestion of species.

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[1] Fry, J., Mailoux, N.A., Love, D.C., Milli, M.C. and Cao, L. (2018). Feed conversion efficiency in aquaculture: do we measure it correctly? *Environmental Research Letters, Volume 13. Number 2. DOI: 10.1088/1748-9326/aaa273*

1 Fish, 2 Fish, Red Fish, Blue Fish – Predict the maximum carrying capacity of an aquaculture system based on the size of ponds or tanks, the requirements of a species, and farming technique T158

Name:

Date:

Maximum Carrying Capacity?

If you have invested a lot of money into an aquaculture business, you may be tempted to overcrowd the pond or tank, to sell more fish down the track. As tempting as that may be, overcrowding a tank can be costly in the long run. Every tank or pond has a limit to how many fish you can put in it. It pays to know the maximum carrying capacity of your aquaculture system. This will begin as a prediction based on the size of the ponds or tanks, the requirements of a species and farming technique.

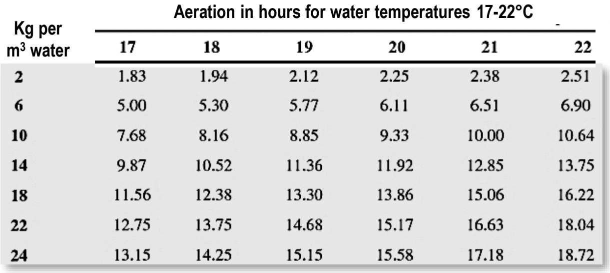
The larger the tank or pond, the greater its (carrying) capacity

Table 1: Data from a Tilapia farm in Inhasorro, Mozambique, with ponds stocked with 3 fish per square metre (open system)[1].

	Pond Size (m^2)	Stocking of Pond
Pond 1	**35 000**	**105 000 fish**
Pond 2	**25 000**	75 000 fish
Pond 3	**22 500**	67 500 fish
Pond 4	**20 000**	60 000 fish

Activity: Complete the table above

Table 2: The required aeration time (in hours) per tank to maintain a DO within 4-5ppm for different fish stocking densities of carp (kg/m^3) and for different water temperatures (°C)[2].



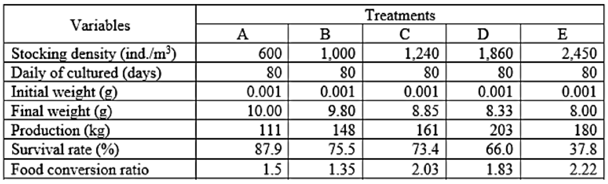
Kg per m^3 water	Aeration in hours for water temperatures 17-22°C					
	17	18	19	20	21	22
2	1.83	1.94	2.12	2.25	2.38	2.51
6	5.00	5.30	5.77	6.11	6.51	6.90
10	7.68	8.16	8.85	9.33	10.00	10.64
14	9.87	10.52	11.36	11.92	12.85	13.75
18	11.56	12.38	13.30	13.86	15.06	16.22
22	12.75	13.75	14.68	15.17	16.63	18.04
24	13.15	14.25	15.15	15.58	17.18	18.72

The larger the aeration capacity of the tank or pond, the greater its (carrying) capacity

Q. Why is aeration important? Ans.

- Fish need to breathe
- Water movement (i.e. no stratification)
- Waste Removal (more fish = more waste)

Table 3: The effect of stocking density on shrimp (*Litopenaeus vannamei*) in 5 tanks (A-E) that were each 5m x 1.5m and filled with $20m^3$ sea water[3].



Variables	Treatments				
	A	B	C	D	E
Stocking density (ind./m^3)	600	1,000	1,240	1,860	2,450
Daily of cultured (days)	80	80	80	80	80
Initial weight (g)	0.001	0.001	0.001	0.001	0.001
Final weight (g)	10.00	9.80	8.85	8.33	8.00
Production (kg)	111	148	161	203	180
Survival rate (%)	87.9	75.5	73.4	66.0	37.8
Food conversion ratio	1.5	1.35	2.03	1.83	2.22

Growth rates and survival rates can, for some species, decline as stocking density increases

Q. Which treatment (A-E) in Table 3 causes the shrimp survival rate (%) to *plummet*? Ans. E

Q. At what stocking density would *you* choose to farm *L. vannamei*, based on the data in Table 3? Justify your decision. Ans. (*hint:* compare the feed conversion ratios!)

answers may vary

Note: feed conversion ratio is smallest for Treatment B.

The perfect stocking density amount largely depends on the requirements of the species

Q. Why the difference in stocking density between Tilapia in Table 1 and shrimp in Table 3 (B)? Ans.

Because they are different species with different requirements.
Different farming technique.

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[1] Adapted from: Schnell, C. and Schnell, A. (2017). *Tilapia Farm in Inhasorro.* Xibaha. Accessed 24.06.2019 from: http://xibaha.info/tilapia-farm-in-inhasorro/

[2] Adapted with permission from: Elmessery, W.M. and Abdallah, S.E. (2014). Intelligent Dissolved Oxygen Control System for Intensive Carp System. *Journal of Agricultural Engineering and Biotechnology. Vol. 2. Issue 4. Pp. 49-62. DOI: 10.18005/JAEB0204001*

[3] Adapted from: Tahe, S. and Makmur (2016). *The effect of stocking density on productions of Super intensive white shrimp (Litopenaeus vannamei) cultured in fiberglass tanks.* Asian-Pacific Aquaculture 2016 – Meeting Abstract. World Aquaculture Society Inc. (US). Accessed 24.06.2019 from: https://www.was.org/meetings/ShowAbstract.aspx?Id=43456

Dynamic Systems – Contrast different aquaculture systems (e.g. open, closed or recirculating, intensive and extensive) T159

Name:

Date:

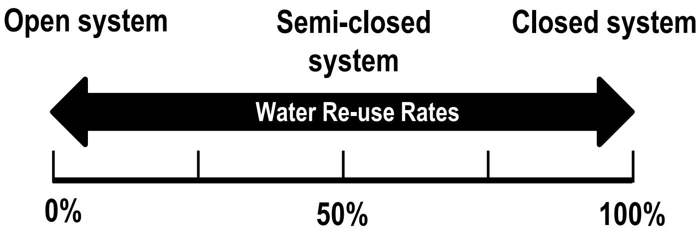

Figure 1: Water re-use rates for open, semi-closed and closed systems[1].

Q. Which system in Fig. 1 re-uses the most water?
Ans. Closed system

Open vs. Closed

- **Open** systems rear organisms in nature. No water is pumped or reused. E.g. floating netpens, floating racks, longlines, on-bottom culture, cages[2].
- **Semi-closed** systems rear organisms in man-made impoundments. Water is pumped or diverted from nature. E.g. ponds and raceways, tanks[2].
- **Closed** systems use sophisticated water filtration and treatment systems. E.g. aquariums, aquaponics[2].

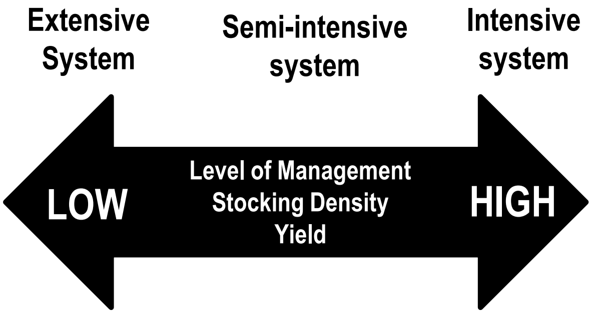

Figure 2: Difference between extensive and intensive culture systems[2].

Extensive vs. Intensive

- **Extensive** systems are in natural waters where it is left up to nature to feed the organisms and maintain water quality. E.g. oyster farms.
- **Semi-intensive** systems include the addition of feed and fertilizers.
- **Intensive** systems are highly controlled systems (inside or outside) to maximise production in minimal space. E.g. trout raceways, prawns.

Q. Which system in Fig. 2 has the highest capacity to *control* water quality? Ans. Intensive

Activity: Complete the table below.

	Extensive System	Intensive System
Description	Low level of management Low stocking density Low yield	High Level of management High stocking density High yield
Examples	Oyster farms Herbivore farms	Trout raceways Prawns (all same size) Crayfish

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[1] Adapted from: Florida Atlantic University Harbour Branch (n.d.). *Recirculating Aquaculture Systems.* SlidePlayer. Accessed 21.06.2019 from: https://slideplayer.com/slide/6021113/

[2] Adapted from: Jayachandran, P.R. (2015). *Jayachandran aquaculture systems*. SlideShare. Accessed 21.06.2019 from: https://www.slideshare.net/JayachandranPR/jayachandran-aquaculture-systems

Issues with Aquaculture – Understand issues with output pollution, biosecurity and waste removal and production of feed for aquaculture T160

Name:

Date:

What is the issue?

- Loss or alteration of natural habitat (i.e. mangroves and wetlands)
- Displacement of indigenous fisheries with multi-national corporations
- Uneaten food and waste products can smother benthic organisms
- Uneaten food and waste products can over-fertilise the water (leading to eutrophication)
- Fish meal and fish oil can go into water column (from oily fish like mackerel and anchovies)
- Ammonia (from fish urine and gill excretion) can be toxic if not removed.
- Illegally sourced feed product is a biosecurity threat (heavy penalties apply)
- The introduction of non-native seed stock can be a biosecurity threat (i.e. importing Atlantic salmon eggs from Europe)
- Feed stock supply may be coming from an unsustainable source
- Disease risks to the stock (see right)
- Drug resistant pathogens can prevail, making disease outbreaks difficult to avoid or fix
- Drugs (antibiotics, hormones, anaesthetics, etc.) and herbicides can go into the water column
- Genetically modified species can *escape* and threaten local species with extinction

Disease threats

Infectious disease agents

- Ectoparasites (e.g. *Cryptocaryon*)
- Bacteria (e.g. *Vibrio spp.*)
- Fungi (e.g. *Saprolegnia*)
- Viruses (e.g. koi herpes virus, whispovirus)

Non-infectious disease agents

- Water quality problems
- Nutritional deficiencies or excess nutrients
- Toxicity (e.g. heavy metals, pesticides)

Activity: Complete the table below

Issue	**Why it is an issue** (*hint:* see above)
Output Pollution	Uneaten food and waste products can over-fertilise the water (leading to eutrophication). Drugs, herbicides, etc.
Biosecurity	Genetically modified species can escape. Illegally sourced feed product and seed stock.
Waste Removal	Uneaten food and waste products can smother benthos. Ammonia can be toxic if not removed.
Production of Feed for Aquaculture	Fish meal and fish oil can go into the water column. Finding enough supply from a sustainable, legal source.

Aquaponics: Aqua Gardening

Aquaponics is the combination of aquaculture and hydroponics (gardening without soil). The aquaculture system acts as a source of organically fertilized irrigation water (from fish waste water) for the hydroponics system, and, the hydroponics system acts as a filter for the aquaculture system. It is a win-win!

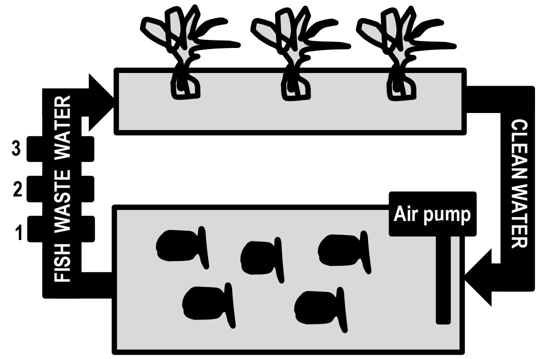

Figure 1: Fish waste water passes through the mechanical filter (1) biofilter (2) and sump (3) of the hydroponics system, which cleans the return water.

Q. How does aquaponics solve the issue of waste removal in aquaculture? Ans.

Fish waste is used for plant growth. Whereby, the aquaculture system acts as a source of organically fertilised irrigation water (from fish waste water) for the hydroponics system.