Educational Resource Unit
for Secondary Schools

THE OCEAN OF TOMORROW

Ocean Acidification and the Marine World

Te Moana a Haere Ake Nei
Te Whakakawatanga o te Wao nui a Tangaroa

NEW ZEALAND
MARINE STUDIES CENTRE

The New Zealand Marine Studies Centre, part of the University of Otago's Department of Marine Science, showcases marine life from southern NZ waters and provides expert knowledge and education about New Zealand's marine environment. Their educational programmes involve students in the excitement of scientific discovery, help them develop knowledge and skills, and encourage individuals to take responsibility and action for the future of our ocean resource.

The New Zealand Marine Studies Centre produces fact sheets, teacher guides, workbooks, activities and a range of Seashore ID Guides covering Northern and Southern New Zealand. Many of these resources are available in te reo Māori. These publications can be downloaded, free of charge, from ***www.marine.ac.nz***

Contact us about the range of educational programmes and resources available for schools and interest groups.

New Zealand Marine Studies Centre
Phone (03) 479 5826 | Email marine-studies@otago.ac.nz | www.marine.ac.nz

ISBN: 978-0-473-38953-6

Acknowledgements

This publication has been supported by a generous donation from ***The Lou and Iris Fisher Charitable Trust.***

The NZ Marine Studies Centre is grateful to the Ocean Acidification Research Theme, based at University of Otago, and the New Zealand Ocean Acidification Community (NZOAC) for expert assistance and to NIWA and the CARIM project for the use of the "*Acidification Studies*" infographic.

Photos: Abby Smith, Chris Hepburn, Tessa Mills and Philippa Crick.
Design by www.cre8ive.co.nz and printed by Otago Daily Times Print.

UNIVERSITY of OTAGO Te Whare Wānanga o Otāgo NEW ZEALAND
Otago Ocean Acidification Research Theme
www.otago.ac.nz/oceanacidification

NZOAC
New Zealand Ocean Acidification Community
Working together to understand the changing ocean *www.nzoac.nz*

CARIM Coastal Acidification: Rate, Impacts & Management

NIWA Taihoro Nukurangi

cre8ive MARKETING

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Why Study Ocean Acidification

The increase in atmospheric carbon dioxide (CO_2) caused by the burning of fossil fuels over the last 250 years has caused the effect popularly known as global warming, where the atmosphere and ocean is warming. It is also having another very important but mostly unseen effect on the world's ocean; acidification.

Ocean acidification is the process by which carbon dioxide from the atmosphere dissolves into seawater, thus forming carbonic acid and making the ocean more acidic. This also reduces the amount of carbonate in the water and increases the dissolution of calcium carbonate shells and skeletons.

The ocean has taken up about half of total fossil fuel CO_2 emissions since the start of the industrial revolution but this cannot continue forever. CO_2 in the atmosphere knows no borders and all areas of the ocean are taking up CO_2 even around New Zealand where our fossil fuel emissions are relatively low.

The effects of ocean acidification on the marine ecosystem are varied and often invisible to most people, but they have the potential to cause huge negative effects. Scientists all over the world are working towards understanding how ocean acidification interacts with global warming, weather and other climate issues. We rely on the ocean for a variety of resources and services including food, medicine, transport, waste removal, drinking water and leisure activities. Looking after our ocean is a big task, but we should treat this precious resource with respect. Understanding the impact that humans have on the natural world is being understood more and more every year thanks to scientific research. Greater understanding will allow us to predict, manage and even slow down the negative effects that ocean acidification will have on the animals, plants and humans who live on, in and by the water.

Working through this booklet, students will act as scientists investigating the effects of ocean acidification on the oceans around New Zealand and elsewhere in the world.

They will take a close look at the chemical processes which regulate acidification and find out how different environments and different animals respond. At the end, they will carry out their own scientific research project into a related topic which interests them, so encourage them to jot down any ideas along the way. In performing these experiments, they are joining the global community of marine scientists and coastal communities who are collecting knowledge for future generations.

Notes to Teachers / Educators

This resource is designed to help teachers and educators deliver lessons in the classroom that focus on the impact of climate change and more specifically ocean acidification on the marine environment.

The material is organised with background information, instructions to carry out the investigations and data forms for the students to record their results. There are 5 lessons that could be carried out in a classroom or science lab. The lessons should be delivered in order, as each one builds on the learning from the previous lesson. The lessons are generally designed to fit within a 50 minute period, although Lesson 2 will required a double period. Lessons 2 and 5 will also require the collection of tidepool species and seawater in advance.

Two independent research projects have been included along with ideas for extension. These ideas could provide the basis for homework assignments, keep students busy when they are waiting for the completion of the experiments or provide additional challenges for interested students. The activities could also form the basis of a science fair project.

Alternatively the programme could be delivered at the New Zealand Marine Studies Centre (NZMSC) in Dunedin over a one or two day period with experienced educators and scientists. The NZMSC education staff are also available to provide training for educators and teachers.

In summary this resource provides:

- A range of background information (supporting presentation and poster - see resource list page 39)
- A survey of before-and-after understanding of a sample population (the class) about ocean acidification
- Activities exploring the relationship between carbon dioxide and acidity
- Activities exploring the interaction of seaweed and animal biological activity and pH changes
- Investigation into the Impact of increasing acidity on corrosion of carbonate exoskeletons and vulnerability of different species and life stages
- Background information about changes through time
- An extension experiment investigating interactions of temperature changes and pH changes on survival and behaviours of marine invertebrates
- An extension experiment investigating interactions of temperature changes and pH changes on survival and behaviours of marine invertebrates
- Lead-in material to discussion about the role of humans past and present in climate change and ocean acidification

Curriculum Links

This unit of work is targeted at year 10 science students. Some activities may be adapted for year 9 students or extended for senior students. The resource material and activities have strong practical links to the key competencies as well as to a wide range of achievement objectives at level 4 and 5.

The unit provides an introduction to the global interdisciplinary nature of the science, the problem and the solutions. It can be used as springboard to enquire into predictions and present and potential consequences, and actions individuals, communities and nations can engage in to reduce future increases in ocean acidification.

Achievement Objectives

Level 4 - Science

Nature of Science:

- Understanding about science
  - Identify ways in which scientists work together and provide evidence to support their ideas.
- Investigating in science
  - Build on prior experiences, working together to share and examine their own and others' knowledge.
  - Ask questions, find evidence, explore simple models and carry out appropriate investigations to develop simple explanations.
- Participating and contributing
  - Use their growing science knowledge when considering issues of concern to them. Explore various aspects of an issue and make decisions about possible actions.

Living World: Ecology

- Explain how living things are suited to their particular habitat and how they respond to environmental changes, both natural and human-induced.

Material World: Chemistry and society

- Relate the observed characteristic chemical properties… to… natural processes.

Level 5 - Science

Nature of Science:

- Understanding about science
  - Understand that scientists' investigations are informed by current scientific theories and aim to collect evidence that will be interpreted through processes of logical argument.
- Investigating in science:
  - Show an increasing awareness of the complexity of working scientifically, including recognition of multiple variables.
  - Develop and carry out more complex investigations including using models.

Level 4 - Social Studies

Students will gain knowledge, skills and experience to:

- Understand that events have causes and effects.
- Understand how formal and informal groups make decisions that impact on communities.
- Understand how people participate individually and collectively in response to community challenges.

Level 5 - Social Studies

Students will gain knowledge, skills and experience to:

- Understand how people's management of resources impacts on environmental and social sustainability.
- Understand how the idea and actions of people in the past have had a significant impact on people's lives.
- Communicate in science
  - Use a wider range of science vocabulary, symbols and conventions.
  - Apply their understandings of science to evaluate both popular and scientific texts (including visual and numerical literacy).
- Participate and contribute
  - Develop an understanding of socio-scientific issues by gathering relevant scientific information in order to draw evidence based conclusions and to take action where appropriate.

Living World: Ecology

- Investigating the interdependence of living things (including humans) in an ecosystem.

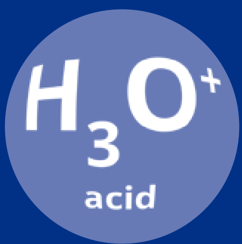
LESSON 1

Introduction to Ocean Acidification

Many students will have little understanding of what ocean acidifcation means or what it implies for a future ocean. A 2016 study in the UK, revealed that 80% of the public had never heard of ocean acidification and public awareness of ocean acidification was extremely low compared to their awareness of climate change (Capstick et al, 2016).

Investigating what we already know and how to measure acidity is a good starting point for learning about ocean acidification.

The most common definition of 'acid' is a substance that releases H_3O^+ ions in solution (also sometimes described as H^+ ions in older sources).



A common misconception concerns the term 'acidification'. It does not mean that we face a crisis like 'acid rain' of the 1970s when lakes became very acidic. No, the ocean is alkaline and will always remain so. However, the ocean is becomming less alkaline. That is, the pH is moving in the acid direction. This is like saying a cup of coffee is 'cooling' as it approaches room temperature but realising that it will never become actually 'cool' or 'cold' as in icy.

The higher the concentration of H_3O^+ ions in a solution, then the more acidic that solution is.

The complication is that in natural waters, like rivers or the ocean, the concentration of H_3O^+ ions can vary by a factor of many thousands. To compare these concentrations, scientists use the same sort of maths that geologists use to compare earthquakes. The scale used to compare acidity is called the pH scale. Both the Richter scale (for earthquakes) and the pH scale (for acidity) are 'logarithmic'.

A log is how many times you need to multiply 10 by itself to get the number you want. For example, the log of 100 is 2 because 100 = 10 x 10 (two lots of 10). Similarly, the log of a million is 6, because 1,000,000 = 10 x 10 x 10 x 10 x 10 x 10 (6 lots of 10).

The important take home message is that a pH difference of 1 means the concentration of H_3O^+ ions differs by a factor of 10. So a change of ocean pH from 8.14 (today) to a predicted 7.8 (year 2100) is a 120% change in concentration of H_3O^+. The current value of 8.14 is itself about 0.1 less than the preindustrial value of about 8.2 (about 30% change in H_3O^+ concentration) so by 2100 the H_3O^+ concentration will have changed by about 150% since the start of the industrial revolution.

An additional lesson about logarithmic scales and pH may be useful including an experiment to make a cabbage juice indicator.

ACTIVITY 1A. What do we know about ocean acidification?

Objective

To assess how much students know about ocean acidification.

Materials

- *1A Student Survey Form* for each student
- *1A Class Survey Results Form* for the class
- pencils, graph paper
- Computer (optional for graphing of results)

Methods

1. Complete survey - hand out the student survey form and ask students to complete it, independently, when they enter the classroom.
2. As a class, review the response categories on the class survey results form. The responses for question 1 are straightforward and easily collated. With the class, review the themes listed for question 2 on the class survey results form and highlight on the board. If there are any results that do not fit the themes listed you may add an additional theme. With the class, review the responses to question 3 and come up with your own themes for causes of ocean acidification. List these on the board and the class survey results form.
3. Code the student surveys – students may code their own survey form or swap with a neighbour and code someone else's response. If a result does not fit any of the categories listed, a new category may be made in consultation with the rest of the class.
4. Collate the class results – pass around the class survey results form, so that each student may add their response (eg. Add tally mark to the appropriate category).
5. Code surveys - ask students to swap their survey form with their neighbours to code the results in the categories provided on the summary sheet. Add tally marks to the the summary table.
6. Graph the results – this can be done individually or different students can graph different sections.
7. Compare the results – how do your results compare with the UK results or other classes? Repeat this survey at the end of the programme (see Lesson 5) and see how your understanding has changed.

Discussion

1. How would you describe your class' understanding of ocean acidification?
2. How does your class' understanding compare with other classes, the UK public, etc.
3. Why do you think it is low or high?
4. How do you think you could find out more about ocean acidification?

Extension

1. Survey a different group of people (seniors, community group, younger class, older class) - how did their results compare?
2. What factors might affect people's understanding of ocean acidification (eg. educational level, profession, location)? Design a survey to investigate your prediction.

ACTIVITY 1A. What do we know about ocean acidification?

STUDENT SURVEY FORM

Please answer the questions independently. There are no right or wrong answers.

1. How much, if anything, would you say you know about ocean acidification?

_____ I have not heard of ocean acidification before

_____ I have heard about ocean acidification but I know almost nothing about it

_____ I know just a little about ocean acidification

_____ I know a fair amount about ocean acidification

_____ I know a great deal about ocean acidification

2. List the first three thoughts, images or phrases that come to mind when hearing the term 'ocean acidification':

i. ______________________________

ii. ______________________________

iii. ______________________________

3. What do you think are the causes of ocean acidification?

i. ______________________________

ii. ______________________________

iii. ______________________________

School: ______________________________ Age: ______________

Name (Optional): ______________________________ Date: ______________

ACTIVITY 1A. What do we know about ocean acidification?

CLASS SURVEY RESULTS

Use this form to summarise the class results. Graph the results.

Number of students surveyed? n = ____

1. UNDERSTANDING OF OCEAN ACIDIFICATION – tally the class results.

Statements	Tally	Total
I have not heard of ocean acidification before		
I have, but I know almost nothing about it		
I know just a little about ocean acidification		
I know a fair amount about ocean acidification		
I know a great deal about ocean acidification		

2. THEMES WHICH PEOPLE ASSOCIATED WITH OCEAN ACIDIFICATION – code individual responses and tally the class results.

Theme	Tally	Total
Pollution		
Harm to marine organisms		
Concern & negative language		
Climate change		
Harm to people		

3. CAUSES OF OCEAN ACIDIFICATION - as a class decide on your own themes for causes of ocean acidification, code individual responses and tally the class results.

Theme	Tally	Total

ACTIVITY 1B. What is pH? And how do we measure it?

Objective

To explore acidity and pH.

1. What does pH measure?
2. How do we measure pH?
3. What substances have high and low pH?
4. What does that mean?

Materials

- pH paper (optional)
- pH meter (see resource list for where to purchase)
- variety of liquids with different pH (eg. Tap water, seawater, milk, coke, soda water, lemon juice, vinegar, milk of magnesium or antacid tablet dissolved in water)
- *1B Student Data Form*
- pencils, pens
- spoons for tasting (1 per student and wipes for students to clean their spoon between tastings)

Methods

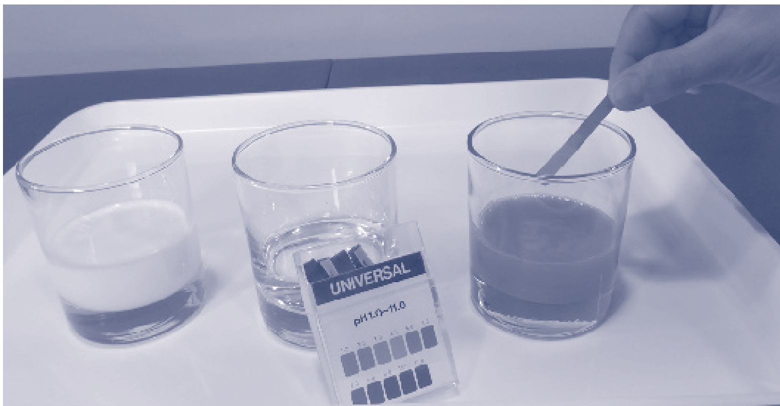
1. Describe what pH is in your own words to your neighbour, then record on data form.
2. Describe something edible that tastes acidic. Give examples.
3. Describe something edible that tastes basic (alkaline). Give examples.
4. Taste a number of different liquids and place in order from most acidic to least acidic (basic). Record these on the data form.
5. Measure the pH of these substances with pH paper (optional).
6. Measure the pH of these substances with a pH meter. Remember that the instrument must be calibrated against a known standard.
7. Record your data in the student data form.

Discussion

1. How did the results with pH paper and the pH meter compare?
2. How could you ensure that the pH meter is giving you accurate measurements?
3. Which liquids have the highest pH, which have the lowest?
4. Were your predictions accurate?
5. Why is measuring pH important?

Extension

1. Do some research to find out the pH of other substances (eg. amonia, stomach acid, blood, distilled water).
2. Predict the pH of rain water, measure it, then explain why it is not neutral.



pH paper being used to measure some tasting liquids

A neutral pH (that of pure water that is not in contact with the atmosphere) is assigned a value of 7. We define acids as a solution with pH less than 7, and bases as solutions with pH greater than 7.

$pH = -\log [H_3O^+]$

ACTIVITY 1B. What is pH? And how do we measure it?

STUDENT DATA FORM

Describe what pH means:

____

____

If something edible is acidic, what do you think it tastes like? Give examples.

____

____

If something edible is alkaline, what do you think it tastes like? Give examples.

____

____

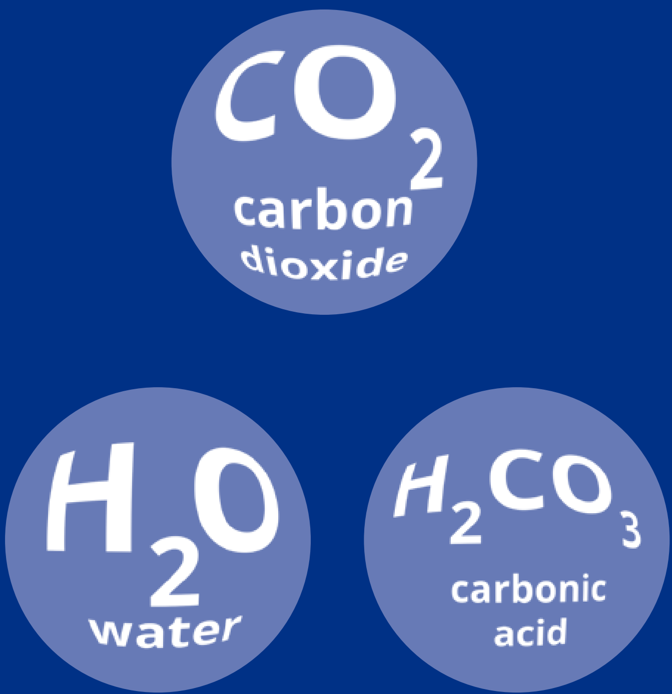
Substances (listed from low acidity to high acidity based on taste)	**pH (Paper)**	**pH (Meter)**	**High or Low Acidity?**

Student / group name: ____________________________ Date: ________________

LESSON 2

The pH of the ocean changes naturally all the time. This lesson investigates how pH changes in the natural world and gives an understanding of the chemical, physical and biological processes which can affect ocean pH. These naturally occuring processes are simulated in a rock pool type environment.

The session requires two 50 minute periods back-to-back in order to have enough time to record a change in pH. It needs to start with the set up of the tide pool simulation. The second activity, rock pool processes, should be done once the experiment is running, although you will need to stop every 15 minutes for data collection.



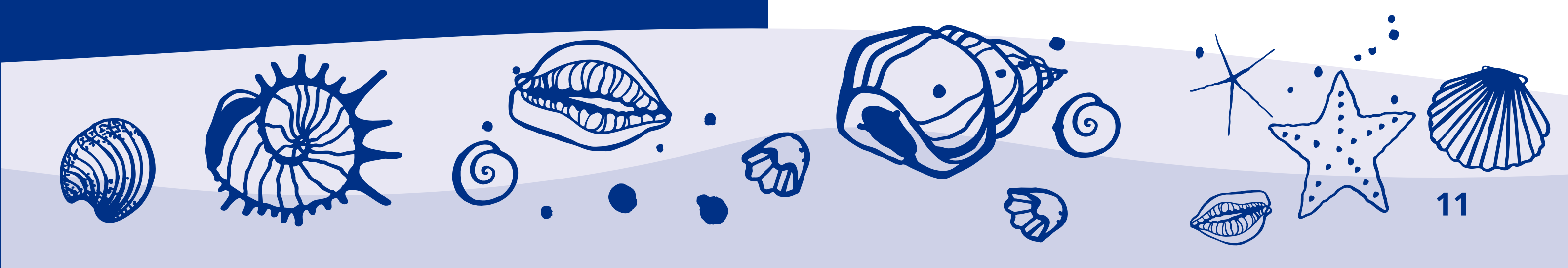
Natural Changes in pH

Generally speaking, the deeper the ocean the more stable the pH – at the surface, there are many factors which can contribute to changes in pH, such as temperature, season, weather, rivers. Deeper in the ocean (below a kilometre or two), however, there is a smaller natural pH range, generally keeping within a range of 8.0 – 8.2.

Along the coastline, pH variation is greater than in the open ocean, due to a combination of factors. These include temperature, tidal and wave mixing, the influence of pollution and shipping, freshwater input from river mouths, dissolution of soft rocks and the action of marine animals and plants. This variation makes coastal oceans a good place to study natural variation in seawater pH. In a harbour, when the tide goes out leaving rock pools behind, rock pools can be studied as a microcosm ("small world") to simulate changes in seawater pH in the open ocean.

The longer the rock pool water is isolated from the main body of the sea, the more the physical, chemical, and biological properties of the seawater change. Animals and plants living in the rock pool need to have the physiological flexibility to cope with these changes for long enough to survive until the tide comes in again.

Natural changes in seawater pH result from dissolution of atmospheric CO_2 into the ocean.



Equations for CO_2 dissolution and the loss of carbonate:

1. $$CO_2 + H_2O \rightleftharpoons H_2CO_3$$
carbon dioxide | water | carbonic acid

2. $$H_2CO_3 + H_2O \rightleftharpoons HCO_3^- + H_3O^+$$
carbonic acid | water | bicarbonate | acid

3. $$CO_3^{2-} + H_3O^+ \rightleftharpoons HCO_3^- + H_2O$$
carbonate ions | acid | bicarbonate | water

Reaction 1:

When CO_2 dissolves in water, it forms carbonic acid (H_2CO_3).

Reaction 2:

The carbonic acid (H_2CO_3) then reacts with water (H_2O) to form a bicarbonate ion (HCO_3-) and a H_3O^+ ion (remember producing H_3O^+ is the definition of an an acid). Most carbon in the ocean is already in the form of bicarbonate ions.

Reaction 3:

Some of the H_3O^+ produced in reaction 2 reacts with some of the carbonate ions (CO_3^{2}-), thereby reducing the amount of carbonate in the ocean. The rest of the H_3O^+ from reaction 2 'hangs around' causing a decrease in pH (ie. more acidic).

This is a problem for two reasons:

1. A change in pH places a strain on an organism.
2. Calcium carbonate shells dissolve more easily when carbonate levels are low.

ACTIVITY 2A. Rock pool simulation

Objective

To investigate what causes natural rises and falls in pH.

1. Where in the ocean would you expect to find naturally occurring changes in pH?
2. How do you think pH varies in a rock pool and why?
3. What other factors might affect the pH of seawater?

Materials

- pH meter, thermometer, salinity meter, dissolved O2 meter
- 8 aquaria/containers (5 – 10 litres each)
- 4 dark clothes to cover 4 aquaria
- Tide pool animals and plants
- Seawater (to half fill the aquaria)
- *2A Student Data Form*

Methods

Ideally the full experiment would be carried out by each group of students, with half of the teams carrying it out in the light and half carrying it out in the dark.

1. Measure temperature, dissolved oxygen and pH in the bucket of seawater.
2. Half fill each container with seawater.
3. Leave container 1 with just seawater (control).
4. In container 2 place some seaweed in the light (make sure there is a large surface of seaweed exposed to light, but not so much that it is covering seaweed below).
5. In container 3 place a few (2-3) marine animals.
6. In container 4 simulate a rock pool using both animals and seaweed.
7. Repeat the setup in the remaining 4 containers and cover each with a dark cloth.
8. Record the temperature, dissolved oxygen and pH in each aquarium.
9. Leave undisturbed for 60 minutes or more, while you do Activity 2B.
10. Measure temperature, dissolved oxygen and pH again and record on data form.
11. Graph the results.

Results and Discussion

1. Summarise your results
2. Why was one container left with just seawater?
3. Why was the experiment replicated in dark conditions?
4. What conditions changed over time? What didn't change over time?
5. Where in the ocean would you expect to find stable pH over time?
6. Which sea creatures are likely to be better adapted to shifts in pH? Coastal, intertidal or open ocean?
7. How could the experiment be improved?
8. Why is replication important?

Extension

- Do some library research on how pH levels might change in coastal areas vs open ocean. Which environment is likely to be more stable? Why?

Aquarium tanks set up in light conditions

ACTIVITY 2A. Rock pool simulation

STUDENT DATA FORM

Student / group name: ______________________________ Date: ________________

Start time: ______________ Finish time: _______________ Time elapsed: __________

Temperature

	Condition? Light or Dark	Start temp.	Finish temp.	Change in temp.	Increase or decrease
1	Seawater				
2	Seaweed				
3	Marine animals				
4	Marine animals and seaweed				

Dissolved oxygen

	Condition? Light or Dark	Start O_2 level	Finish O_2 level	Change in disolved O_2	Increase or decrease
1	Seawater				
2	Seaweed				
3	Marine animals				
4	Marine animals and seaweed				

pH

	Condition? Light or Dark	Start pH	Finish pH	Change in pH level	Increase or decrease
1	Seawater				
2	Seaweed				
3	Marine animals				
4	Marine animals and seaweed				

Observations:

____

____

ACTIVITY 2B. Rock pool processes

Objective

To explore what biological processes cause the change in pH in a rock pool.

Materials

- *2B Student Data Form*

Methods

This activity should be done after Activity 2A is set up and before the results are collected.

1. Discuss the physical condition that a rock pool is exposed to when the tide is high and when the tide is low. List on the *2B Student Data Form*.
2. Discuss what the terms photosynthesis and respiration refer to and record on the *2B Student Data Form.*
3. On the diagram list the animals and plant found in your rock pool.
4. List what is needed for their survival under inputs. These are things that they require to carry out life sustaining biological processes (eg. photosynthesis, respiration, feeding).
5. Under outputs list what is released into the rock pool by the plants and animals on a daily basis.

Discussion

1. Predict how you think temperature, oxygen levels and pH might change over time.
2. Think about the design of Activity 2A, how could the experiment be improved to test your predictions?
3. What factors might affect the degree of change observed?
4. What other effects might increasing CO_2 have on marine plants and animals?

ACTIVITY 2B. Rock pool processes

STUDENT DATA FORM

Student / group name: ______________________________ Date: ______________

1. Describe and compare the physical conditions of a rock pool with the ocean.

Rock Pool	Ocean

2. Define the following terms

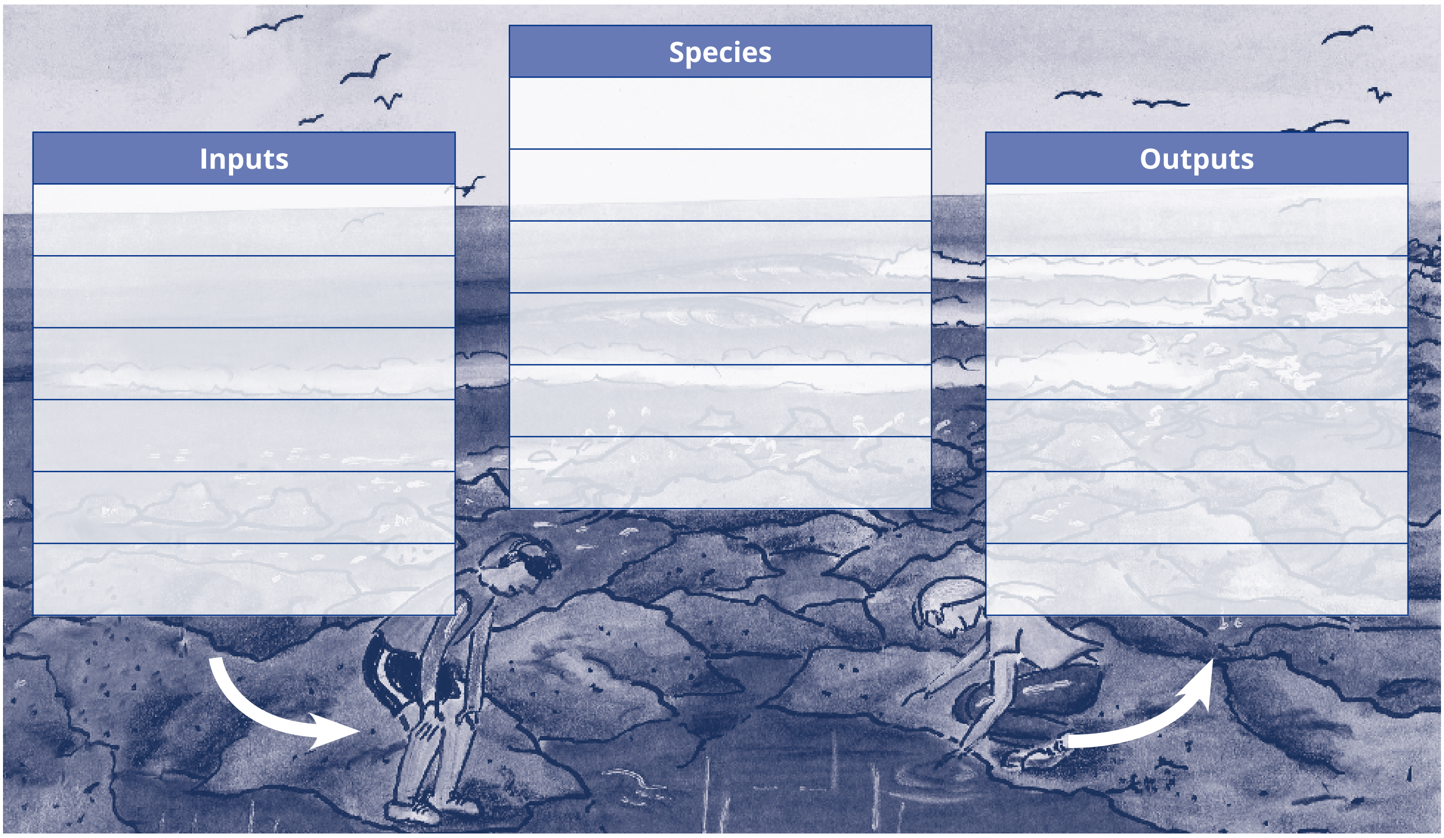
Photosynthesis:

____

Respiration:

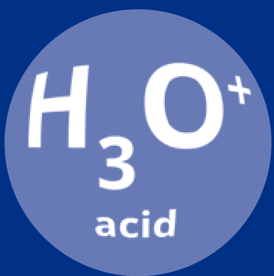
____

3. On the diagram below list the animals and plants found in your pool. List what is needed for their survival under inputs. These are things that they require to carry out life sustaining biological processes (eg. photosynthesis, respiration, feeding). Under outputs, list what is released into the rock pool by the plants and animals on a daily basis. Think about how it might change from day to night.



LESSON 3

The main source of carbon dioxide (CO_2) in the oceans is from the atmosphere. In a natural state, the CO_2 concentrations of the atmosphere and the ocean equibrate (see next page). However, burning of fossil fuels has increased the amount of CO_2 in the atmosphere rapidly so that the equilibrium between CO_2 in the atmosphere and CO_2 in the ocean has changed. This lesson will look at how excess CO_2 in the atmosphere changes pH of seawater and how this can affect the animals in the oceans.



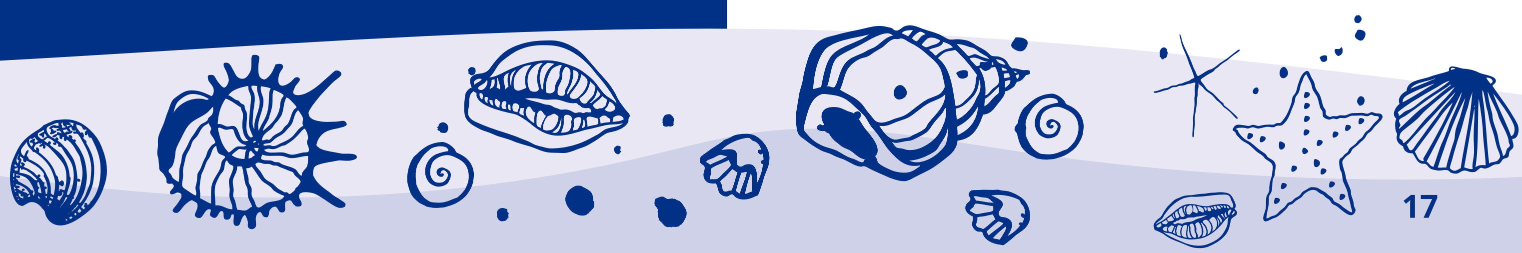
Anthropogenic Changes in pH

Carbon dioxide is produced as a waste gas from the burning of fossil fuels. Fossil fuels are things like oil and coal that are have been buried for hundreds of millions of years. CO_2 is a greenhouse gas, meaning that it contributes to the warming of the planet.

We measure CO_2 in the atmosphere in the units "parts-per-million" (ppm). Over the last 150 years, anthropogenic emissions have increased atmospheric CO_2 by over 40% from pre-industrial levels, from around 280 ppm in the year 1750 to around 400 ppm in 2017.

As the release of fossil CO_2 increases, the amount of carbon dioxide absorbed by the oceans increases as well but it cannot continue to indefinitely absorb CO_2 at the rate it has up until now. The last lesson examined the natural changes in pH and how dissolved CO_2 in the oceans can cause an increase in the concentration of H_3O^+ ions and therefore a decrease in pH.

A few hundred parts per million may not seem like a big deal but these seemingly small changes have an enormous effect.



Southern Ocean Tipping Points

Carbon dioxide (CO_2) is not absorbed equally by water all over the globe. A complex interaction of big waves, wind, and high CO_2 solubility in cold waters means that the Southern Ocean and adjacent waters usually take up more CO_2 than tropical waters. The waters around New Zealand, especially the colder sub-Antarctic waters, are therefore likely to acidify slightly faster compared to other parts of the global ocean.

Ocean acidification increases the overall amount of carbon in the ocean but decreases the amount of carbonate ions (CO_3^{2-}). Lower levels of carbonate makes it easier to dissolve shells. This means organisms living in Southern Ocean waters will find it harder to make shells, or that they will need to use a lot of energy to maintain their shells.

Substances are not infinitely soluble and one of the things that controls how easily calcium carbonate shells dissolve is the ratio of carbonate ions actually present compared to the theoretical maximum amount of carbonate ions. This ratio decreases with depth meaning that shells in deep water dissolve more easily than shells in shallow water.

What is Equilibrium?

Almost all reactions are reversible as indicated by the $\rightleftharpoons$ symbol. In any sample some molecules are doing the reverse reaction. An equilibrium helps describe the relative balance between what chemists call the forward reaction (going from left to right) and the reverse reaction (from right to left). Equilibrium describes the number on each side of the reaction but does not mean the two sides have to be balanced.

To illustrate this, a quick hands-on activity can be done. Divide the class into two groups: Small group (1/5th) of class, large group (4/5th of class). Ask the small group to crumple up A5 sized squares of newspaper to form balls. The task is for the small group to throw these ball as fast as they can at at the large group. And the large group to throw them back, and for both groups to continue to throw them back until the teacher says to stop.

Equilibrium is reached at any one time. About the same number balls are with the small group, in flight, or with large group. The number of balls is not the same for each group (ie not equal) - but equilibrium is reached (ie a ‘consistent balance; is reached). Ask the students to think about how they could disturb the equilibrium. For example adding more balls would equate to adding CO_2. It takes time time for a new equilibrium to be established, the consequences of this can be discussed.

ACTIVITY 3A. Can we change the pH of the ocean?

Objective

To explore how the increase in atmospheric CO_2 changes the pH of seawater.

Materials

- Straws
- 2 medium size containers (2 litre)
- 1.5 litres of seawater per container (tap water could also be used if seawater not available)
- *3A Student Data Form*
- *3A Charts*

Methods

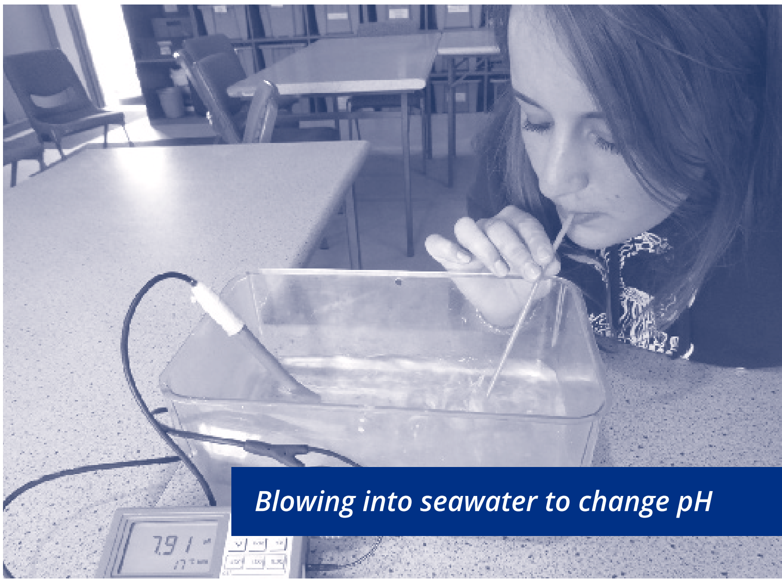
1. Investigate the gases that we breath out.
2. Measure the pH and temperature of the water and record.
3. Get a team volunteer to use the straw provided to blow bubbles into the seawater sample for 20 seconds exactly.
4. What is the pH of this water now? Record. (Keep this seawater for Activity 3B).
5. Use the graph provided to convert the change in pH (log scale) to a % change in pH.
6. Repeat the experiment with water of lower or higher temperature (~10°C difference) and record results.
7. Brainstorm human activities that increase CO_2 in the atmosphere and record. Circle the activities that you are involved in.

Results and Discussion

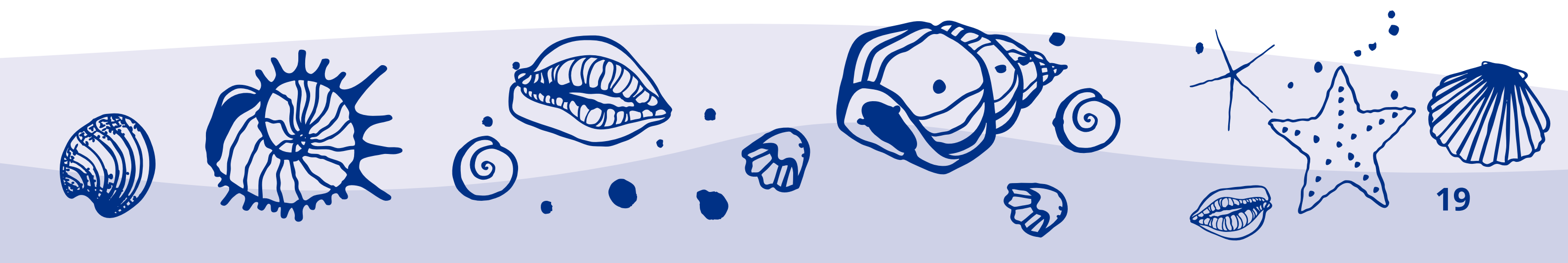
1. What happened to the pH levels when you blew?
2. What biological process is involved?
3. What situation does blowing through a straw simulate?
4. What would happen if you piped the exhaust from your car into the water?
5. Can you describe the effects of increased CO_2 in the atmosphere (from anthropogenic pH change) on the oceans? How about on a rock pool at low tide?
6. How do global warming and ocean acidification interact to influence ocean pH?
7. How do you think this affects places like the Antarctic, the Southern Ocean (around NZ) and the Great Barrier Reef?

Extension

1. What is the level of CO_2 in the atmosphere right now? Where would you look to find out?



Blowing into seawater to change pH



ACTIVITY 3A. How can we change the pH of the ocean?

STUDENT DATA FORM

Student / group name: ______________________________ Date: ________________

1. Record the change in pH of water when you 'blow into it'.

Sample #1 Temp. = ___ºC	pH of water at start	pH of water at end	Change in pH (log scale)	% Increase or decrease
Your sample				
Class average				

Sample #2 Temp. = ___ºC	pH of water at start	pH of water at end	Change in pH (log scale)	% Increase or decrease
Your sample				
Class average				

2. What was the effect of temperature on pH?

____

____

____

3. List human activities that increase CO_2 in the atmosphere. Circle the ones that you do.

____

____

____

4. Define the word "anthropogenic".

____

____

____

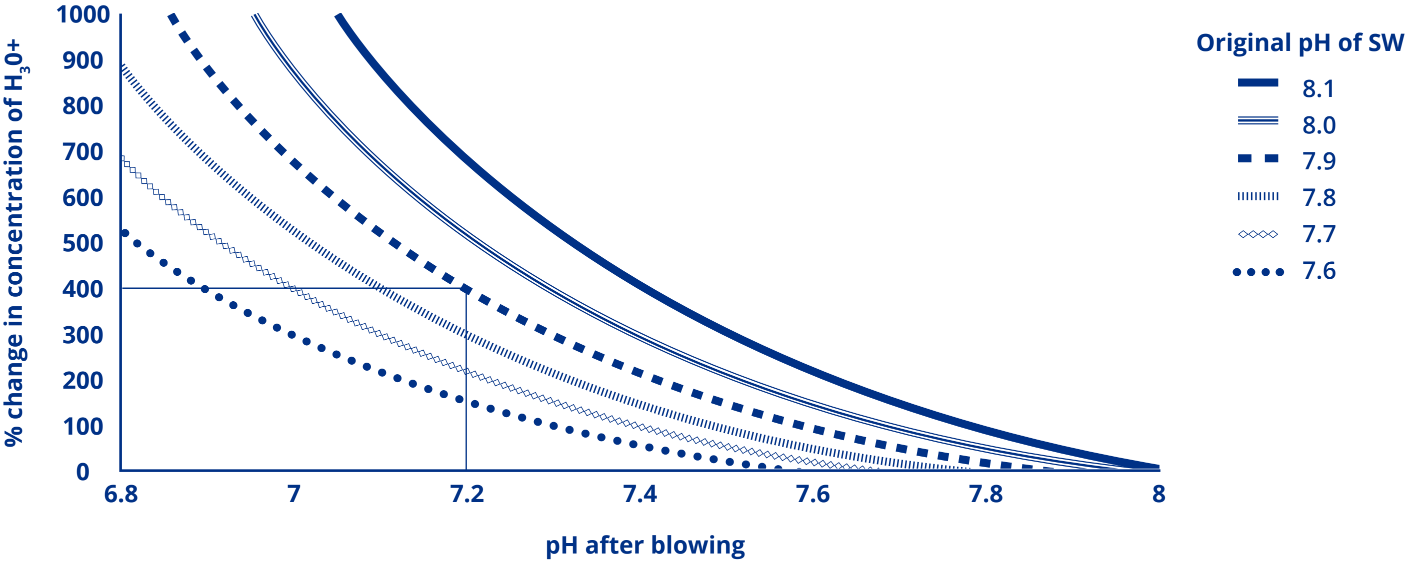
ACTIVITY 3A. How can we change the pH of the ocean?

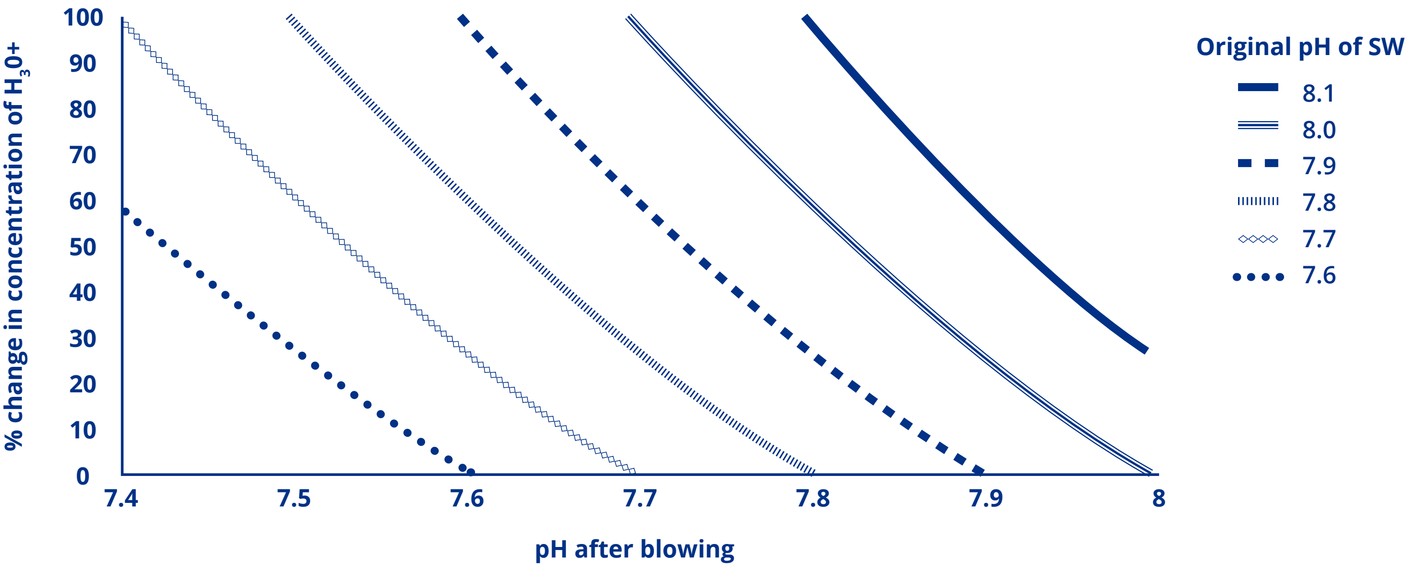
CHARTS

These charts show the % change in concentration of H_3O^+ that corresponds to the final pH of seawater after blowing into it. To use this chart select the line that is closest to the START pH of the seawater and follow the line. The pH reached after blowing into the seawater is read on the x-axis (horizontal) and the % change in H_3O^+ concentration is found on the y-axis (vertical).

For example, if you start with seawater at pH 7.9 and end up at pH 7.2, then the concentration of H_3O^+ has increased by about 400%, (see below).

The second chart shows a zoomed in view of the region most relevant to real world ocean acidification levels.





ACTIVITY 3B. Combined effects of increased temp and increased ocean acidity

Objective

We will investigate the effect of temperature increase and pH decrease on the turn-over response of a marine animal.

A turn-over response is a simple tool to get an idea of the general health / well-being of an animal. The time it takes an animal to right itself once flipped over onto its back can be related to the resilience of the animal and its survival.

Materials

- 4 living spotted black top snails (*Diloma aethiops*) per group (all approximately the same size)
- Seawater at 2 different pHs (from Activity 3a) and 2 different temperatures (see the conditions listed below)
- 1 ice cream container / group
- 1 small pottle / group
- Stopwatch / timer
- *3A Student Data Form*
- Microwave / water heaters
- pH meter
- Thermometer
- Teaspoons

Methods

1. This activity works well when done in groups of three or four. Assign one of the four different seawater treatments to each group, making sure at least one group is is assigned to each of the following treatments:
   - Control (normal ocean temperature and pH)
   - Increased temperature (25-27°C) but normal pH
   - Lowered pH (7.3 – 7.6) but normal temperature
   - Increased temperature (25-27°C) and lowered pH
2. Place seawater in the ice cream container and adjust the temperature or pH accordingly.
3. Place 4 snails in the containers. They must be acclimated (approximately 15 minutes) in the seawater before starting the experiment.
4. Turn over all the snails in each treatment using a spoon and start the stopwatch. (Touching the snail's operculum with your hand seems to affect their behaviour.)

   As soon the shell has flipped over, stop the stopwatch and record the time. Remove from the container.
5. Repeat with the remaining 3 animals in each treatment. Record results as you go into the table provided.

Discussion

1. Summarise your results. How do they compare to the combined class results?
2. What does this tell you about value of replication?
3. Why do you need to leave the animals to acclimatise before the experiment?
4. Define the term synergy and investigate how it is relevant to pH changes in the ocean.

ACTIVITY 3B. Combined effects of temperature and ocean acidity

STUDENT DATA FORM

Student / group name: ______________________________ Date: ________________

Record time to turn over and behaviours observed (eg. Time for antennae to appear, number of attempts to turn over, time for foot to reach over the edge of the shell for the first time)

Condition # ____	Temperature = pH =	
	Behaviours observed	Turn-over time
Snail #1		
Snail #2		
Snail #3		
Snail #4		
Average turn-over time		

Record the turn-over time for snails under the following conditions (class data):

Snail	#1. Normal T and pH (control)	#2. Increased T normal pH	#3. Decreased pH normal T	#4. Increased T & decreased pH
Temperature				
pH				
Replicate 1				
Replicate 2				
Replicate 3				
Replicate 4				
Average turnover time				

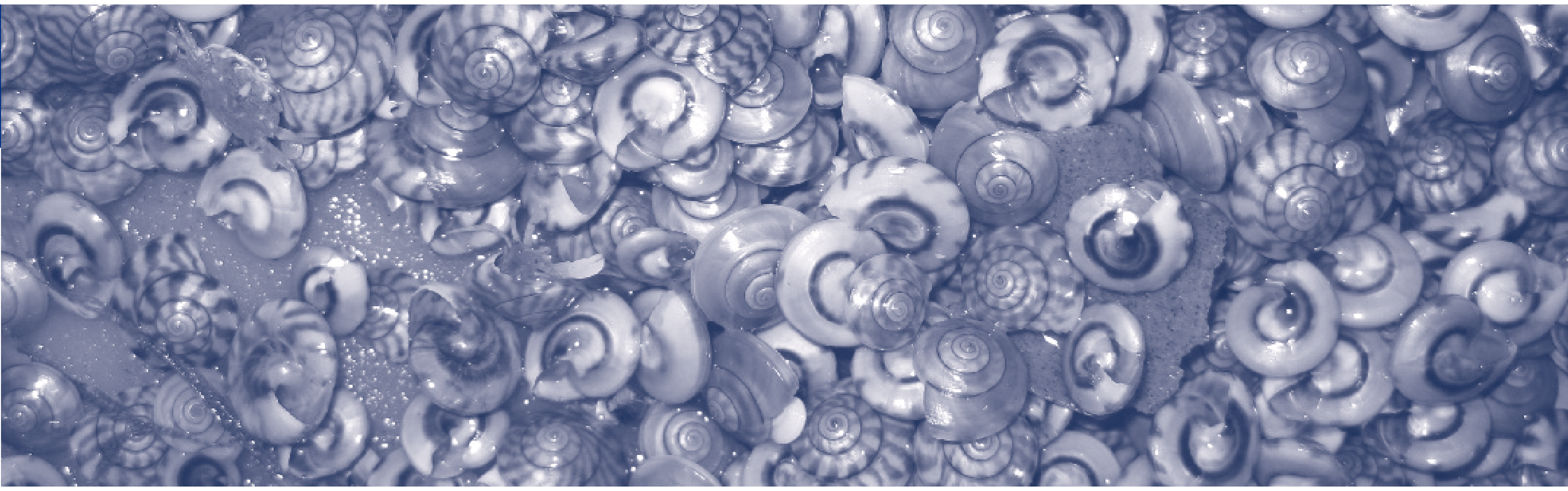
LESSON 4

The pH of our ocean is changing and some animals (and algae) are more vulnerable than others. It is generally agreed by scientists that animals which produce calcium carbonate shells are among the most vulnerable to the effects of ocean acidification. In this lesson, we will investigate how ocean acidification affects marine life and to understand that not all marine species are affected by acidification in the same way and to the same extent.

Impacts of Ocean Acidification on Marine Life

Ocean acidification can affect marine biological communities in many different ways. Currently, global research is focussing on the impacts of ocean acidification on reproduction, development of young and juvenile animals, as well as physiology and adult metabolism. Scientists are also studying the effects of ocean acidification on whole ecosystems through the use of 'natural labs'.

In New Zealand, one of the main areas of research is the effect of low pH on the hard shells of marine invertebrates. Animals such as tio (oysters), kina (urchins), paua (abalone) and tuangi (cockles) make hard shells made out a mineral called calcium carbonate ($CaCO_3$). Calcium carbonate is the main component of marble. (Marble is made of old shells that have been heated and squeezed). Calcium carbonate is also a component of eggshells but not bones. (Bones are various calcium phosphate minerals).



The chemistry behind dissolution of calcium carbonate shells

Organisms with calcium carbonate shells are vulnerable to ocean acidification because the lower pH and lower levels of carbonate both promote the dissolution of calcium carbonate.

It is not so much a scarcity of carbonate to make shells that is a problem, because for most species, shell building involves combining calcium ions (Ca^{2+}) and bicarbonate ions (HCO_3^-). It surprises many people to learn that the formation of calcium carbonate shells is a *source* of CO_2 not a *sink* for CO_2. Making 1 molecule of $CaCO_3$ from a calcium ion requires 2 molecules of bicarbonate (HCO_3^-) and releases 1 molecule of H_2O and 1 molecule of CO_2. (Yes, it is possible to write other equations that seem to describe the formation of calcium carbonate and you may see these as you search for information but these are not correct.)

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$$

calcium ion	2 bicarbonate ions	calcium carbonate	carbon dioxide	water

This reaction in the equation occurs in the forward (left to right direction) under the conditions in the surface oceans. That is, marine organisms like corals and shellfish are able to extract bicarbonate ions from seawater to make their shells or skeletons. However, as we will see, those conditions can be changed so that the reverse reaction happens, causing the calcium carbonate to dissolve:

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$$

calcium carbonate	carbon dioxide	water	calcium ion	2 bicarbonate ions

This is what happens when limestone rocks are weathered by the action of rain and air. It is no surprise, therefore, that the most abundant ions in most river waters, calcium (Ca^{2+}) and bicarbonate (HCO_3^-), are derived from weathering. This reverse reaction, the dissolution of calcium carbonate, is promoted by low levels of carbonate.

The CARIM poster will help explain this information to your students (see page 37).

ACTIVITY 4A. Shell response to ocean acidification

Objective

To investigate what effect high acidity solutions will have on shells.

1. Will more acidic solutions have more effect on the shells?
2. Will small shells be affected more or less than larger shells by more acidic conditions?

Materials

- Seawater, distilled water (for rinsing)
- Acetic acid (vinegar)
- Hydrochloric acid (HCl) 10% (1M)
- pH paper, filter paper, petri dishes, paper towels, teaspoon
- Oyster shells (and container and mallet to crush them)
- Balance (to a 10th of a gram)
- Plastic 3ml transfer pipettes , 10-20 ml measuring cylinder, tray
- *4A Student Data Form*
- Pen, pencil, safety glasses, gloves

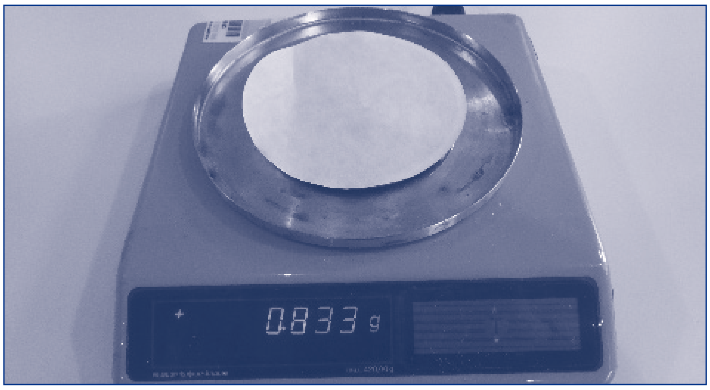
Methods

Measuring pH

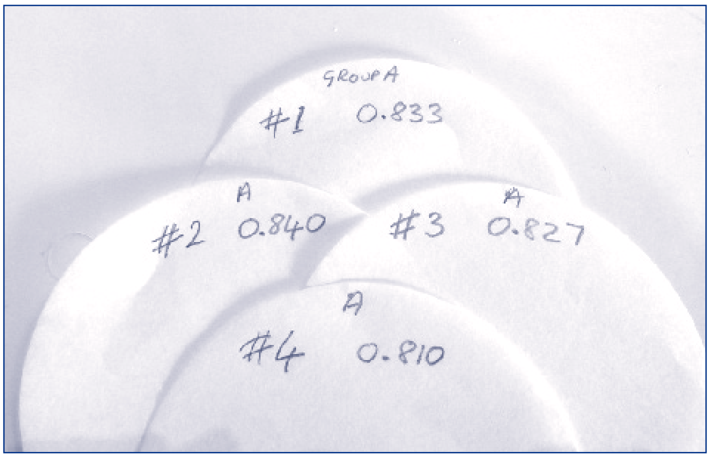
1. Use your pH paper to carefully test the pH of each of the liquids you have in front of you (seawater, acetic acid, hydrochloric acid). Safety glasses and gloves should be worn.
2. Which is least acid? Which is most acid?

Preparing oyster shells

3. Use the pencil to number the circular filter papers (#1, #2, #3, #4). Write your team name on each paper too.

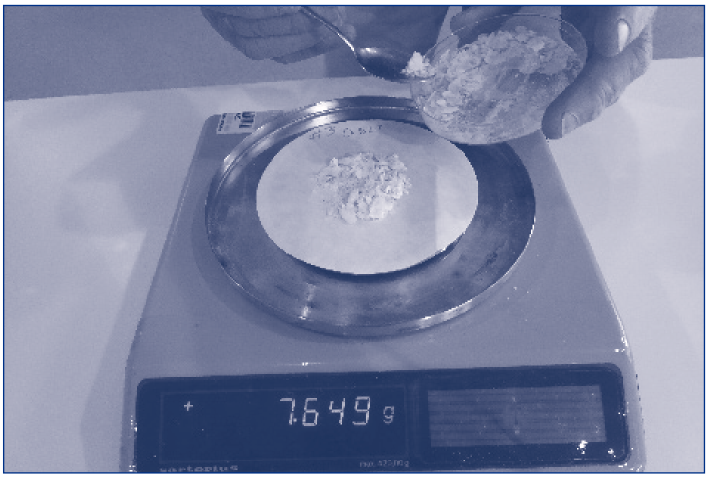


4. Then weigh each paper – and record the weight in the laptop spreadsheet (or data form).



5. Crush the oyster shell until a mixture of fine and coarse pieces are formed. Safety glasses should be worn.
6. Place a plastic petri dish on the balance and tare (T) to zero. Then carefully collect and place all the crushed shell material in the dish. Record the weight of crushed shell in the spreadsheet. Calculate the weight of a quarter of this sample.

Separation of oyster shell pieces



7. Return the balance to zero and place filter paper #1 on the balance (DON'T ZERO THIS), scales should read somewhere between 0.8 and 0.9g.

8. Pick out the largest pieces of oyster shell and place approximately a quarter of the crushed sample on paper 1. Note and record total weight of paper and sample in the data form. Place paper and sample carefully on a petri dish.

9. Return the balance to zero and place paper 2 on the balance (DON'T ZERO THIS), scales should read somewhere between 0.8 and 0.9g. Use the teaspoon to mix the remaining pieces and to scoop up another quarter weight of mixed sample. Note and record total weight of paper and sample in the spreadsheet. Place paper and sample carefully on a petri dish.

10. Return the balance to zero and place paper 3 on the balance (DON'T ZERO THIS), scales should read somewhere between 0.8 and 0.9 g.
Use the teaspoon to mix the remaining pieces and to scoop up another quarter weight of mixed sample. Note and record total weight of paper and sample in the spreadsheet. Place paper and sample carefully on a petri dish.

11. Return the balance to zero and place paper 4 on the scale (DON'T ZERO THIS), scales should read somewhere between 0.8 and 0.9g. Use the teaspoon to mix the remaining pieces and to scoop up another quarter weight of mixed sample. Note and record total weight of paper and sample in the spreadsheet. Place paper and sample carefully on a petri dish.

Treating samples with acidic solutions

12. Mark three pipettes with red, yellow and green tape.

13. Using pipette with red tape carefully take 1ml of HCl and drop onto sample 1 (large shell pieces). Record your observations. Leave for exactly 2 minutes while continuing with next steps. Rinse the sample after 2 minutes (see step 17).

14. Using plastic pipette with green tape carefully take 1 ml of seawater and drop onto sample 2 (small shell pieces). Record your observations. Leave for exactly 2 minutes while continuing with next steps. Rinse the sample after 2 minutes (see step 17).

15. Using plastic pipette with yellow tape carefully take 1 ml of acetic acid and drop onto sample 3 (small shell pieces). Record your observations. Leave for exactly 2 minutes while continuing with next steps. Rinse the sample after 2 minutes (see step 17).
16. Using plastic pipette with red tape carefully take 1 ml of HCl and drop onto sample 4 (small shell pieces). Record your observations. Leave for exactly 2 minutes while continuing with next steps. Rinse the sample after 2 minutes (see step 17).
17. After 2 minutes gently wash each sample with 10 ml distilled water measured in small beaker by very slowly pouring the water over the sample. Let them drain for about 1 minute.

Drying the samples

18. Fold 4 paper towels in half, one for each sample. Carefully lift filter paper #1 with shell sample and carefully place on folded paper towel. Repeat for sample #2, #3, #4.
19. Let them settle for about 1 minute then carefully place on tray, take to the "pie-warmer" dryer and carefully transfer to a rack for drying. Leave for 40 minutes.
20. If a drying oven isn't available, leave overnight in a warm place and finish the experiment during the next class.
21. Clean and tidy work space.

Weighing of dried samples

22. After drying, carefully transfer samples back to tray, take to your scales. Check scales are zeroed.

23. Carefully and slowly lift filter paper sample off paper towel and reweigh. Note and record final paper plus sample weight in spreadsheet. Do this for each of the 4 samples. Calculate change in weight, as a percentage change from original weight (the laptop spreadsheet will do this automatically for you).
24. Graph your results.
25. Post your result on the board to compare with other groups.

Results and discussion

- Which changed more - small or large pieces - when treated with hydrochloric acid?
- Did the solutions with higher acidity (lower pH) have a more corrosive effect on the shells?

STUDENT DATA FORM

Student / group name: ______________________________________ Date: ____________________

Total weight of crushed shells _______________ ¼ of Total weight of crushed shells: ____________

		Large shell pieces + HCl	Small shell pieces + seawater	Small shell pieces + acetic acid	Small shell pieces + HCl
A	Filter paper #	1	2	3	4
B	Filter paper weight				
C	Filter paper & shell pieces (dry start)				
D	Shell pieces only (dry start) CALCULATE (C - B = D)				
E	Filter paper + shell pieces (dry finish)				
F	Shell pieces only (dry finish) CALCULATE (E – B = F)				
G	% change in weight CALCULATE ((D-F/D)x 100 = G)				
H	Observations (eg. degree of fizzing)				

ACTIVITY 4B. Weathering of shells

Objective

To investigate what causes the breakdown of shells after the death of the mollusc.

Materials

- Cockle shells (some recently dead, some weathered shells which have been dead for some time)
- Rulers / calipers
- Pencils
- Scale (precision to 0.1g)

Methods

1. Take out the container of dead shells.
2. What criteria could you use to decide how long it's been since they died?
3. Decide on three criteria and record them.
4. Line up your shells from the freshest (most recently dead) to the oldest. Describe them using your criteria.
5. Make 5 pairs of same sized valves, 1 is recently dead, 1 dead for longer.
6. Weigh the 5 recently dead shells and record the weights and measure lengths.
7. Weigh the 5 long time dead shells and record the weights and measure the lengths.
8. Calculate the length:weight ratio for each shell.

Discussion

1. Explain what has happened to the shells over time since death.
2. What is weathering? What other processes might weaken the shell?
3. How do these processes impact the cockles when they are alive?
4. How do you think a change in ocean pH and increased storm events will affect cockles and other shell forming creatures in the future?
5. Are all molluscs vulnerable to increasing ocean acidification? Think about location and size.

Extension

1. Investigate different structures of calcium carbonate. Look at limestone, marble, egg shells and oyster shells to understand the different forms the mineral can take and how the hardness relates to the different forms of the mineral.
2. Do you think all forms of calcium carbonate react to pH changes in the same way?
3. Design an experiment to test your answer to question 2.

ACTIVITY 4B. Weathering of shells

STUDENT DATA FORM

Student / group name: ______________________________ Date: ________________

1. Time from death criteria.

Criteria	Description
1	
2	
3	

2. Description of recently dead vs long time dead shells.

How long since death	Description
Recent	
Long time	

Comparison of size of recently dead vs long time dead shell valves.

	Recently dead shell			Long time dead shells		
Shell pair	length	weight	Ratio (l/w)	length	weight	Ratio (l/w)
1						
2						
3						
4						
5						
TOTAL						
AVERAGE						

LESSON 5

The marine environment is changing and some animals and algae will be affected. But how that affects the marine food web, biodiversity, fisheries, tourism and New Zealand's economic growth are also important to review.

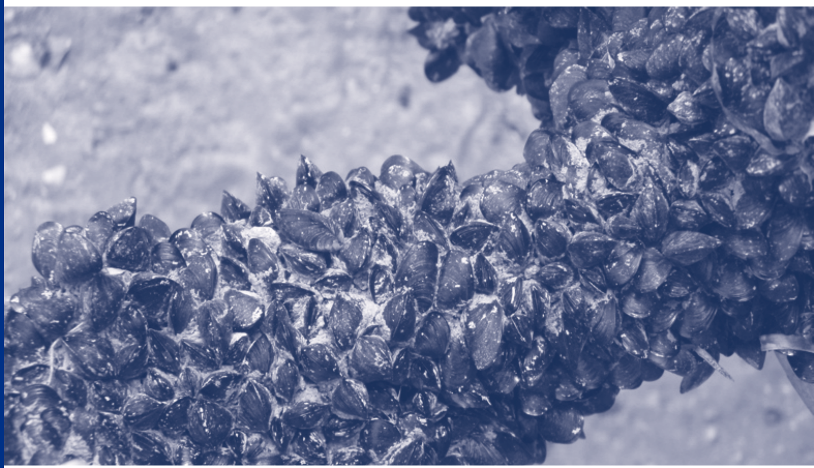
This lesson assesses how much we have learnt through the unit about ocean acidification and further develops our understanding of how our human activity affects the oceans and what we can do to try and lessen that effect.

Before starting this lesson, students may need to complete experiment 4A. *Shell Responses to ocean acidification*, as the samples may have been left overnight to dry.

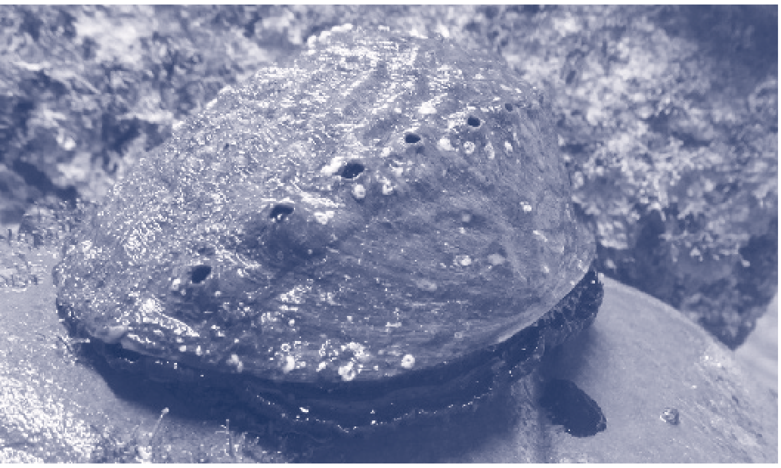
Our Role in Ocean Acidification

In New Zealand, we rely on the ocean as a food source. Many sources of seafood including snapper, paua, kina and oysters, are vulnerable to ocean acidification. The seafood industry in New Zealand employs about 20,000 people and earns nearly $2 billion per year for the country's economy. Any effects of ocean acidification on New Zealand's marine life could therefore have consequences for human communities as well as the marine ecosystem.
The health of the ocean is closely linked with our communities and culture in New Zealand. How we take care of the coastal oceans within our waters is important to how sustainable they are for future generations.

- Mussels are the focus of a large study at the Cawthron Insititute. Scientists have been looking into whether mussels can be resilient to ocean acidification, and whether the more resilient individuals can be selectively bred together to create a breed of mussels which are able to tolerate acidic conditions better than the current stock. The NZ mussel industry is worth $224 million per year to the New Zealand economy, so any drop in the production of mussels due to ocean acidification could cause a lot of damage, both to the animals and the people who make their living farming mussels.



- Paua are one of the most recognisable seafood species from New Zealand, a very popular recreationally fished species as well as a big export. Paua exportation brings about $51 million every year into New Zealand. They are found around the coasts, and currently the University of Otago is researching how paua are affected by ocean acidification. Researchers have found that the settlement of juvenile paua onto encrusting coralline algae can be disrupted if seawater conditions are not 'just right' – and that juvenile paua are more vulnerable to ocean acidification than their adult counterparts.



- Snapper are a key New Zealand seafood and one of the most high-value fish on sale in this country alongside blue cod, but their juvenile and larval life stages are vulnerable to ocean acidification. Slower growth and physical deformity are both possible outcomes of young snapper being exposed to acidic seawater, and adult snapper may have their sensory behaviour changed. Exposure to ocean acidification can cause some adult fish to lose their sense of smell and hearing, and affect their ability to recognise that a predator is near. This could cause losses in the adult snapper industry in New Zealand, which was worth $706 million dollars in 2015 and employs over 3000 people.

But the 'cost' of ocean acidification to New Zealanders is not only measured in monetary value. Culturally important species such as paua, kina and bull kelp are at risk, as well as whole ecosystems.

For example, cold water oyster reefs are at risk because the oysters themselves are vulnerable to dissolution from acidification, meaning that whole marine communities centred around these oyster reefs are in danger if the oysters themselves are damaged. These are important not only for their value as a tourist attraction but are important to the health of the oceans, for example as a nursery for juvenile fish species.

The true 'cost' of ocean acidification could be thought of as a "perfect storm" combination of vulnerable species, effects on the marine food web, chemical changes to the seawater itself as well as ecosystem-wide biodiversity losses and impacts on fisheries to create a whole picture of how connected we are to the ocean in New Zealand. Damage to the marine ecosystem is damage to us.

The associated CARIM poster will help explain this information to your students (see page 37).

ACTIVITY 5A. What do we now know about ocean acidification?

Objective

To assess how your understanding about ocean acidification has changed since you started studying it.

Materials

- *5A Student Survey Form*
- Pencils
- Class survey results form
- Computer (optional for graphing of results)
- Class survey results from Lesson 1

Methods

1. Complete survey - hand out the student survey and ask students to complete it, independently, when they enter the classroom.
2. Review response categories - review the results sheet and the response categories listed for question 2. No categories have been listed for question 3 so the students will have to come up with the categories as a class (as per the instructions in Lesson 1).
3. Code surveys - ask students to swap survey forms with a neighbour to code the results in the categories provided on the summary sheet. Add tally marks to the the summary table (as per the instructions in Lesson 1).
4. Graph the results – this can be done individually or different students can graph different sections.
5. Compare the results with the class results obtained at the beginning of the unit (Lesson 1).

Discussion

1. How has the class' awareness changed since the beginning of the unit?
2. Do you think the results reflect the awareness levels of the New Zealand public? Why or why not?
3. How do the results compare with the English public (Capstick et al, 2016).
4. How would you describe the way the ocean acidification is communicated by the media in New Zealand?
5. How could scientists change the way ocean acidification is represented? What could you do?
6. Survey parents/friends/community. What do they know about ocean acidification and do they think it affects their lives?

ACTIVITY 5A. What do we now know about ocean acidification?

STUDENT SURVEY FORM

Please answer the questions independently. There are no right or wrong answers.

1. How much, if anything, would you say you know about ocean acidification?

_____ I have not heard of ocean acidification before

_____ I have heard about ocean acidification but I know almost nothing about it

_____ I know just a little about ocean acidification

_____ I know a fair amount about ocean acidification

_____ I know a great deal about ocean acidification

2. List the first three thoughts, images or phrases that come to mind when hearing the term 'ocean acidification':

   i. ______________________________

   ii. ______________________________

   iii. ______________________________

3. What do you think are the causes of ocean acidification?

   i. ______________________________

   ii. ______________________________

   iii. ______________________________

School: ______________________________ Age: ______________

Name (Optional): ______________________________ Date: ______________

ACTIVITY 5A. What do we now know about ocean acidification?

CLASS SURVEY RESULTS

Use this form to summarise the class results. Graph the results.

Number of students surveyed? n = ____

1. UNDERSTANDING OF OCEAN ACIDIFICATION – tally the class results.

Statements	Tally	Total
I have not heard of ocean acidification before		
I have, but I know almost nothing about it		
I know just a little about ocean acidification		
I know a fair amount about ocean acidification		
I know a great deal about ocean acidification		

2. THEMES WHICH PEOPLE ASSOCIATED WITH OCEAN ACIDIFICATION – code individual responses and tally the class results.

Theme	Tally	Total
Pollution		
Harm to marine organisms		
Concern & negative language		
Climate change		
Harm to people		

3. CAUSES OF OCEAN ACIDIFICATION - as a class decide on your own themes for causes of ocean acidification, code individual responses and tally the class results.

Theme	Tally	Total

ACTIVITY 5B. What can we do about ocean acidification?

Objective

1. To communicate our knowledge of ocean acidification to the wider world.
2. Identify ways in which ocean acidification will affect our life.
3. Investigate what WE can do to reduce ocean acidification.
4. Encourage others to take action.

Materials

- CARIM Acifidification Studies poster (see resource list on page 39)
- Poster making materials
- Example of posters aimed at changing people's behaviour

Methods

1. Review the CARIM poster and other ocean acidification information. Identify and discuss what are the effective elements in an information poster. How does it grab people's attention? How is the information presented to make it easier for the reader to access it?
2. Review posters aimed at changing people's behaviour. How do they get their message across effectively?
3. Brainstorm the ways in which ocean acidification will affect our world.
4. Research what people can do to reduce greenhouse gases.
5. Put together a poster for your school that addresses the following questions:
   a. What is ocean acidification?
   b. How do people's actions cause ocean acidification?
   c. What can we do to help?

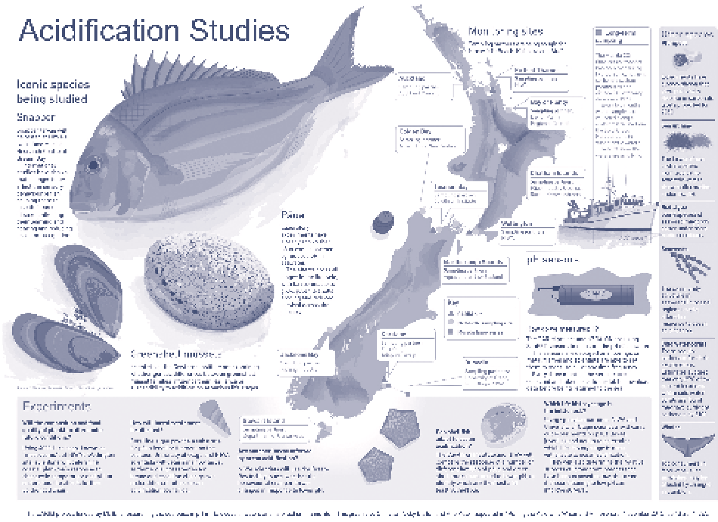
Discussion

1. What other ways can we effectively communicate the issue of ocean acidification to the wider community?
2. How can we encourage people to change their behaviours to reduce the production of greenhouse gases?

Extension

Science affects and informs policy. It is important to recognise that our actions in New Zealand have global political effects, and also that science done in New Zealand contributes to global solutions and recommendations.

- Write a report or perform a speech (with visual aids and scientific data included) to convince the government to invest money into funding ocean acidification research in New Zealand. What research areas do you think are most important to support and why?



The CARIM Acidification Studies poster is available from the New Zealand Marine Studies Centre website: *https://goo.gl/rbNsl7*

Individual Research Projects

These projects could be done during the unit: while waiting to collect data, or assigned as a homework project. Use the internet, libary, local experts and references at the end of this unit to find out more about the topics listed below. You can choose either to investigate an animal or an area of research that is taking place in New Zealand. Note: If you use the internet, make sure you identify the sources of the information, and evaluate their reliability.

A. Who might be vulnerable to changes in ocean acidification?

1. Identify and investigate 2 marine animals that have a shell and do not move (sessile). Are they vulnerable to ocean acidification? Why?
2. Identify and investigate 2 mobile animals with shells. Are they vulnerable to ocean acidification? Do you think they are as vulnerable as sessile animals? Why?
3. Identify and investigate 2 marine animals without shells. Are non-calcifying animals affected by ocean acidification? Why?
4. Identify and investigate a marine organism that photosynthesizes and has calcareous parts. Is it vulnerable to ocean acidification? Why?
5. Identify and investigate 2 marine organisms that have a shell and lives in a colony (group). How are they affected by ocean acidification?
6. Identify and investigate 3 micro-organisms that have a skeleton or shell. Are they more vulnerable to ocean acidification? Why?

B. Ocean acidification research in New Zealand

1. Why would the following groups be interested in ocean acidification research - schools, universities, businesses, local council, national government, communities, iwi?
2. The aquaculture industry employs many scientists who are researching ocean acidification in NZ and around the world. Who are they and what has their research found?
3. One area of interest is the Southern Ocean. Research the CARIM project and describe what you found interesting about the methods and initial findings.
4. Check out the website of the NZOAC (New Zealand Ocean Acidification Community) and describe an area of research which interests you. How is it relevant to your life?
5. The NZOA-ON (New Zealand Ocean Acidification – Observing Network) measures ocean pH around New Zealand. Investigate how they do this and how they co-ordinate data from all over the country.
6. Find a scientist who is studying the effects of ocean acidification on fish and one who is studying the effect on oysters. Describe why ocean acidification affect these groups differently?
7. Why are scientists interested in the effect of ocean acidification on corals? What are the other threats to coral reefs and how does ocean acidification interact with those other threats?

Further Reading and Resources

Supporting Resources

On the New Zealand Marine Studies Centre website: *https://goo.gl/rbNsl7*

- The oceans of tomorrow – Presentation, produced by the NZ Marine Studies Centre to support this resource.
- Acidification Studies, Infographic produced by CARIM project, NIWA.

Films

Acid Ocean, 2013, Australian Institute of Marine Science, 360 Degree Films: *https://goo.gl/DbVOes*

Ocean Acidification, Interview with Dr Cliff Law, NIWA (7 min): *https://goo.gl/42qbLu*

Ocean Acidification - Interviews with University of Otago Scientist, Dr. Abby Smith, Science Learning Hub (2.5 min): *https://goo.gl/jx2XVL and https://goo.gl/BLJhtU*

Ocean Acidification in Google Earth Tour: *https://goo.gl/xhxWBN*

Posters

New Zealand's marine environment at a glance – Infographic: *https://goo.gl/ViC90h*

Our Southern Wilderness Revealed II. Sir Peter Blake Trust: *https://goo.gl/cCoaHb*

Interactive version: *https://goo.gl/PnpFmv*

Articles and Websites

CARIM (Coastal Acidification: Rate, Impacts & Management), a research project funded by MBIE to look at the decrease in pH in NZ's coastal waters and its effect on marine life: *https://goo.gl/zFyYsz*

Carbon Dioxide Information Analysis Centre (CDIAC): *https://goo.gl/FwMLWz*

EarthLabs, educational unit on climate and the carbon cycle with lab on ocean acidification: *https://goo.gl/vuGUKa*

Environmental reporting on atmosphere and climate, 2015, Ministry of the Environment, Environment Aotearoa: *https://goo.gl/Ddrhko*

Environmental reporting on marine, 2016, Ministry of the Environment, Environment Aotearoa: *https://goo.gl/fg6ikP*

European Project on Ocean Acidification (EPOCA): *https://goo.gl/leCCYF*

Impacts from Climate Change and Ocean Acidification, NOAA Coral Reef Conservation Programme: *https://goo.gl/JXhpPm*

Investigating Ocean Acidification, article and infographics, 2016, NIWA: *https://goo.gl/cA5mHX*

NZOAC (New Zealand Ocean Acidification Community) highlights current research in OA in New Zealand: *https://goo.gl/7sxllV*

Ocean Acidification, Australian Institute of Marine Science (AIMS): *https://goo.gl/DZUKJw*

OA not Ok – downloadable booklet on the chemistry of OA: *https://goo.gl/8Frp19*

Ocean Acidification - a study of the evil twin to global warming in Antarctica, LEARNZ: *https://goo.gl/bMC2BT*

Ocean Acidification, National Geographic: *https://goo.gl/n0SZb8*

Ocean Acidification Research Theme, University of Otago: *https://goo.gl/8h2gT8*

What is Ocean Acidification? NOAA, PMEL Carbon Programme: *https://goo.gl/dPlp6J*

Ocean Acidification UK: a scientific research programme webpages detailing the research findings: *https://goo.gl/5DsHzQ*

Pacific Islands Fisheries Science Center webpage looks at how ocean acidification affect the Pacific Island communities: *https://goo.gl/rvV8iW*

Virtual marine scientist, unit designed for secondary students by University of Gothenburg: *https://goo.gl/IMw9Oq*

Scientific Papers / Books

Brinkman TJ & Smith AM.2014. Effect of climate change on crustose coralline algae at a temperate vent site, White Island, New Zealand. Marine and Freshwater research. 66, p 360–370: *https://goo.gl/fXVMxB*

Capstick, Stuart, Pidgeon, Nicholas Frank, Corner, Adam J., Spence, Elspeth and Pearson, Paul Nicholas. 2016. Public understanding in Great Britain of ocean acidification. Nature Climate Change 6 (8), pp. 763-767: *https://goo.gl/FChL4N*

Gattuso JP & Hansson L, 2011. Ocean Acidification. Oxford University Press: *https://goo.gl/lD7oNb*

Law, C.S., Rickard, G.J., Mikaloff-Fletcher, S.E., Pinkerton, M.H., Gorman, R., Behrens, E., Chiswell, S.M., Bostock, H.C., Anderson, O. and Currie, K. (2016) The New Zealand EEZ and South West Pacific. Synthesis Report RA2, Marine Case Study. Climate Changes, Impacts and Implications (CCII) for New Zealand to 2100. MBIE contract C01X1225. 41pp: *https://goo.gl/h0vl8G*

Equipment

There are a variety of pen type or portable pH meters available. It is very important to follow the instructions to keep the probes immersed in a buffer solution and to calibrate the meter before each use. Note that pH standards must be replaced regularly as they do drift with time. The standards commercially available are designed for freshwater, not seawater, however in the context of this unit they should be fine.

Many of the scientific suppliers carry pH meters. Pen type pH meters are available from a variety of sources:

Lab Warehouse: *https://goo.gl/j4VvpM*

Cresendo: *https://goo.gl/ZmrTdN*

A slightly more expensive portable meter with detachable probes is a better option. See Cresendo: *https://goo.gl/ZmrTdN* (eg INS-201 pH Meter)

Citizen Science

Do you want to learn first-hand about the effects of global climate change on the natural world? Consider lending a hand to scientists by observing the world around you and reporting what you find. Here are some of the types of information you can collect and organisations that need your help:

Record sightings of marine mammals, seabirds, and other local plants and animals:

- Nature Watch NZ: *https://goo.gl/9l1FE6*
- Bird Surveys: *https://goo.gl/LymC1G*
- Backyard Bird Count: *https://goo.gl/JsnONu*

Collect information on coastal communities:

- Marine Metre Squared: *https://goo.gl/LoKWGD*
- Call to Action – Video interviews with Mm^2 Scientists: *https://goo.gl/qGhy8i*
- Seashore Guides: *https://goo.gl/CVj9G4*
- NZ Marine Field Guide: *https://goo.gl/Dd80FL*
- NIWA Marine Identification Guides (crabs, ascidians, echinoderms, sponges etc): *https://goo.gl/RJQQYW*

Monitor invasive species:

- Marine Pest Identification Guide: *https://goo.gl/iYMSKa*

Sample planktonic communities / Water Quality:

- Be a Planktonaut – Plankton Planet: *https://goo.gl/yh498h*
- Study of Marine Phytoplankton: *https://goo.gl/hM17O8*
- Ocean Sampling Day: *https://goo.gl/lJ9LB7*
- Healthy Harbour Watchers: *https://goo.gl/GZzOau*

What could the ocean of tomorrow look like?

Use this cartoon and the photos on the cover of the book to initiate discussion.
Consider the impact of our generation's action or inaction on the future of our ocean.

Cartoon courtesy of Austin Milne

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The Lou and Iris Fisher Charitable Trust