The Scholars Programme

From Fossil Fuels to Fish

Key Stage 4 Programme

Pupil Name

Handbook Designed by Cameron Hird

Timetable and Assignment Submission

Timetable – Tutorials

Tutorial	Date	Time	Location
1 (Launch Trip)			
2			
3			
4			
5			
6 (Feedback)			

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Tutorial 1		
Tutorial 2		
Tutorial 3		
Tutorial 4		
Tutorial 5		

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after midnight on 5th April 2017	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

The Brilliant Club KS4 Programme – Pupil Feedback Report

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at AS-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Name of PhD Tutor			
Title of Assignment			
Name of Pupil			
Name of School			
ORIGINAL MARK / 100		FINAL MARK / 100	
DEDUCTED MARKS		FINAL GRADE	

If marks have been deducted (e.g. late submission, plagiarism) the PhD tutor should give an explanation in this section:

Learning Feedback Comment 1 - *Enter Key Learning Priority Here*	
What you did in relation to this Key Learning Priority *Enter feedback here*	How you could improve in the future *Enter feedback here*
Learning Feedback Comment 2 – *Enter Key Learning Priority Here*	
What you did in relation to this Key Learning Priority *Enter feedback here*	How you could improve in the future *Enter feedback here*
Learning Feedback Comment 3 – *Enter Key Learning Priority Here*	
What you did in relation to this Key Learning Priority *Enter feedback here*	How you could improve in the future *Enter feedback here*
Resilience Comment	
How you showed learning resilience during the course *Enter feedback here*	How you could build learning resilience in the future *Enter feedback here*

Contents

Course Rationale

From the burning of fossil fuels to the felling of trees, most of us are aware of increasing carbon dioxide (CO_2) concentrations in our atmosphere. Terms such as 'global warming' and 'climate change' have become commonplace in recent years, but what about CO_2 in our oceans? After all, don't our oceans cover 71 % of the Earth's surface? Have you ever even heard of 'ocean acidification'? The 'From Fossil Fuels to Fish' course aims to bridge the knowledge gap between the chemical processes of CO_2 pollution and biological consequences for marine organisms.

The first tutorial will cover the basics of 'what is ocean acidification?', encompassing the causes and mechanisms of CO_2 uptake by the oceans. Tutorials 2 and 3 will consider the biological repercussions of ocean acidification, to include case studies on the effects of CO_2 pollution in marine organisms, including fish. Once you are self-assured with these concepts, the remaining tutorials will consider how these processes are likely to change in the future, following population growth and contemporary industrialisation, in addition to discussing means by which these impacts could be reduced. Ultimately, you will complete a final assignment within which you will use the knowledge and skills you have acquired throughout the course to address the question: 'How might ocean acidification affect marine organisms by the year 2300?'

Transferrable skills that you will gain from completing this programme include the ability to interpret complex data and apply it to novel situations. You will also have the opportunity to design and run your own experiment, for which you will receive feedback to enable you to reflect on your opinions. Finally, you will get the opportunity to study a novel subject in depth providing you with knowledge and understanding of biological and chemical systems that you can apply to many scientific scenarios.

'One way or another, the choice will be made by our generation, but it will affect life on Earth for generations to come'

[Lester R. Brown, 2013]

Mark Scheme Table

Skill	What this means…	1st	2.2
Analysis of Information	The ability to look at an image / data set or read an article and critically review its content; evaluating and using it to justify opinion of the subject. This includes writing in a logical and well-informed way.	☐ Writing is relevant, coherent and well-structured with sources integrated in the text effectively. ☐ The student can clearly and accurately describe what is shown in images and data sets to inform conclusions of their own. ☐ Conclusions drawn are novel and well-informed by referenced evidence.	☐ Information included may form an illogical sequence with sources disjointed from the content or irrelevant. ☐ Interpretation of data or images may not be present or are incorrect and / or ill-judged. ☐ Little evidence is shown of conclusions being drawn from the evidence with the focus being on content only.
Scientific Application	The ability to recall knowledge and understanding of the subject and apply it to situations you may be unfamiliar with.	☐ The use of new scientific vocabulary is demonstrated clearly and effectively throughout. ☐ Concepts such as carbonate chemistry and indirect effects are confidently demonstrated with full accuracy.	☐ Simple language is used with little or inappropriate use of new scientific terms. ☐ Concepts and explanations of processes may be used incorrectly or misunderstood leading to a lack of scientific accuracy or fluency.
Contextualising	An appreciation of the topic and an understanding of fundamental scientific research and its importance.	☐ A 'bigger picture' approach has been made to consider where ocean acidification fits in to society and global processes. ☐ The pupil has demonstrated relevant background information and used accurate predictions to inform future scenario judgements.	☐ No demonstration of the 'bigger picture' has been considered in the assignment, often being focussed on smaller processes. ☐ A lack of background information is provided with little context to explain the written text. Judgements may appear ill-informed or inaccurate.
Realistic Creativity	Using knowledge of other subjects such as population growth and technological advances to apply knowledge to a future scenario in a fictional context.	☐ The pupil has been realistic in their assessment for the future, making informed judgements about future conditions that are supported by evidence. ☐ Opinions conveyed are always balanced and reasonably supported by evidence that is included.	☐ The pupil has vastly over / under extrapolated future scenarios to come to unlikely conclusions about future scenarios. ☐ Opinions listed within the text may be strongly biased with little or no supporting evidence provided.
Research Skills	Gathering a range of sources about ocean acidification in addition to those provided and judge the validity and reliability of each effectively.	☐ A range of additional sources have been sourced and correctly referenced to support the assignment which were not originally provided. ☐ References used are from considered and reliable sources. The pupil has evaluated source-reliability in-text and justified the use of information for the context.	☐ Some attempt has been made to include personally-sourced information, but those used are dominated by ones provided in the material and may not be referenced. ☐ Information gathered may be unreliable or unconventional in nature with no attempts made to justify reliability in-text.

Glossary of Keywords

Word	Definition	In a Sentence...
Adaptation	The process where an organism or species becomes better adapted to is environment.	Developing a strong shell is an adaptation to avoid predation.
Advancement	The development of new technology to supersede older technology at all costs.	Human society is going through a number of advancements.
Anthropogenic	Human-caused activities or processes.	Ocean acidification is increased by anthropogenic carbon dioxide.
Calcium Carbonate	A chemical used to make shells and bones made from calcium.	Marine snails have a calcium carbonate shell.
Carbon Capture and Storage (CCS)	The process by which carbon dioxide is captured and re-used or stored.	Carbon capture and storage can help reduce ocean acidification.
Carbon Footprint	An individual human's CO_2 emissions, often broken down in to categories of release.	In modern society, we regularly have a large carbon footprint.
Carbonate Chemistry System	A buffer system that chemically acts to maintain a constant ocean pH.	Ocean acidification can disrupt the carbonate chemistry system.
Contemporary Industrialisation	A period of modern advancement in electronics, property and technology.	Europe is in a state of contemporary industrialisation.
Direct Effect	A clear and primary response to a stressor event.	Shell dissolution is a direct effect of ocean acidification.
Dissolution	The breaking apart of compounds in to their constituent chemicals.	Ocean acidification can cause shells to undergo dissolution.
Emissions	The release of gases from human activities in to the atmosphere.	Factories often produce a lot of emissions.
Environmental Stressor	A change in condition in the environment that causes stress to an organism.	Changes in pH are an environmental stressor
Exoskeleton	A tough structure that forms on the outside of an organism to provide protection.	A crab has a hard calcium carbonate exoskeleton.

Word	Definition	In a Sentence...
Fecundity	A measure of fertility for determining the number of offspring produced.	Ocean acidification can reduce the fecundity of marine worms.
Indirect Effect	Secondary effects caused as a consequence of a direct effect of a stressor.	Changes in metabolic rate are an indirect effect of ocean acidification.
Ion	A particle with a charge (positive or negative).	The pH scale is controlled by hydrogen ion concentrations.
Metabolism	The chemical processes that occur in an organism to maintain life.	Metabolism can be affected by stress.
Noble Gas	A gas from a group of similar, odourless, colourless and unreactive gases.	Argon is a noble gas.
Ocean Acidification	The ongoing decrease in pH of ocean surface waters caused by the uptake of atmospheric CO_2.	Ocean acidification is happening in our oceans.
Otolith	A calcium carbonate structure in fish ears that can pick up vibrations from the environment.	Fish ears have an otolith that helps them to sense their surroundings.
Peer Review	A process by which work is read by others and feedback is made to improve accuracy.	Journal articles are reliable as they have been through peer review.
pH Scale	A scale to determine acidity based on concentrations of hydrogen ions.	An acid will have a lower value on the pH scale than an alkaline.
Polychaete	A group of worm species that are segmented and have bilateral symmetry.	A polychaete worm has a lot of legs.
Predictive Model	A statistical method of using data from one or more inputs to predict a future output.	Predictive models can be used to anticipate changes in future pH.
Refinement	An improvement on existing technology without needing to develop new technology.	Improving cars to reduce their emissions would be a refinement.
Saturation	A maximum concentration of absorption where no more uptake can occur.	Eventually the oceans will reach CO_2 saturation and stop taking it up.
Trade-Off	Where one process is impacted by a change in another due to having shared requirements.	Increased growth at the expense of fecundity is a trade-off.

Tutorial 1 – What is Ocean Acidification?

What is the Purpose of Tutorial 1?

By the end of tutorial 1, you should be able to:

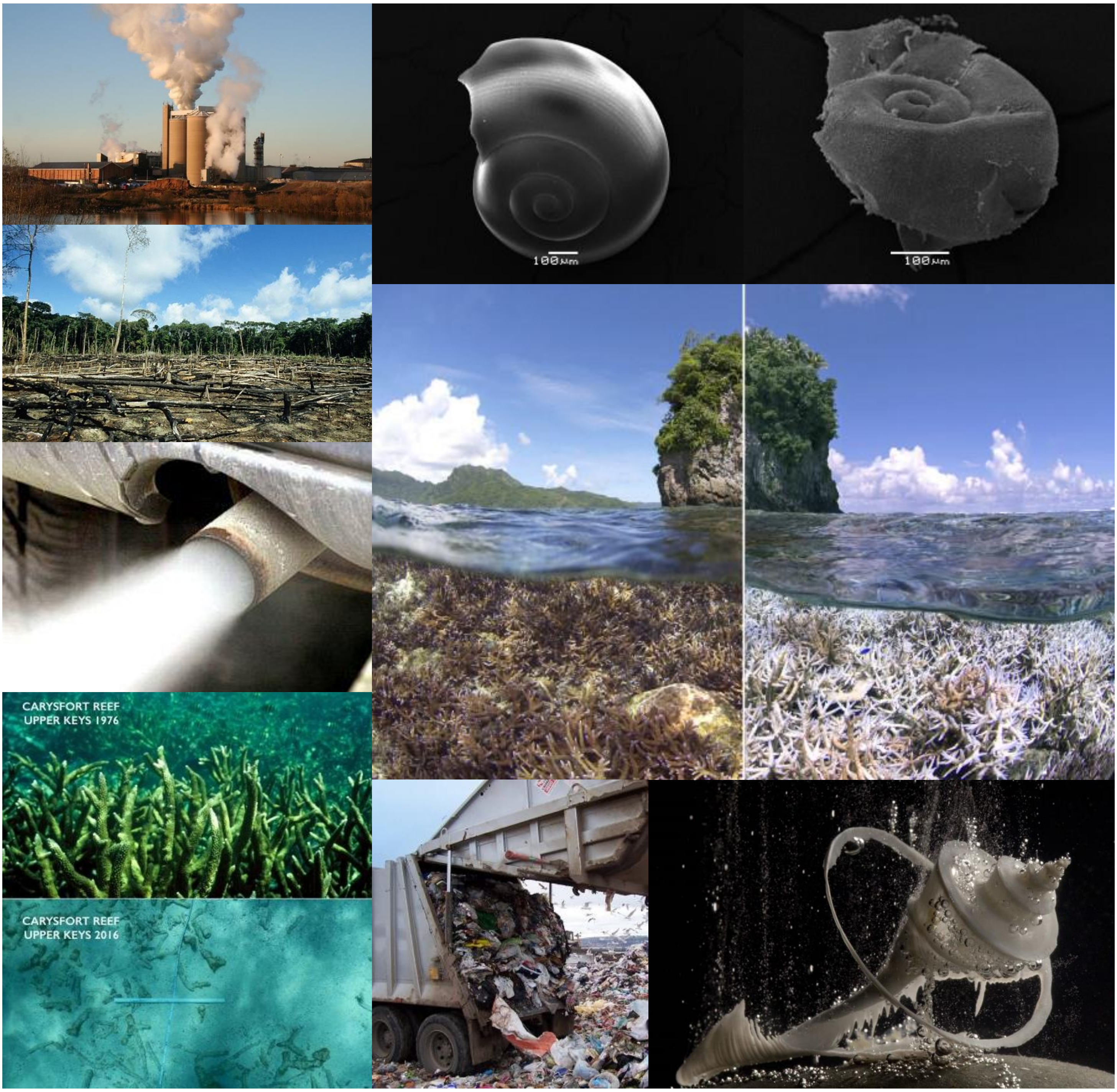
- Objective 1: Describe the proportions and inputs of gases in to the Earth's atmosphere, with particular reference to carbon dioxide (CO_2).
- Objective 2: Demonstrate the concepts of acidity and the pH scale.
- Objective 3: Interpret the role of CO_2 in the carbonate chemistry system.

Ocean Acidification: A Definition

Ocean Acidification can be defined as: 'the ongoing decrease in pH of ocean surface waters, caused by the uptake of carbon dioxide (CO_2) from the atmosphere'.

Starter Activity: Pictures Tell a Thousand Words…

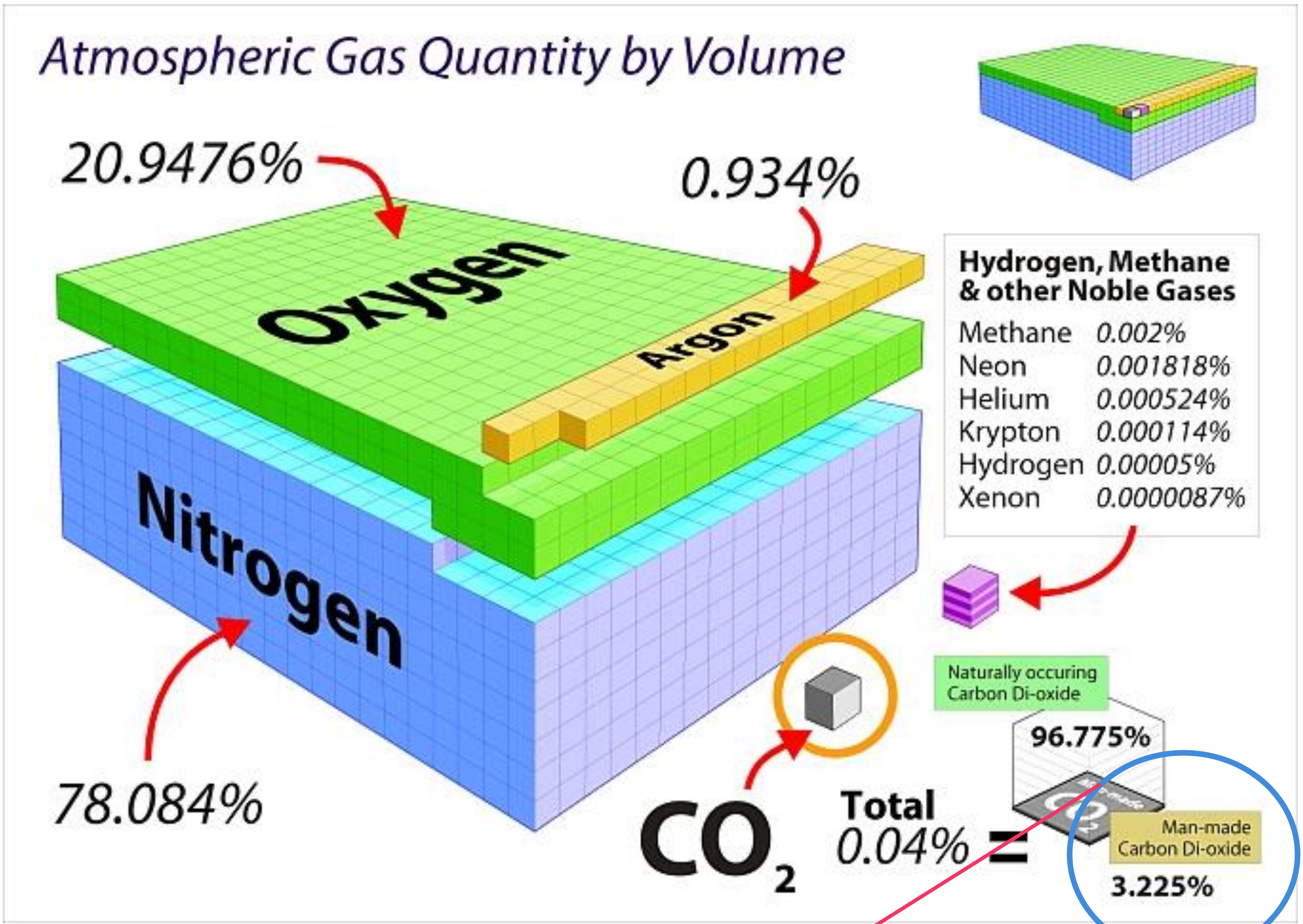
Look at the following picture collage. What keywords spring to mind? Write them in the space below. Try to think of at least 10.



Keywords:

Our Atmosphere

The relative concentrations of gases in Earth's atmosphere have remained relatively unchanged for over 100 million years. Over three quarters of the atmosphere by volume is occupied by nitrogen, an odourless, colourless and relatively inert gas. Oxygen occupies almost 21 %, followed by argon (<1 %) and carbon dioxide (0.04 %). The remainder is a mix of noble gases as well as hydrogen and methane. The noble gases are a group of similar, odourless, colourless and mostly chemically unreactive gases and include argon, neon, helium, krypton, xenon and radon. Below is a diagram of atmospheric gases by volume:



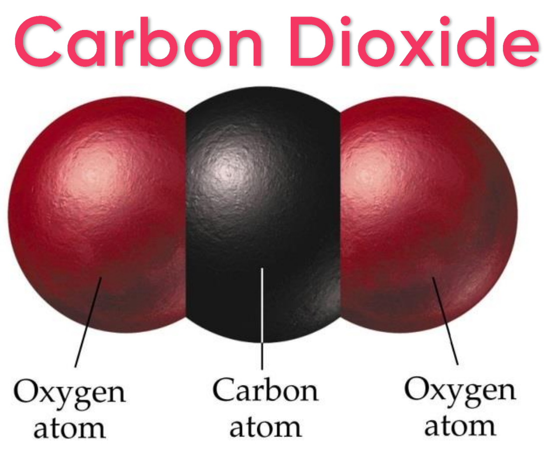
This course is all about the 3.225 % of CO_2, totalling just 0.001 % of our atmosphere.

Activity 1 – The Atmospheric Gases:

Fill in the blanks with the correct atmospheric gases:

The most common atmospheric gas is __________. After this, it is __________, which is the most important gas to humans for respiration. Humans breathe out __________________, but this can then be used by trees for photosynthesis. The gaseous product of photosynthesis is __________. There are also six noble gases, the most common of which is __________, although together with hydrogen and __________ these only constitute approximately 1 % of Earth's atmosphere.

So, Why Carbon Dioxide?



The current composition of gases in Earth's atmosphere has been stable for approximately the last 100 million years. For carbon dioxide, this has been at a concentration of approximately 280 ppm (parts per million) – or 0.028 %.

Since the industrial revolution (around 1750), the burning of fossil fuels has caused this to increase to over 400 ppm (0.04 %). This is a greater than 40 % increase in just over 250 years. Despite attempts to reduce CO_2 emissions, they are still increasing globally year on year. This is due to further advances in technology and developing countries increasing their emissions, this can be collectively referred to as contemporary industrialisation. This is especially important in animals that are sensitive to changes in CO_2, as carbon dioxide is increasing at a much faster rate than evolution can occur.

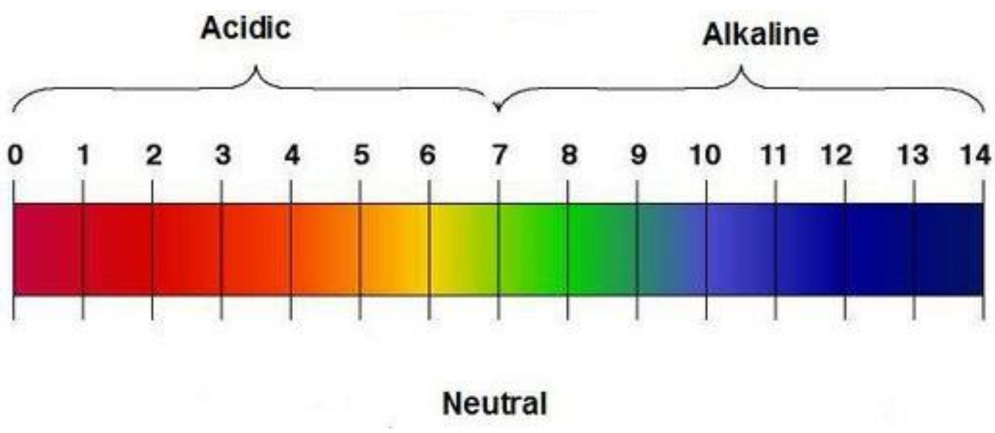
Activity 2 – Causes of CO_2 Emissions:

Individually, list as many causes of CO_2 emissions as you can:

Now, share your answers with a partner and make note of any you missed:

The pH Scale

You will probably recognise the diagram on the right. This is a classic pH scale, with acids on the left and bases/alkalis on the right. An alkali is a base that can dissolve in water.



Activity 3 - The pH of Water:

What do you think the pH of freshwater is?...

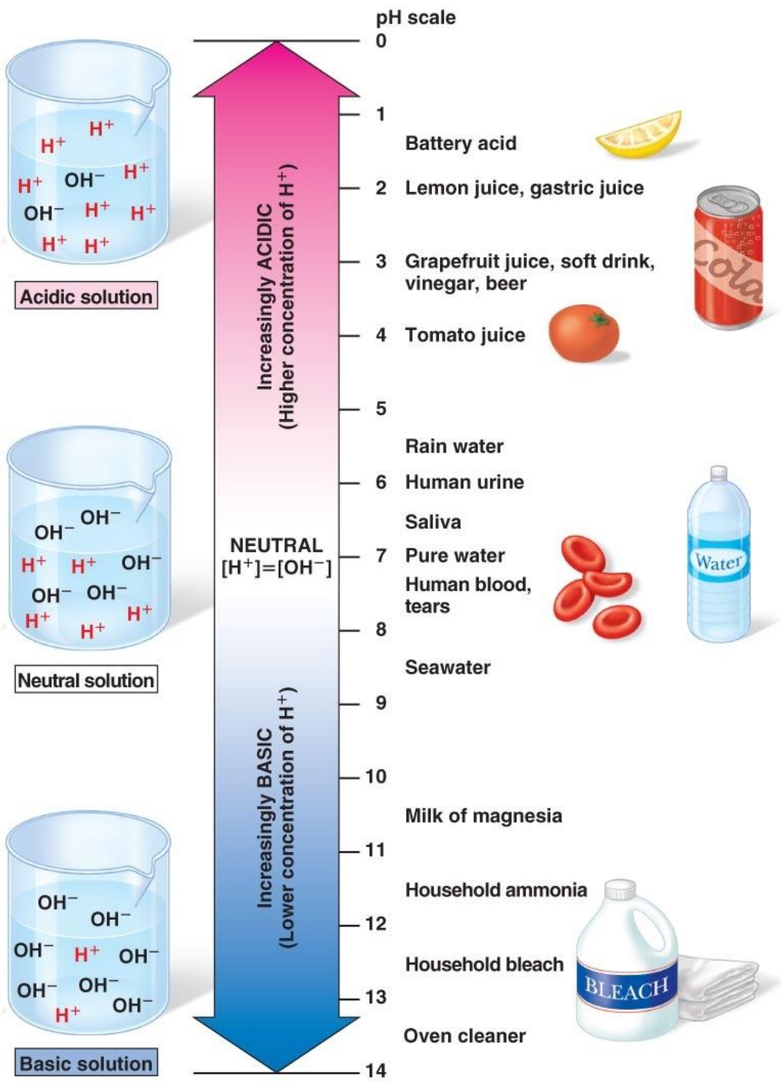
....

Do you think seawater will be different to freshwater? If so, why? ....

....

....

How it Works



The pH scale revolves around H^+ particles. H^+ is a hydrogen ion. An ion is a particle with a charge (positive or negative). The more acidic something is, the more H^+ ions it will have. Equally, the more basic something is, the less H^+ ions it will have. As acidity decreases, and H^+ ions decrease, they are replaced by OH^- ions. These are called hydroxide ions. The pH scale is logarithmic, meaning a small change in pH will have a big change in acidity, as shown below:

pH	H+ (moles per liter)	change in acidity
7.2	6.3×10^{-8}	+900%
7.3	5.0×10^{-8}	+694%
7.4	4.0×10^{-8}	+531%
7.5	3.2×10^{-8}	+401%
7.6	2.5×10^{-8}	+298%
7.7	2.0×10^{-8}	+216%
7.8	1.6×10^{-8}	+151%
7.9	1.3×10^{-8}	+100%
8.0	1.0×10^{-8}	+58%
8.1	7.9×10^{-9}	+26%
8.2	6.3×10^{-9}	

Moles is a chemical term for amount

What Has This Got to do With the Oceans?

The oceans act as a sink for carbon dioxide. This means that they absorb carbon dioxide from the air. Turbulence at the surface of the water incorporates the CO_2 in to the water, where it becomes chemically integrated. These are the ocean surface waters, and they are often much more variable than the deep ocean. This is because carbon dioxide can interfere with an important chemical cycle in ocean surface waters called the carbonate chemistry system. In turn, this alters the pH of the oceans. The change in pH of the oceans is typically small (0.1 pH units) but has the potential to impact marine animals.

Marine animals are adapted to live in conditions which are very stable, much like humans. A small change in pH can alter a marine animal's abilities to grow, breathe, feed and reproduce, among other things. This is a bit like humans breathing air. If the air we breathe has a CO_2 percentage of 1 % we would feel drowsy, at 2 % we would have difficulty breathing. By 3 %, the blood in our veins begins to become more acidic, which can change how our major organs function and make us feel very unwell.

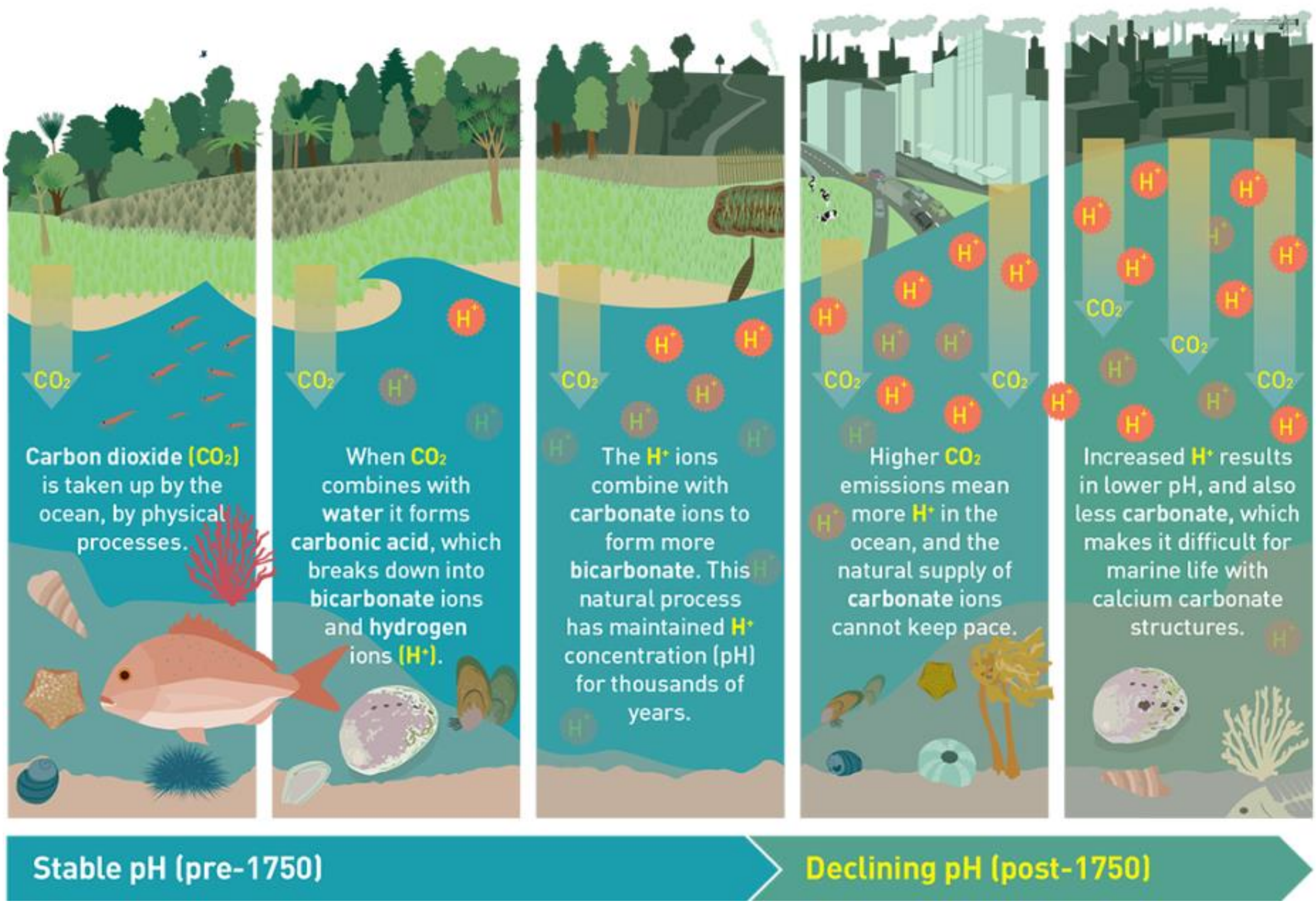
The Carbonate Chemistry System

The carbonate chemistry system is a form of buffer system. Buffer systems act to maintain a stable condition, in this case pH. They do this by releasing ions to try and neutralise a change caused by introduction of new chemicals that could alter the pH. However, all buffers have a capacity, beyond which they become ineffective. This is called buffering capacity. The following diagram depicts the seawater carbonate chemistry system:

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$

$CO_2 + H_2O$	H_2CO_3	$H^+ + HCO_3^-$	$2H^+ + CO_3^{2-}$
Carbon Dioxide and Water	Carbonic Acid	Hydrogen Ions and Bicarbonate	Hydrogen Ions and Carbonate

As CO_2 in the atmosphere increases, there is a greater reaction with water to form carbonic acid. In turn, this dissociates (splits) to form carbonate and bicarbonate, releasing hydrogen ions in the process. Based on what we have learned about the role of H^+ ions in the pH scale, this then decreases the pH of the water. Although this process is reversible, there is not a high enough natural supply of carbonate ions to drive the reaction in reverse, in addition to the CO_2 levels continually increasing. Furthermore, carbonate is vitally important to many marine animals as they use it to form shells and skeletons during growth. They are unable to do this efficiently when the carbonate supply available to them is depleted by the formation of carbonic acid with CO_2.



Notes

Homework Assignment 1 – It's all about CO_2

1) What is the chemical process of aerobic respiration? [1]

__________ + __________ → __________ + __________ (+ energy)

2) What is the chemical process of photosynthesis? [1]

__________ + __________ (+ light energy) → __________ + __________

3) John cuts down a forest to make firewood which he then burns. What consequences will this have on local atmospheric carbon dioxide (CO_2)? [2]

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....

4) Can you name three ways in which CO_2 emissions in to the atmosphere can be reduced? [3]

i) ....

ii) ....

iii) ....

5) Research a source of information about ocean acidification. What are the main points of the source you have chosen and do you consider it to be reliable? Why? [3]

Source Name / Web Address: ....

Main Points: ....

....

....

....

....

Reliability: ....

....

....

.... [Total marks __ / 10]

Tutorial 2 – Where the Chemistry Meets the Biology…

What is the Purpose of Tutorial 2?

By the end of tutorial 2, you should be able to:

- Objective 1: Review the evidence that ocean acidification impacts marine animals and apply it to determining the species at risk.
- Objective 2: Design and conduct an experiment to show the effects of acidification on calcifying species.
- Objective 3: Describe, with examples, the differences between direct and indirect impacts.

Starter Activity – Visualising Ocean Acidification:

In the space below, draw a diagram from memory of the process of ocean acidification:

Back to the Carbonate Chemistry System

$CaCO_3$

In tutorial 1 we learnt that carbon dioxide has the ability to disrupt carbonate availability. Carbonate is a vital chemical for marine animals as it combines with calcium to form calcium carbonate ($CaCO_3$). Calcium carbonate is what animals use to make shells. Crabs, mussels, urchins and corals (among others) all require calcium carbonate to form their shells and exoskeletons. An exoskeleton is a tough structure that forms on the outside of an organism to protect it from predation and allows it to manipulate its environment.

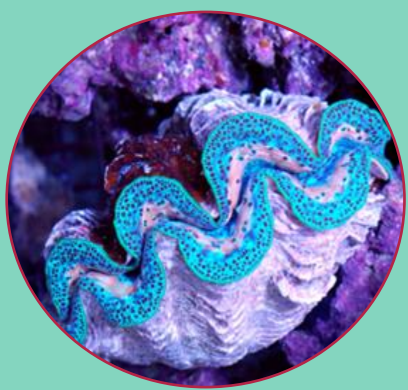
Ocean acidification has the ability to impact calcium carbonate in two ways that can affect marine animals. Firstly, it reduces available carbonate ions, so calcium carbonate cannot be utilised by animals. Animals need this to grow, renew and strengthen their shells and exoskeletons. If an animal has reduced calcium carbonate during development it may be at risk to predation or may not develop properly (e.g. reduced growth, lack of strength, inability to exchange minerals). Secondly, dissolution can occur. Dissolution is where the constituent chemicals (in this case Ca and CO_3) break apart and are released in to the water again. This looks a bit like dissolving and can have similar consequences to reduced $CaCO_3$.

Activity 1 – Predicting Species Sensitivity:

Look at the images below; put a cross through any species you think will not be affected by ocean acidification due to calcium carbonate limitation:









Activity 2 – Designing an Experiment:

You will be provided with the following:

- An assortment of sea shells
- 8 x 50 mL Eppendorf tubes containing a range of unknown pH solutions, labelled A to H
- A marker pen

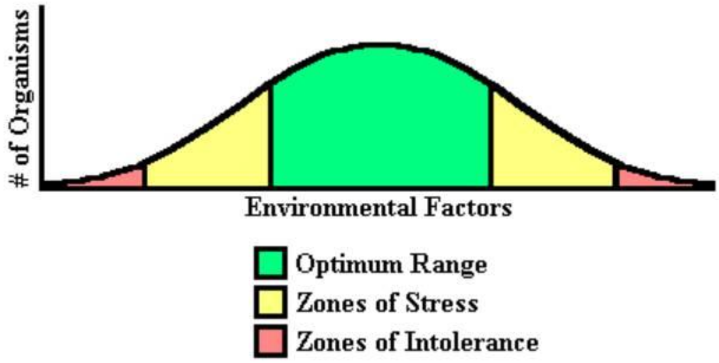
In groups of three, in the space below, design an experiment that allows you to test the effects of acidification on shells. You will set this up today and check on the results in Tutorial 3:

Things to Think About…

Metabolic Costs and Consequences

Calcium carbonate dissolution and disruption can be classed as a direct effect of ocean acidification. This is because it happens as a clear and straightforward primary response to changes in carbonate chemistry and pH. In contrast, there can also be indirect effects, such as metabolic costs and consequences which are secondary effects. Metabolism can be defined as 'the chemical processes that occur in an organism to maintain life'.

Ocean acidification can be considered an 'environmental stressor'. By environmental stressor, we mean a change in condition of the environment that causes stress to an organism.



Naturally, when conditions are optimal, most organisms will not experience stress. However, when conditions change, an increasing number of organisms will be under stress.

Organisms cope with stress by changes in their metabolism. This could include increasing their metabolic rate. An increase in metabolic rate allows an organism to take up more oxygen and increase production of proteins, antibodies, hormones and other biochemical products that cope with stress. However, these are costly for the body to produce and trade-offs occur. A trade-off is where one process is impacted by another due to having a shared requirement.

An example of a consequence of the metabolic cost of ocean acidification would be in mussels. Under ocean acidification, mussels have a higher energy requirement for basic processes such as respiration and metabolism. As a result, they have less energy remaining for investment in to reproduction. This means when they spawn (release eggs and sperm in the water for reproduction), they release fewer eggs and sperm that are not of as high quality (less chance of survival). As a result of this, each generation of offspring will have fewer numbers and the overall population size and population growth rate will be reduced. This is especially important in species such as mussels which are often also harvested for human consumption.

Activity 3 – Direct or Indirect?:

Read the following statements and determine whether they are direct or indirect effects:

- Crabs being smaller when fully grown. Direct / Indirect
- Snails having deformed shell growth. Direct / Indirect
- Fish breathing at a faster rate. Direct / Indirect
- Worms reducing burrowing behaviour / activity. Direct / Indirect
- Lobsters having a weak exoskeleton. Direct / Indirect
- Limpets with thin shells being eaten by predators. Direct / Indirect

Notes

Homework Assignment 2 – Finding a Case Study

Next tutorial we will look at 2 individual case studies of the effects that ocean acidification has on marine animals where we will be using marine worms and marine fish as examples.

Based on what we have learnt so far, calcifying organisms may be at the greatest risk of ocean acidification compared to many other species, so for this homework we will focus on them.

In this assignment you will create your own case study on the effects of ocean acidification on a shellfish species.

Research online about the effects of ocean acidification on a shellfish species of your choice and write no more than 600 words to create a case study, addressing the following questions:

1) What is the species and why is it an important species?
2) What effects of ocean acidification were measured and at what pH?
3) What do you think the consequences of these effects are for both this species and other species?
4) Where did you get your information from and are your sources trustworthy?

Tips:

By shellfish, we mean any marine animal that uses calcium carbonate to form a shell. This includes marine snails, mussels and clams, as well as lobsters and crabs.

Choose your case study based on the information you find – it is much more difficult to find information for a specific species if you choose the species first.

Appendices 3 and 4 (pages 54 - 55) provide information on what makes a reliable source and sources that are useful for ocean acidification research.

Things to Remember:

- The quality of you writing is more important than the word count.
- Try and incorporate the knowledge you have learned so far.
- Sources that are reliable are much better than unreliable sources

Tutorial 3 – From Fossil Fuels to Fish: Case Studies

What is the Purpose of Tutorial 3?

By the end of tutorial 3, you should be able to:

- Objective 1: Analyse the results of your own experiments to reach conclusions about the pH values for the solutions you used.
- Objective 2: Read and evaluate a journal article to prepare a case study summary.
- Objective 3: Compare and contrast the effects of ocean acidification in different species.

Starter Activity – Sharing is Caring (About the Environment):

1. Get in to groups of three. Number yourselves 1, 2 and 3.
2. Person 1 must spend 1 minute summarising the findings of their case study to person 2 (out of earshot of person 3).
3. Person 2 now has one minute to relay this information to person 3.
4. Person 3 now has one minute to tell the class what person 1 found out in their case study.

Notes:..

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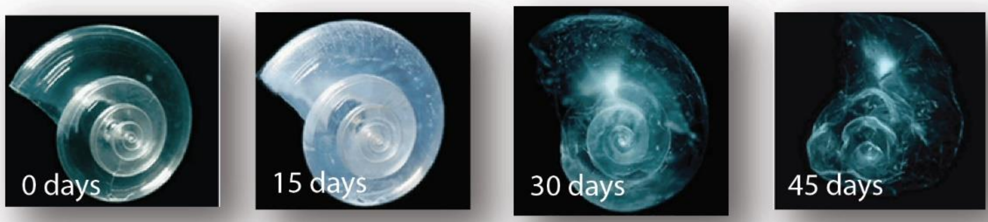
Practical Results:



In tutorial 2, you set up an experiment to test the effects of pH (ocean acidification) on shells. You will now be provided with your shells (liquid removed 24 h prior to tutorial) to analyse.

Look at your samples; is there any clear effect on some of them? Are some more impacted than others? One way of measuring the extent of damage to the shells is to predict the amount of dissolution as a percentage. Do this using the area of the shell and estimating how much the area has been reduced by throughout the experiment. This is a crude measure and could be analysed in much more detail using time-lapse and image analysis software if these were available to you. Based on this, can you see why using similarly sized and shaped shells would have been advantageous?

Activity 1 – What do Your Results Tell You?:

In your groups, analyse your shells as described above. Using this information, try to determine which of the original solutions had the lowest pH conditions

Low pH → High pH

Eppendorf Letter ____ ____ ____ ____ ____ ____ ____ ____

Dissolution (%) ____ ____ ____ ____ ____ ____ ____ ____

You will now be provided with the actual pH conditions of the original solutions – See how well they match your predictions? Are there any differences? If so, why do you think this is?

Actual pH Values ____ ____ ____ ____ ____ ____ ____ ____

Reflecting on your experiment, if you were to do anything differently if you had to repeat it in future what would it be and why?

____

____

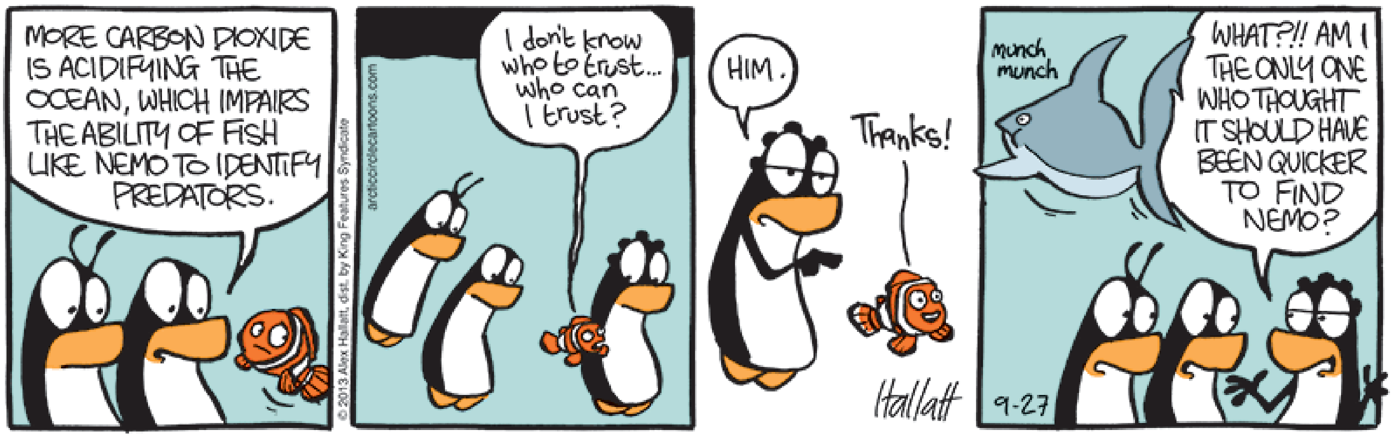
____

The following page (p 25) contains a sheet of graph paper. Plot a graph for your results. Use actual pH values when plotting your graph. Use the following tips to help you:

- **At university we do not use graph titles, information goes in a figure legend.**
- **When hand-drawing a graph, use as much of the space as possible.**
- **The independent variable goes on the x-axis: this is the controlling factor.**
- **Use a straight line of best fit, which does not need to go through the origin.**

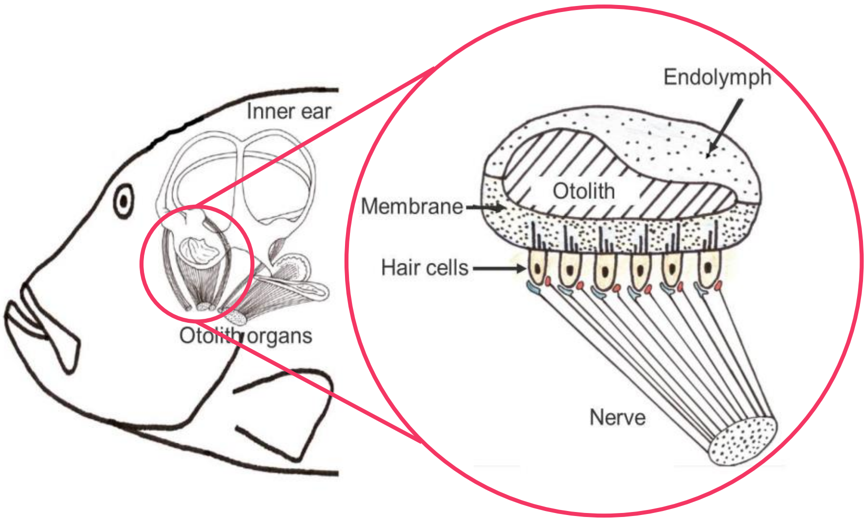
Use the space below to draw a graph of your results. This can be either portrait or landscape. Use the tips on the previous page (p 24) to help you.

Case Study 1: From Fossil Fuels to Fish



The tutorials to date have shown us that ocean acidification can impact calcium carbonate availability by disrupting the carbonate chemistry system with negative consequences for shellfish. However, other species rely on calcium carbonate for entirely different reasons.

Marine fish need calcium carbonate for their ears to function effectively. 'Wait, fish have ears??!'. Fish ears are not like human ears as they are contained inside the head behind earflaps. Fish ears contain a calcium carbonate structure called an otolith which is linked to hair cells and nerves which allow the fish to pick up vibrations in their environment. These allow fish to communicate and navigate. On coral reefs, fish locate food and shelter and avoid predators using auditory cues.



It has been discovered that ocean acidification has the ability to alter the development of otoliths in marine fish, often changing their size and shape, all of which will impact the ability of the fish to live effectively in its environment, including avoiding predators.

The following pages (p 27 – 28) contain extracts from a journal article about the effect of ocean acidification on fish behaviour. This has been used to create a case study (p 28).

Activity 2 – Understanding Journal Articles:

Read the following journal article extracts and note down at least six words you do not understand. You can ask your tutor to define these afterwards:

1) ____________________ Definition: ____
2) ____________________ Definition: ____
3) ____________________ Definition: ____
4) ____________________ Definition: ____
5) ____________________ Definition: ____
6) ____________________ Definition: ____

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Global change biology

Ocean acidification erodes crucial auditory behaviour in a marine fish

Stephen D. Simpson[1,*], Philip L. Munday[2], Matthew L. Wittenrich[3], Rachel Manassa[2], Danielle L. Dixson[2], Monica Gagliano[4] and Hong Y. Yan[5]

Ocean acidification is predicted to affect marine ecosystems in many ways, including modification of fish behaviour. Previous studies have identified effects of CO_2-enriched conditions on the sensory behaviour of fishes, including the loss of natural responses to odours resulting in ecologically deleterious decisions. Many fishes also rely on hearing for orientation, habitat selection, predator avoidance and communication. We used an auditory choice chamber to study the influence of CO_2-enriched conditions on directional responses of juvenile clownfish (*Amphiprion percula*) to daytime reef noise. Rearing and test conditions were based on Intergovernmental Panel on Climate Change predictions for the twenty-first century: current-day ambient, 600, 700 and 900 μatm *p*CO_2. Juveniles from ambient CO_2-conditions significantly avoided the reef noise, as expected, but this behaviour was absent in juveniles from CO_2-enriched conditions. This study provides, to our knowledge, the first evidence that ocean acidification affects the auditory response of fishes, with potentially detrimental impacts on early survival.

Keywords: ocean acidification; auditory response; sensory behaviour; clownfish; reef noise

1. INTRODUCTION

Since the Industrial Revolution, approximately 142 billion tonnes of anthropogenic CO_2 has been absorbed by the oceans, resulting in ocean acidification at a rate far faster than any time in the last 650 000 years [1], and causing the average pH of the ocean to drop by 0.1 units [2]. If global emissions continue on the current trajectory, atmospheric CO_2, currently at 390 ppm, is predicted to reach 730–1020 ppm by 2100 [2,3], causing a further drop in ocean pH of 0.3–0.4 units [1,2]. Acidified conditions compromise the ability of marine calcifiers to build skeletons and shells [4], but the combined influences on non-calcifiers including fishes are far less understood [5]. Determining the effects of acidification on crucial behavioural responses in marine species is essential for predicting the ecosystem and societal effects of ocean acidification in the twenty-first century.

Following a planktonic larval phase in the open ocean, juvenile coral reef fishes use a suite of sensory capabilities to detect, orient towards, and discriminate between potential settlement sites [6]. Olfactory cues provide valuable information for settling fishes, but recent work has demonstrated that fishes reared in CO_2-enriched conditions lose their ability to distinguish odours, preferring the odours of inappropriate habitats and failing to avoid predator cues [7]. Auditory cues from coral reefs, dominated by the clicks and chirps of resident crustaceans and fishes, are also important in guiding directional behaviour [8] and habitat preferences [9], and nocturnal reef sounds promote settlement [10] while daytime predator-rich noise is avoided [11,12]. Central to fish hearing is the inner ear, which includes dense carbonate otoliths (earbones). Otolith growth can be altered by elevated-CO_2 conditions during development [13], suggesting that acidification could also affect the auditory response. A key question that emerges from recent work is whether elevated-CO_2 conditions deleteriously affect the auditory response of reef fishes in their early life-history stages, confounding the effects of ocean acidification on other sensory modalities and further eroding orientation, habitat selection and predator avoidance behaviour.

Here, we used information from existing electrophysiological assessment of hearing in juvenile clownfish to set audible and naturally relevant levels of sound for playback in an auditory choice chamber. We studied the influence of CO_2-enriched rearing and test conditions on the directional response of recently settled juvenile *Amphiprion percula* (orange clownfish, 17–20 days post-hatching) to a daytime recording of reef noise that was avoided by larvae in a previous experiment [11]. The CO_2-conditions of our rearing and test environments were current-day ambient (~390 μatm), and elevated-CO_2 treatments (approx. 600, 700 and 900 μatm), consistent with the range of Intergovernmental Panel on Climate Change predictions for CO_2 concentrations at the end of the twenty-first century [2].

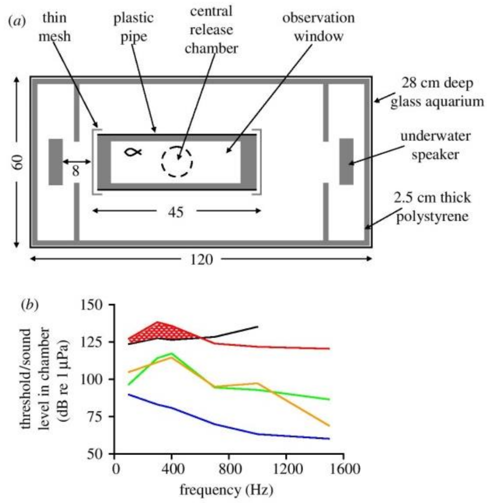


Figure 1. Experimental arena and acoustic conditions during trials. (*a*) Acoustic choice chamber (measurements in centimetres). (*b*) Comparison of audiogram for *Amphiprion ephippium* (17–20 days post-hatching) with measurements of reef noise playback within the chamber. Shaded area indicates predicted audible component of sound near to the speaker. Mean sound levels within the chamber without playback are also shown; maximum s.e. between CO_2-conditions was 1.2 dB (mean 0.6 dB) so error bars are not shown (black, 17–20 days post-hatching audiogram; red, near end of chamber; green, centre of chamber; yellow, far end of chamber; blue, no sound control).

4. DISCUSSION

We found a change in the directional response of recently settled juvenile *A. percula* to a predator-rich daytime reef recording, if reared in CO_2-conditions predicted for the shallow ocean later this century. Daytime reef noise is usually avoided by free-swimming early-stage reef fishes [11,12] and, as expected, clownfish reared in ambient CO_2-conditions avoided our playback, but this response was absent in larvae reared at 600 μatm CO_2 or higher. On the current CO_2 emissions trajectory, the average concentration of CO_2 in the atmosphere and surface waters of the ocean is predicted to exceed 500 μatm by mid-century and could approach 1000 μatm by 2100 [2,3], suggesting that ocean acidification could compromise auditory behaviours crucial for survival.

Previous studies have demonstrated that *A. percula* reared in CO_2-enriched conditions lose their innate avoidance response to olfactory predator cues, becoming attracted to the scent of predators and unable to distinguish predators from non-predators in olfactory y-mazes [15]. Our study demonstrates that the effects of CO_2-enrichment on sensory behaviour are not limited to sensory modalities with external sensory receptors such as olfaction, but that a behavioural response from a sensory system with internal receptors

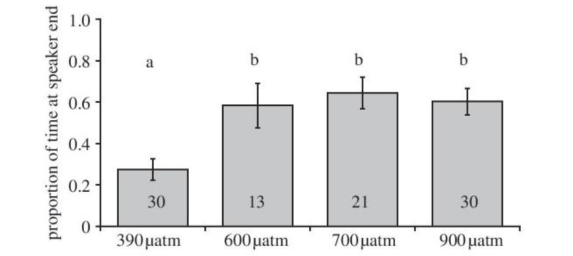


Figure 2. Effects of elevated-CO_2 conditions on the directional response of recently settled juvenile clownfish (17–20 days post-hatching) to acoustic playback of daytime reef noise (r.m.s. intensity = 153 dB re 1 µPa at the speaker). Sample sizes, which varied owing to mortality during rearing, are given on bars, which indicate mean ± s.e.m.; significantly different responses are indicated by letters.

is also affected, suggesting that responses to auditory stimuli are unlikely to compensate for the documented loss of olfactory capability.

Understanding the mechanisms by which sensory and behavioural responses to environmental cues become modified by exposure to CO_2-enriched conditions is essential for predicting the detrimental impact of ocean acidification on fish behaviour. A previous study found increased growth of otoliths (earbones) in fishes reared in highly CO_2-enriched concentrations [13], whereas at the less severe levels of CO_2-enrichment used in this study, we did not see modification of otolith growth that could be attributed to the CO_2 treatment (analysis of otolith morphology in the electronic supplementary material). This is consistent with another study, which found no effects on clownfish otoliths up to approximately 1050 µatm CO_2 [16]. Likewise, no obvious modification was detected in the morphology of the nasal cavity of larval clownfish in an olfaction study [7]. Combined, these results point to disruption of behaviour either through deterioration of neural transmission, perhaps owing to modified internal acid-base balance, or through compromised processing of sensory information. Alternatively, it is possible that the performance of the sensory systems is not directly impacted, but instead state-dependent elicited behaviour is altered, perhaps owing to stress caused by acidification. These alternatives should be teased apart in future experiments combining neuronal electrophysiology with endocrinological manipulations. As the conditions simulated in this study will be reached in relatively few generations, the breakdown of behavioural responses to auditory stimuli, as well as previously documented changes to olfactory responses and other behaviours, suggest that marine organisms face a proximate era of severe evolutionary selection.

Activity 2 – Understanding Journal Articles:

How many words did you find? Ask your tutor to define these for you in the space provided on page 26.

Case Study 1: From Fossil Fuels to Fish

Species:

Orange Clownfish (*Amphiprion percula*)

Aim of Study:

To study the effects of CO_2 on swimming behaviour of clownfish when exposed to ambient noise.

pH / CO_2 Conditions Tested:

CO_2 at 390 (present day), 600, 700 and 900 µatm.

What Effects Were Tested For?:

The location of swimming behaviour within the tank with respect to speaker positioning. The speaker playing reef noises to attract the fish as would be the case in the wild.

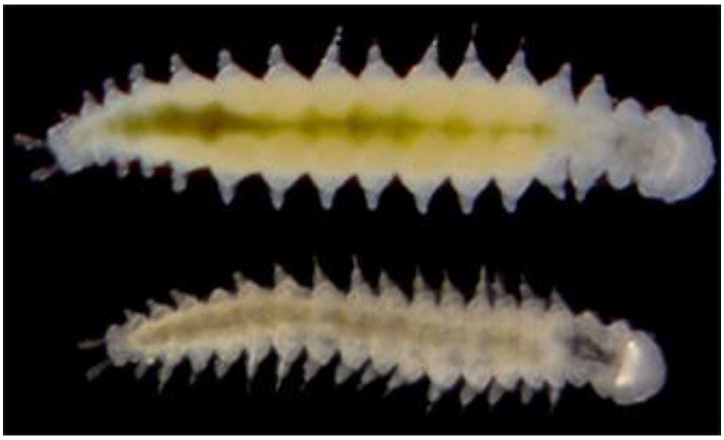
What Were the Main Findings?:

Under CO_2 conditions, fish spent less time near the speaker within the tank, compared to present day CO_2 conditions. This suggests that the fish were unable to pick up / respond to the reef noises being played.

What Could the Long-Term Effects Be?:

Fish would be unable to locate and colonise reef environments which provide food and shelter. As a result the fitness of the fish would be reduced. Furthermore, fish would be at risk of predation, consequently resulting in reduced survival rates. As a result population sizes may decline.

Case Study 2: Worming Our Way in to the Detail



Case Study 1 gave us an example of a direct effect of ocean acidification on a marine animal. Case study 2 is focussed on indirect effects of ocean acidification and uses data from Hird *et al.*, (2015). This study tests the effects of ocean acidification and adaptation to ocean acidification on marine worms. Marine worms are important species because they turn over and burrow in the sediments on the sea floor. This releases nutrients to the surface waters which enables other animals and plants to feed and thrive.

Activity 3 – Creating a Case Study Profile:

Read the quotes from work by Hird *et al.* (2015) on pages 29 – 31. Then create a case study profile similar to the one on page 28 based on this study.

<u>Adaptation to ocean acidification alters species resilience to changing CO_2 environments: life-history consequences of adaptation to elevated CO_2 in the marine polychaete *Ophryotrocha labronica*</u>

Cameron Hird

Introduction

'The increased release of anthropogenic carbon dioxide (CO_2) in to the atmosphere currently poses a major threat to marine ecosystems. Oceanic absorption of CO_2 has resulted in a reduction of the pH of ocean surface waters, a process termed ocean acidification (OA) (Caldeira and Wickett, 2003). For over 25 million years there has been little variation (~ 0.3 units) in global ocean pH (Caldeira and Wickett, 2003; 2005), therefore substantial pH change predictions of a drop by pH 0.3 – 0.5 units by the year 2100 (Orr et al., 2005) are a key cause for concern in marine environments.'

'Ophryotrocha labronica La Greca and Bacci (1962) (Polychaeta: Dorvilleidae) is a small (max length = 4 mm) opportunistic interstitial benthic polychaete that is widely distributed along Mediterranean coasts, particularly in harbour fouling communities (Paxton and Akesson, 2007; Massamba-N'Siala et al., 2011). O. labronica is a gonochoristic species representing slight sexual dimorphism and a female-biased sex ratio of 2:1 (Prevedelli and Simonini, 2002; Massamba-N'Siala et al., 2012). O. labronica is considered as an ideal study species to test for the effects of pollutants on life history traits as a result of having a short life-cycle; large reproductive capacity and few laboratory requirements (Akesson, 1970).'

'In the case of this study, a lab strain of O. labronica was utilised, where individuals were adapted to high [CO_2] / low pH conditions (pH 7.68 ± 0.22) and had been maintained at these conditions for over 30 generations. The current study aims to assess whether adaptation to

elevated CO_2 conditions has an effect on life history traits when exposed to further altered CO_2 conditions. This will be achieved by exposing a high CO_2 adapted strain and a non-adapted wild strain of the marine polychaete Ophryotrocha labronica to a range of CO_2 concentrations (400, 1,000, 3,000 and 10,000 ppm) and measuring the differences between the strains over a range of life-history responses: fecundity, survival and population growth rate.'

Results

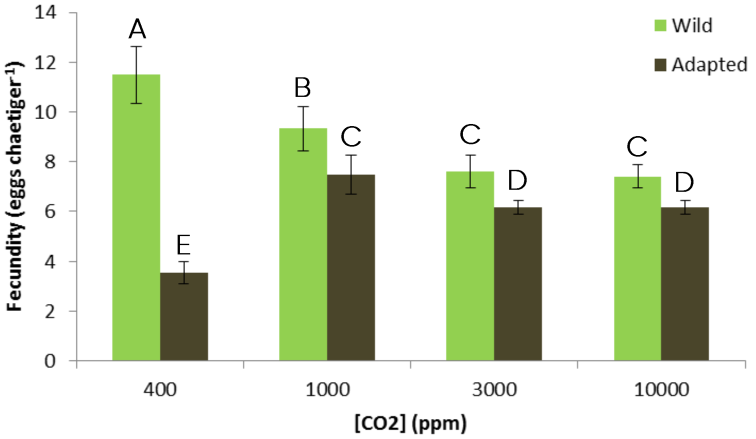


Figure 2 Mean (± S.E.) fecundity (number of eggs laid *per* chaetiger) in wild and high [CO_2] adapted strains of *Ophryotrocha labronica* La Greca and Bacci (1962) under differing CO_2 concentrations (400, 1,000, 3,000 and 10,000 ppm). For 400 and 1,000 ppm, n = 36, for 3,000 and 10,000 ppm, n = 18. Different letters represent significant differences between treatments (p < 0.001; Tukey's *post-hoc* pairwise comparison).

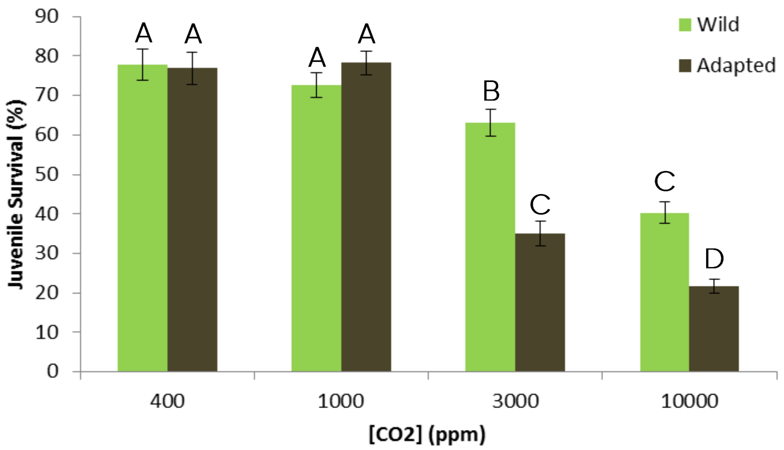


Figure 4 Mean (± S.E.) juvenile survival (% at 12 days post-hatch) in wild and high [CO_2] adapted strains of *Ophryotrocha labronica* La Greca and Bacci (1962) under differing CO_2 concentrations (400, 1,000, 3,000 and 10,000 ppm). For 400 and 1,000 ppm, n = 36, for 3,000 and 10,000 ppm, n = 18. Different letters represent significant differences between treatments (p < 0.001; Tukey's *post-hoc* pairwise comparison).

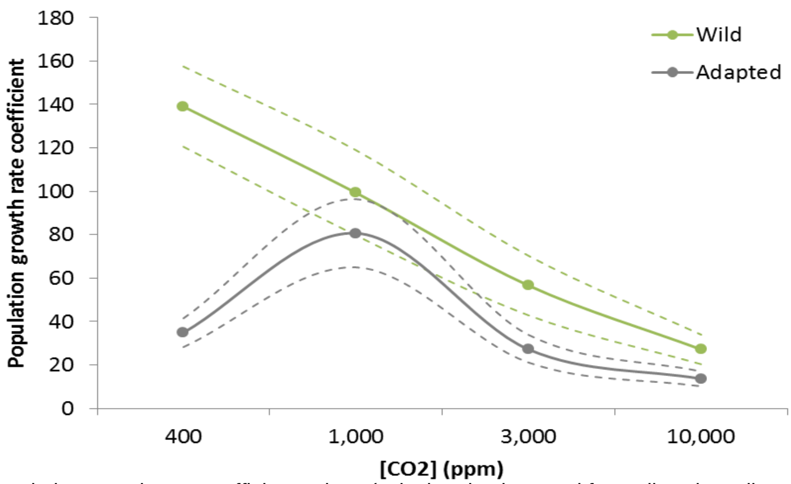


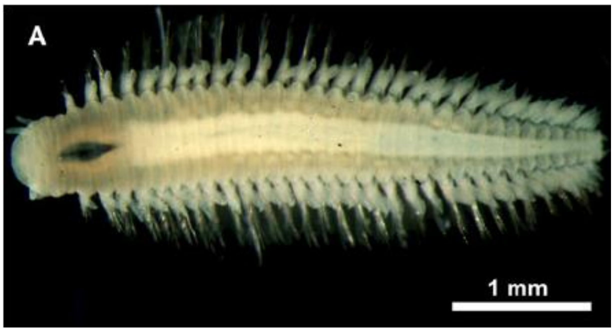
Figure 11 Mean population growth rate coefficient values (calculated using: total fecundity x juvenile survival x adult survival) in wild and high [CO_2] adapted strains of *Ophryotrocha labronica* La Greca and Bacci (1962) under differing CO_2 concentrations (400, 1,000, 3,000 and 10,000 ppm). Dashed lines represent 95 % confidence intervals of the mean. For 400 and 1,000 ppm, n = 36, for 3,000 and 10,000 ppm, n = 18. Areas where no overlap occurs between strains can be considered significantly different to one another.

Discussion

'These results demonstrate that in the marine polychaete O. labronica, adaptation to elevated CO_2 conditions alters the susceptibility of life-history traits to further changes in [CO_2]. Here, it is apparent that adaptation conveys both benefits and constraints due to increases and decreases of life-history trait performance in the adapted strain compared to the wild strain. Furthermore, it is clear that a complex response to CO_2 stress occurs between the strains as a result of significant shifts in relative fitness curves across all traits measured, with potential consequences on both individual and population level scales.'

'The observed reduction in female fecundity with an increase in [CO_2] shown here is a phenomenon for which a possible explanation could be as a result of a change in energy resource allocation away from reproduction and towards growth and maintenance (Sibly and Calow, 1986). This theory supports that of life history theory whereby energetic investment may focus primarily on growth as preparation for future reproductive events (Reznick, 1983). Interestingly, in O. labronica, no difference in fecundity is observed between 3,000 and 10,000 ppm treatments, indicating a potential maintenance of energetic investment in reproductive maintenance under extreme stress levels.'

'A significant effect of [CO_2] treatment was observed on survival rate / mortality in O. labronica in the current study. In contrast, previous studies on the polychaetes Hediste diversicolor (Basallote et al., 2012) and Nereis virens (Widdicombe and Needham, 2007) observed no effect of CO_2 on survival rates. As a result, it would appear that survival rates in response to CO_2 stress may be a highly species-specific response. A possible explanation for the reduced survival of O. labronica under increased CO_2 could be due to differences in male / female survivorship (Kita et al., 2013).'



Activity 3 – Case Study 2: Worming Our Way in to the Detail

Species:

Aim of Study:

pH / CO_2 Conditions Tested:

What Effects Were Tested For?:

What Were the Main Findings?:

What Could the Long-Term Effects Be?:

Notes

Homework Assignment 3 – Looking at the Data

So far, we have learnt about the impacts that ocean acidification could have (and maybe already are having) on marine organisms. Up until this point we have not really considered a timescale for when these changes are likely to occur and considered the extent to which they might affect marine organisms in the future.

In this assignment you will be analysing a data set for carbon dioxide concentrations and predicting the effects this could have on marine organisms.

In no more than 500 words, analyse the graph below and predict the approximate CO_2 concentrations for the year 2100. Then, using the knowledge you have gained from your case studies and own research apply this to predict the effects that may occur in a species of your choice by the year 2100. As a guide, the pH for the carbon dioxide concentration at '2100 Higher Emissions Scenario', would be approximately pH 7.7.

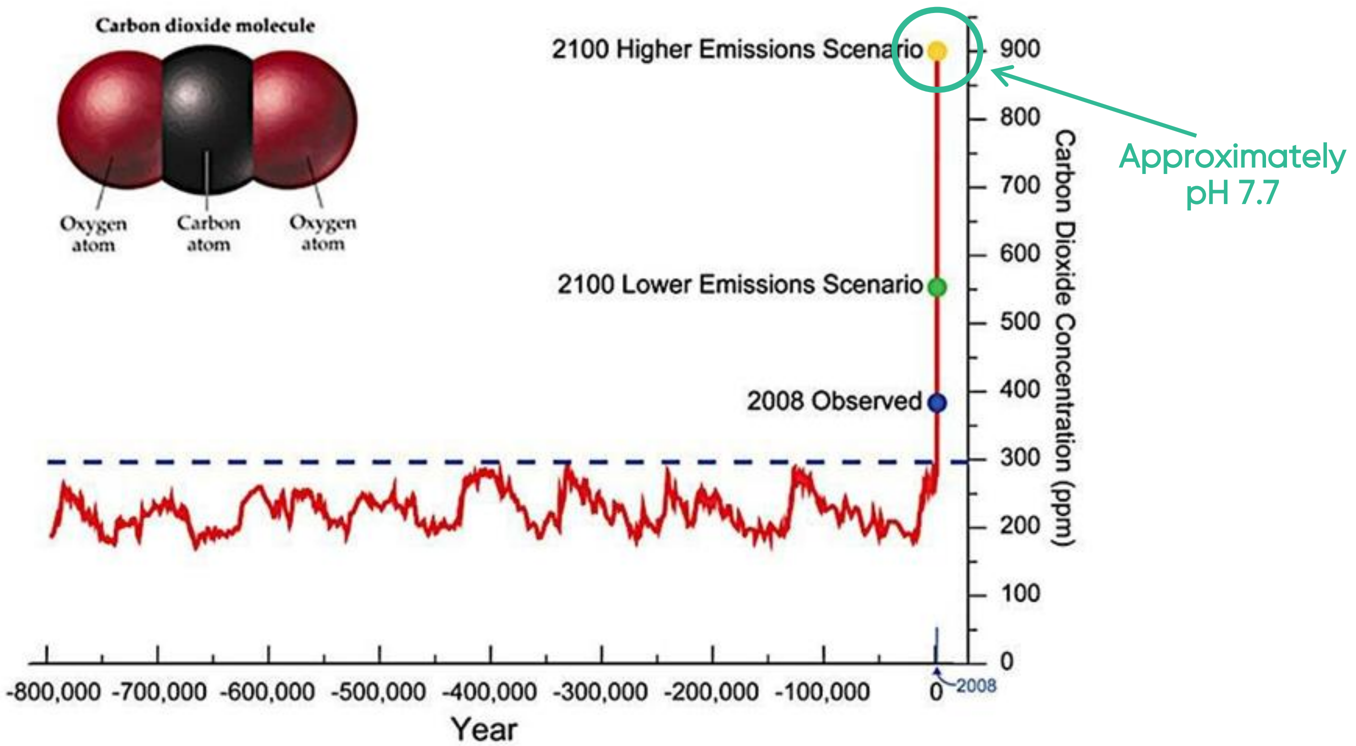
The structure for this should be as follows:

1) Introduction to ocean acidification and your species of choice.

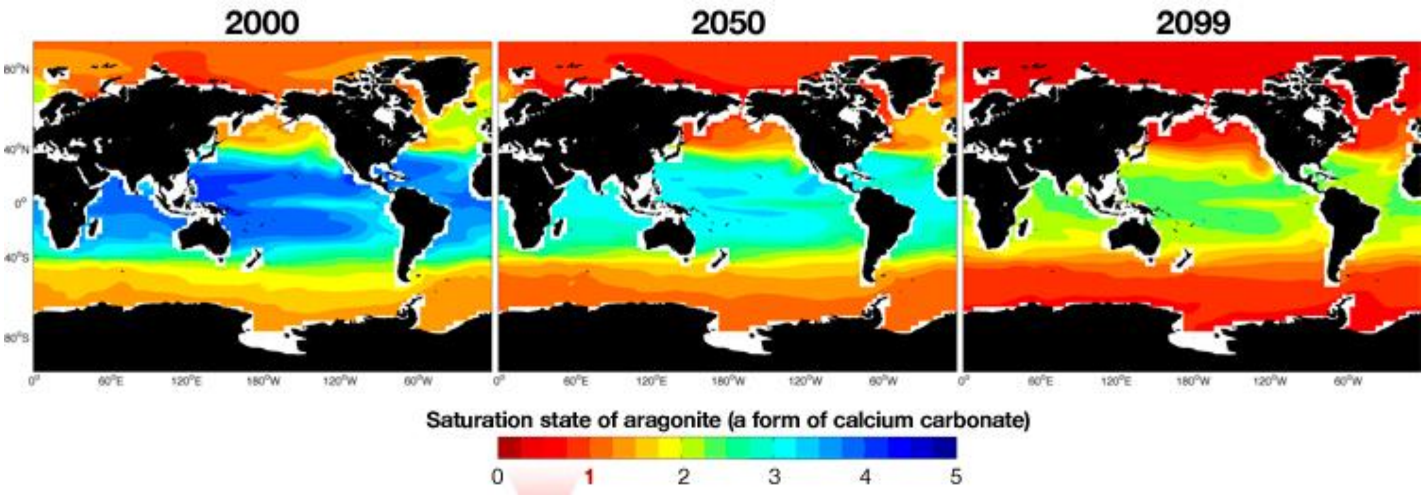
2) Data analysis of the graph to describe the trend of CO_2 over time and the current state of CO_2, to include higher and lower emissions scenarios for the year 2100.

3) A discussion about what extent these CO_2 / pH conditions could impact your species of choice in both direct and indirect ways. Use your own research (referenced) and the case studies to help you put these conditions in to context.

4) Conclusion to summarise your work briefly and identify key findings. This is also an opportunity to discuss limitations and improvements for your study.



Tutorial 4 – What Does the Future Hold?



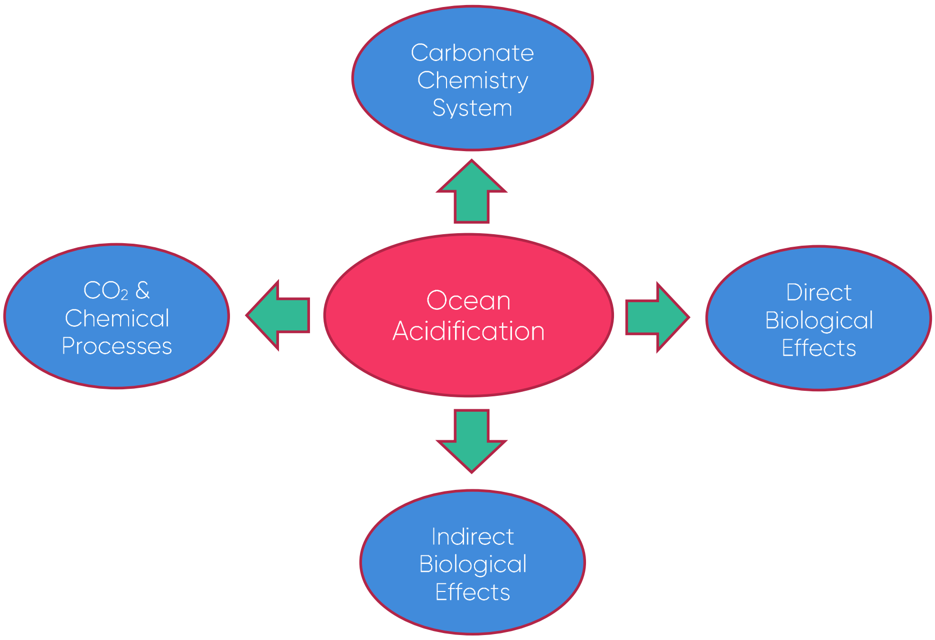
What is the Purpose of Tutorial 4?

By the end of tutorial 4, you should be able to:

- Objective 1: Analyse and interpret academic journal articles that use predictive modelling for CO_2 scenarios.
- Objective 2: Define and identify future pressures that could influence ocean acidification of surface waters.
- Objective 3: Assess the potential impact that modern technological advances could have on atmospheric CO_2 burden.

Starter Activity: Summarising the effects

Based on what you have learnt so far, fill in as much detail as you can on the following mind map:



Predictive Modelling

Predictive models are used to determine with some degree of accuracy what conditions of a named output are likely to look like in the future. To do this they use a range of data from a number of inputs to identify patterns and processes that can be extrapolated upon to come to reasonable conclusions. They can be as simple or as complex as you like.

For example, a simple ocean acidification predictive model may use CO_2 concentration and manufacturing rates as inputs and ocean pH as an output. This could then be extrapolated to determine how future ocean pH conditions could change. Obviously, there are other pressures present which would alter this, and these could be added as additional inputs. The more inputs that you use, generally the greater accuracy your predictive model will achieve. However, more inputs results in more complex models which require more time, money and computer power to produce.

There have been a number of predictive models produced for ocean acidification, the most comprehensive and convincing of which you are now going to look at:

Activity 1 – What Predictive Models Tell Us…:

The following page (p 36) contains the most informative and influential ocean acidification journal article to date. Read it through and answer the following questions:

1) Who are the authors of the article? ……………………………………………………………………

……

2) Where do most organisms live in the water column? ………………………………………………

……

3) What model did the authors use? ……………………………………………………………………

……

4) What is the maximum predicted change in pH at the ocean surface? ………………………

……

5) What did the authors conclude about previous acidification events? ………………………

……

……

……

……

6) Using the graph, what would you expect the pH change to be at 1 km depth in the year 2500 and in the year 3000? ……………………………………………………………………

……

……

Anthropogenic carbon and ocean pH

The coming centuries may see more ocean acidification than the past 300 million years.

Most carbon dioxide released into the atmosphere as a result of the burning of fossil fuels will eventually be absorbed by the ocean[1], with potentially adverse consequences for marine biota[2–4]. Here we quantify the changes in ocean pH that may result from this continued release of CO_2 and compare these with pH changes estimated from geological and historical records. We find that oceanic absorption of CO_2 from fossil fuels may result in larger pH changes over the next several centuries than any inferred from the geological record of the past 300 million years, with the possible exception of those resulting from rare, extreme events such as bolide impacts or catastrophic methane hydrate degassing.

When carbon dioxide dissolves in the ocean it lowers the pH, making the ocean more acidic. Owing to a paucity of relevant observations, we have a limited understanding of the effects of pH reduction on marine biota. Coral reefs[2], calcareous plankton[3] and other organisms whose skeletons or shells contain calcium carbonate may be particularly affected. Most biota reside near the surface, where the greatest pH change would be expected to occur, but deep-ocean biota may be more sensitive to pH changes[4].

To investigate the effects of CO_2 emissions on ocean pH, we forced the Lawrence Livermore National Laboratory ocean general-circulation model[5] (Fig. 1a) with the pressure of atmospheric CO_2 (pCO_2) observed from 1975 to 2000, and with CO_2 emissions from the Intergovernmental Panel on Climate Change's IS92a scenario[1] for 2000–2100. Beyond 2100, emissions follow a logistic function for the burning of the remaining fossil-fuel resources (assuming 5,270 gigatonnes of carbon (GtC) in 1750; refs 6, 7). Simulated atmospheric CO_2 exceeds 1,900 parts per million (p.p.m.) at around the year 2300. The maximum pH reduction at the ocean surface is 0.77; we estimate, using a geochemical model[8,9], that changes in temperature, weathering and sedimentation would reduce this maximum reduction by less than 10%.

A review[10] of estimates of palaeo-atmospheric CO_2 levels from geochemical models, palaeosols, algae and forams, plant stomata and boron isotopes concluded that there is no evidence that concentrations were ever more than 7,500 p.p.m. or less than 100 p.p.m. during the past 300 million years (Myr). Moreover, the highest concentrations inferred from the geological record were thought to have developed over many millions of years owing to slow processes involving tectonics and biological evolution.

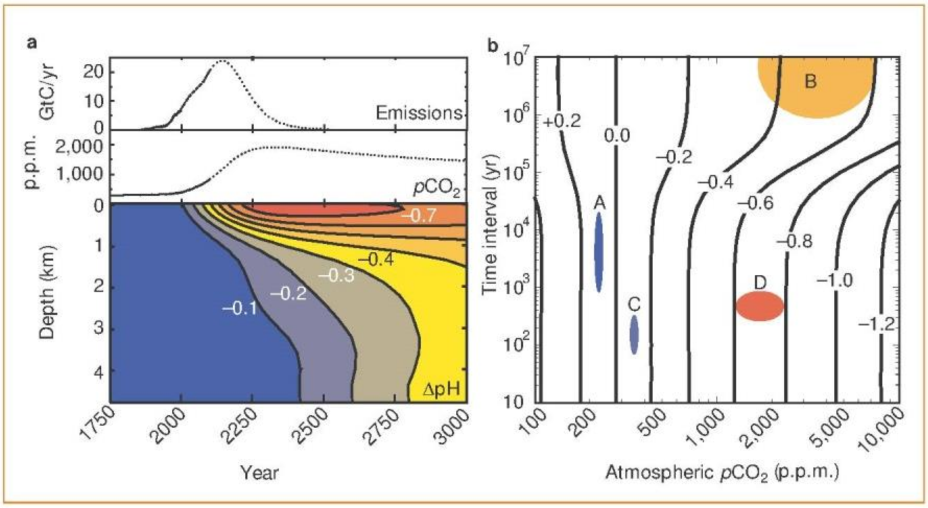


Figure 1 Atmospheric release of CO_2 from the burning of fossil fuels may give rise to a marked increase in ocean acidity. a, Atmospheric CO_2 emissions, historical atmospheric CO_2 levels and predicted CO_2 concentrations from this emissions scenario, together with changes in ocean pH based on horizontally averaged chemistry. b, Estimated maximum change in surface ocean pH as a function of final atmospheric CO_2 pressure, and the transition time over which this CO_2 pressure is linearly approached from 280 p.p.m. A, glacial–interglacial CO_2 changes[13]; B, slow changes over the past 300 Myr; C, historical changes[1] in ocean surface waters; D, unabated fossil-fuel burning over the next few centuries.

We estimated the effect of past changes in atmospheric CO_2 levels on ocean pH by using a four-box ocean/atmosphere model[8,9]. Modelled processes include weathering of carbonate and silicate minerals on land, production of shallow-water carbonate minerals, production and oxidation of biogenic organic carbon, production and dissolution of biogenic carbonate minerals in the ocean, air–sea gas exchange of carbon, and transport by advection, mixing and biological processes.

In a series of simulations, atmospheric pCO_2 was varied linearly from the pre-industrial value (about 280 p.p.m.) to stabilization values from 100–10,000 p.p.m. over time intervals of 10–10^7 yr. For each simulation, we recorded the maximum predicted perturbation in pH in the surface-ocean boxes (Fig. 1b). When a CO_2 change occurs over a short time interval (that is, less than about 10^4 yr), ocean pH is relatively sensitive to added CO_2. However, when a CO_2 change occurs over a long time interval (longer than about 10^5 yr), ocean chemistry is buffered by interactions with carbonate minerals, thereby reducing sensitivity to pH changes[11].

Based on the record[10] of atmospheric CO_2 levels over the past 300 Myr and our geochemical model[8,9], there is no evidence that ocean pH was more than 0.6 units lower than today. Our general circulation model results indicate that continued release of fossil-fuel CO_2 into the atmosphere could lead to a pH reduction of 0.7 units. We conclude that unabated CO_2 emissions over the coming centuries may produce changes in ocean pH that are greater than any experienced in the past 300 Myr, with the possible exception of those resulting from rare, catastrophic events in Earth's history[8,12].

Ken Caldeira*, Michael E. Wickett†
**Energy and Environment Directorate and †Center for Applied Scientific Computing, Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, California 94550, USA*
e-mail: kenc@llnl.gov

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Competing financial interests: declared none.

Pressures on CO_2 Emissions:

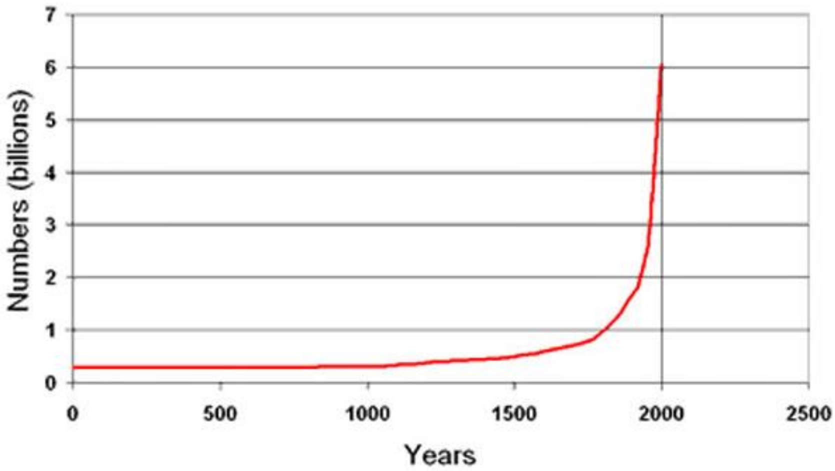
There are countless inputs of carbon dioxide in to the environment. These couple with other factors that result in increased atmospheric CO_2 conditions such as deforestation. Deforestation results in fewer trees to take up CO_2 from the atmosphere and use it to produce glucose and oxygen, as a result there will be less CO_2 removed from the atmosphere. The following are two of the main pressures on increasing CO_2 inputs:

1) Contemporary Industrialisation

Previously, industrialisation has been considered as the development of a country to achieve advanced levels of manufacturing, communications and transport. Nowadays, most countries are in an advanced state of industrialisation as we enter an age of contemporary industrialisation. Contemporary industrialisation is a period of modern advancement in electronics, property and technology. Each if these new 'luxuries' has a carbon dioxide budget associated with it as we become reliant heavily on modern technology. Until modern technology becomes substantially more environmentally friendly, this will continue to increase.

2) Population Growth

Each person has their own emission output. This is based on everyday activities such as cooking, eating, travelling, entertainment and provision of shelter. Population growth is occurring in an exponential fashion, meaning it is currently happening at an ever-increasing rate. See the population curve to the right for an image of how this has changed in recent history. If we have more people on Earth, each with their own carbon footprint, then the total CO_2 emissions attributed to human activity will also increase at an exponential rate.



Activity 2 – Saving the World:

In the space below, list as many ways as you can think that we can reduce carbon dioxide emissions individually and as a society:

Advancement versus Refinement:

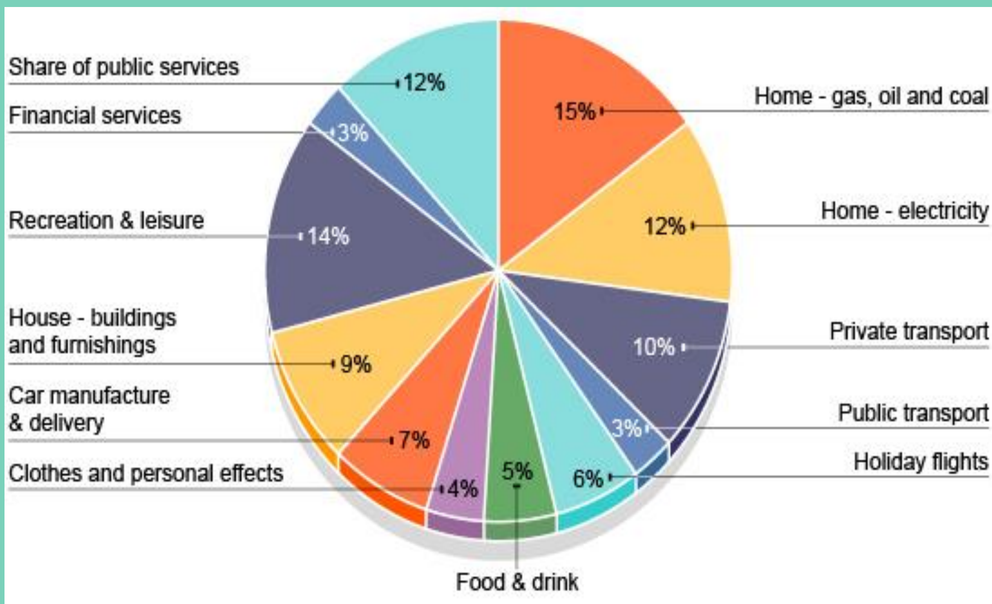
It would be unrealistic to limit the advancement of technology simply due to emissions. We live in a society where advancement improves the quality of lives we live and allows for an ever-connected world which we are able to exploit. However, there is a balance to consider where we need to consider the value of refinement of our current technologies at the expense of advancement.

Refinement provides an opportunity to improve our existing technologies without the need to develop new technologies. This could therefore consider how environmentally considerate the current technologies are. For example, advancement would be to develop faster-flying jets that could get us half way around the world in a couple of hours. Refinement would be to improve our current jets to boost their fuel efficiency which may enable them to fly slightly faster but would also reduce CO_2 emissions at the same time.

There has to be a limit at which society will accept that advancement can be reduced in order to focus on refinement before the environmental quality is reduced to a point where it negatively impacts our quality of lives anyway.

Activity 3 – Your Carbon Footprint:

Look at the following pie chart. This shows the percentage of your carbon footprint that is made up of each constituent of an average person's lifestyle. In the space below, make a note of any of these that would be difficult to reduce:



Based on what we have learnt so far about population growth, if the population doubled in size, we would each have to halve our carbon footprint just to keep the CO_2 emissions at a stable rate. Using the 'difficult to reduce' assumptions you made previously, in the space below calculate a proportion for how much you would need to reduce your footprint in the remaining categories by in order to halve your overall carbon footprint? You can ask your tutor for help with this:

Notes

Homework Assignment 4 – The Draft Assignment

Currently, we have analysed a range of data from a number of experiments and predictive models to build a picture of ocean acidification. This has included some background to the chemistry; then considered how the chemistry interacts with the biology to include case studies; and finally looked at predictions and future pressures that are likely to influence these processes.

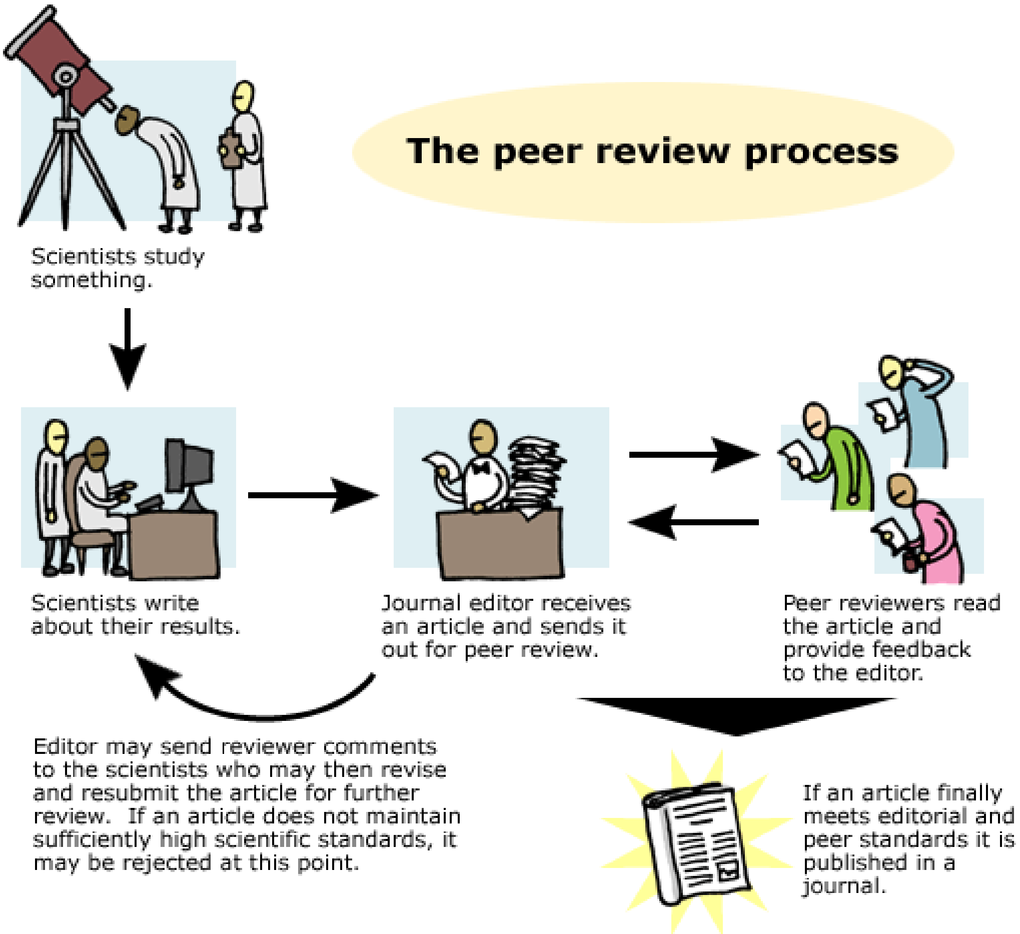
You are now in a position to start summarising everything and applying your knowledge to write a predictive piece of work about the future effects of ocean acidification for your final assignment. The word count for this will be 2500 words (± 10 %). The big question to debate for your final assignment will be:

'How Might Ocean Acidification Affect Marine Organisms by the Year 2300?'

For Homework Assignment 4, you will start drafting your final assignment and submit it through the VLE so that you can receive comments and feedback to help you construct and refine your final assignment. This does not need to be the whole assignment and can be in the form of bullet points and notes (the more you do now, the more you get feedback on). Try to submit at least one full paragraph (e.g. introduction) so that

Furthermore, come prepared to Tutorial 5 ready to stand up and talk for 2 minutes to the group about your main opinions / comments / species choices for your final assignment.

Together, these activities mirror the peer review process that scientists use to ensure the quality and accuracy of the work they produce. The draft assignment will allow your tutor to make comments as an editor would and the talking to your peers in a group allows comments and feedback from others with similar knowledge to yourself.



Please see the following page for some advice on structure and things that you might want to consider in addition to advice on how to write a compelling argument in your work.

Note: There is no right or wrong answer. You may even decide that there will be no effect at all on species by the year 2300 but you would still need to present evidence and justify why you have come to that conclusion.

Assignment Structure:

There are multiple ways that you could structure your assignment. The following is a guide to help you. You paragraphs could consider the following subjects:

1) Introduction: This should briefly introduce what ocean acidification is, how it occurs and why it is / isn't an issue in the environment.

2) Changes in CO_2 in the environment: Consider the pressures on CO_2 with examples and consider how these are likely to change in the future (linking to ocean acidification). Use the year 2300 as an example for this.

3) What are the biological effects likely to be?: This is the main consideration of this assignment and should form the majority. Consider the effects we have studied in our experiments and case studies as well as your own research. Provide examples to support your opinion. Keep referring back to the year 2300 predictions for this.

4) Conclusion: Summarise your findings and overall judgements. Finish by considering what you think can be done to resolve the issue in the future.

Other Things to Consider:

- You may want to use images or diagrams in your work as examples. This is a great way to convey information although make sure you refer to them in text and explain them a bit.

- You could include the results from your own experiment in the work that you produce. This could include making a digital graph of the results you achieved and using the results to explain ocean acidification.

- Opinions are OK in science as long as you can justify why you are using them. It is always best to prevent evidence from competing perspectives and justify why you support one over the other. The following is a 'pearl' diagram. If you make an opinion in your work you should always write it in the following way to ensure you have justified it effectively:

Make your work into a hidden pearl

Point
Evidence
Analyse
Review
Link

Tutorial 5 – So, What Next?

What is the Purpose of Tutorial 5?

By the end of tutorial 5, you should be able to:

- Objective 1: Summarise the process of carbon capture and storage (CCS) as a means of reducing atmospheric CO_2 emissions and critically analyse its potential as a strategy.
- Objective 2: Discuss your work and opinions with your peers and constructively evaluate the work of others.
- Objective 3: Reflect on feedback you have received for your work and apply it to form a plan of alterations to take forward for completing your final assignment.

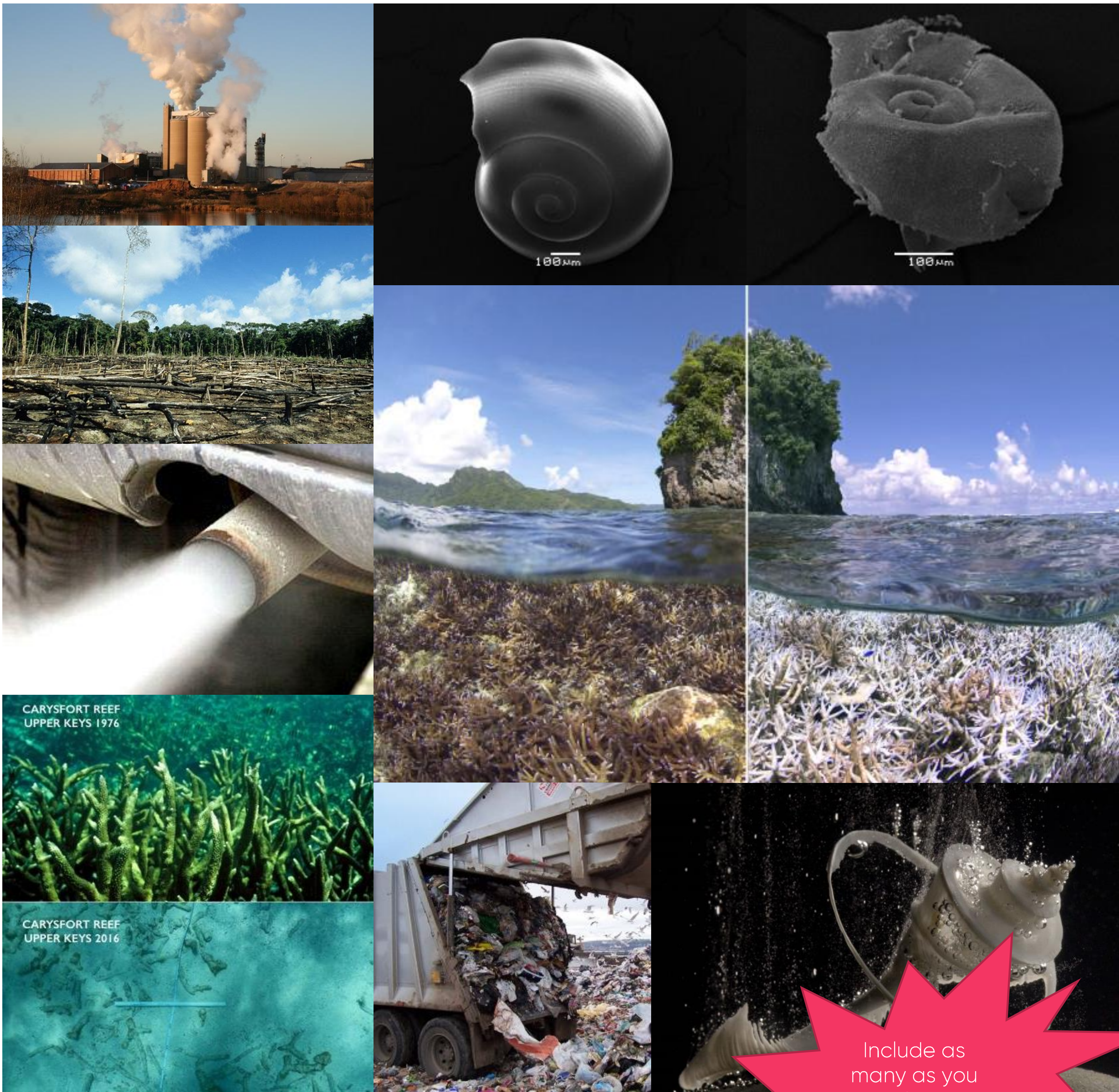
Dedicated Improvement and Reflection Time (DIRT)

Tutorial 5 gives you the opportunity to reflect on your work and improve it before the final hand-in. This will make the work you produce a much higher standard than the original.

The best work you produce is also the DIRTiest.

Starter Activity: Pictures Tell a Thousand **MORE** Words…

Look again at the following picture collage. What keywords spring to mind? Write them in the space below and compare them to those from Tutorial 1 – How have they changed?



Include as many as you can when you write your final assignment

Keywords:

How Might we Solve the Problem?

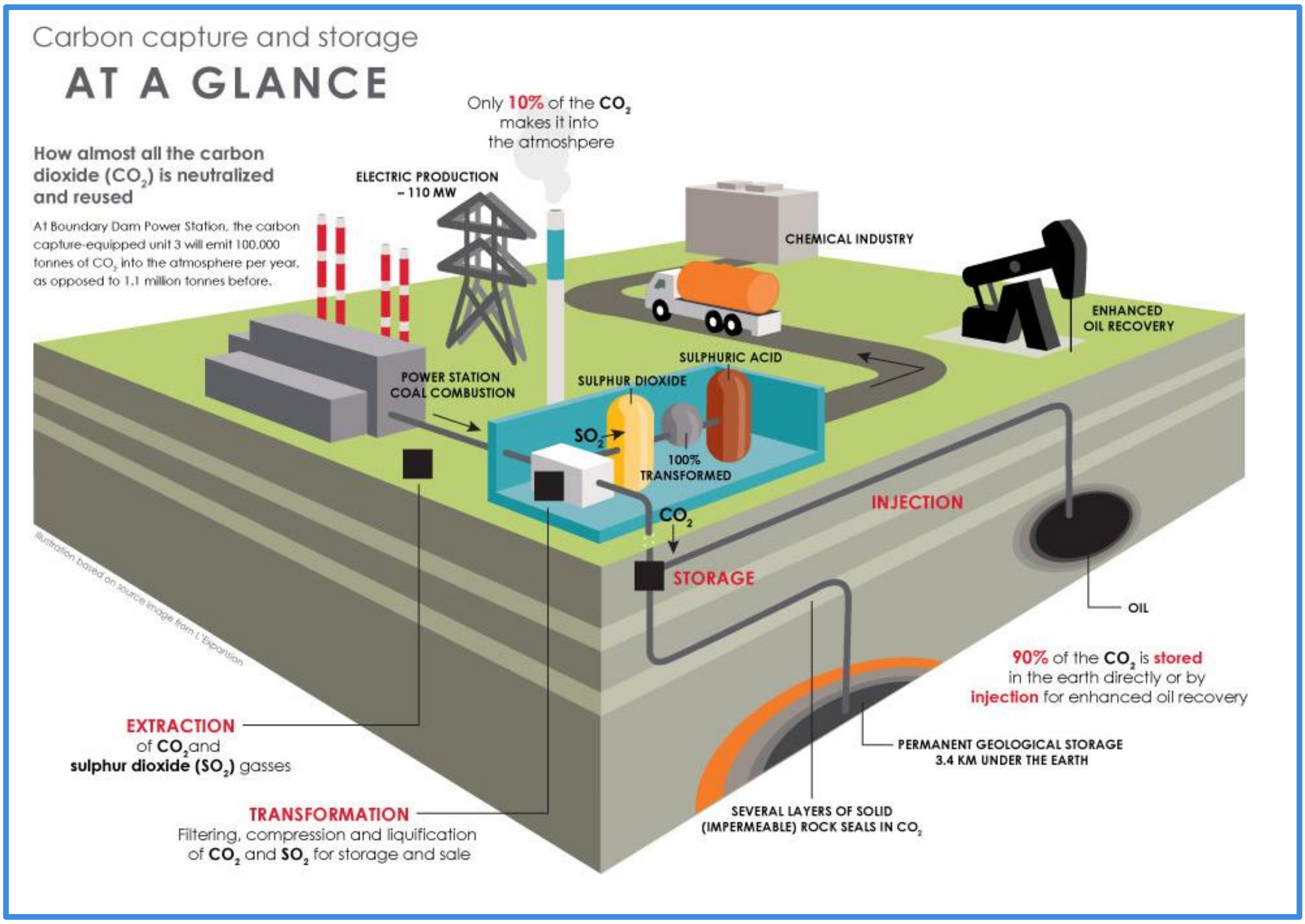
Following on from what we learnt in Tutorial 4, pressures on carbon dioxide emissions are likely to continue to increase at an unprecedented rate over the coming decades. It is unlikely that technological refinement will progress enough to combat these pressures. As a result, solving the problem is inevitably not likely. However, it may be possible to reduce the extent of this problem in the future by using methods to reduce a proportion of the emissions that are released. Furthermore, it may be possible that aquatic organisms could adapt to cope with these changes if they occur over longer periods of time than are traditionally tested for in laboratory studies.

Carbon Capture and Storage (CCS)

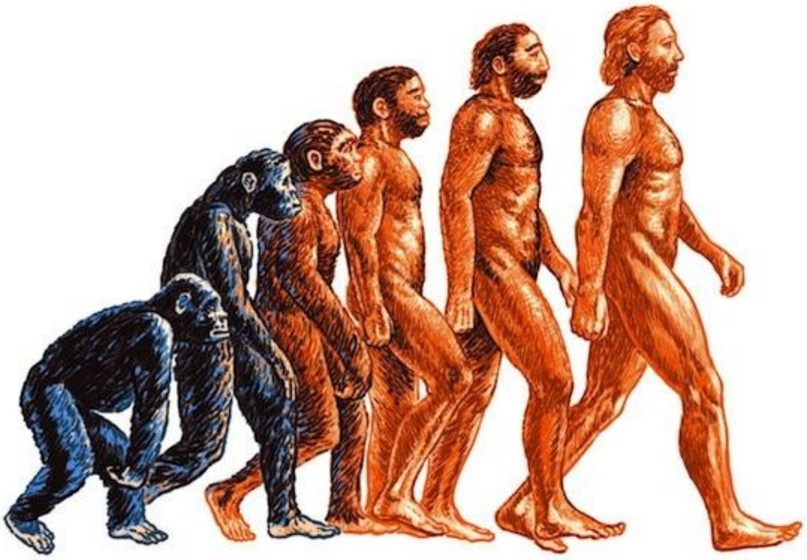
Carbon capture and storage (CCS) is a proposed mechanism by which the release of emissions from industrial sources such as factories may be drastically reduced. The image below summarises the expected processes by which this may be achieved.

Essentially, carbon dioxide produced by manufacturing would be captured before it is released. Then it could be chemically treated and stored for reuse such as in the chemical manufacturing industry. In addition, CO_2 could be pumped in to geological structures for long term storage such as in porous rocks or under the ocean floor.

Unfortunately, this process has two drawbacks. Firstly, it is very expensive and getting industries to agree to expensive processes is difficult. Secondly, it is recognised that on occasions CO_2 may leak from storage under the sea floor. This could result in localised areas of extreme CO_2 saturation and consequent acidification.



Adaptation

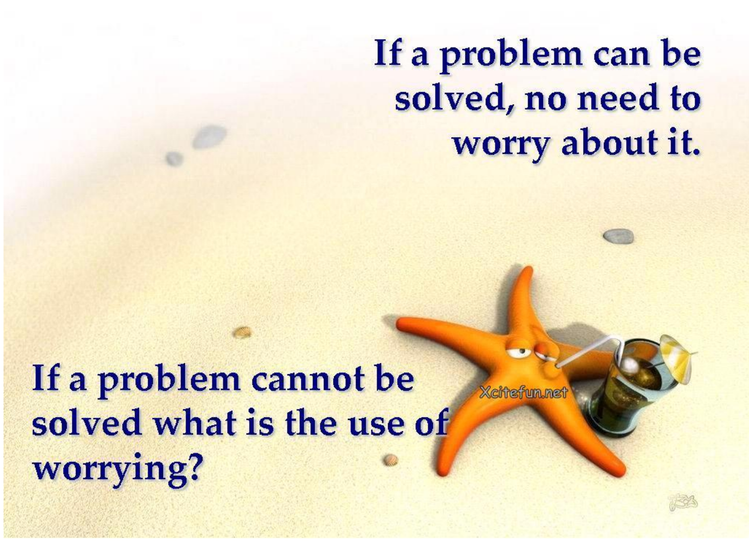


It is often argued that concerns surrounding ocean acidification are false as changes in our atmosphere resulting in increased CO_2 and acidification have been shown to occur historically over periods of millennia. As a result, it is assumed that organisms must have previously adapted to survive in conditions such as these. However, the reason ocean acidification is a cause for concern is that by releasing such a large quantity of 'man-made' CO_2 in to the atmosphere we are speeding up this process substantially.

Adaptation can be defined as 'the process by which an organism or species becomes better suited to its environment'. Over time, this often allows species to live in environments that they previously may not have survived. Adaptation is a slow process, much like the adaptation of modern humans from primitive common ancestors. One thing that we cannot be sure of is whether ocean acidification is occurring too quickly for adaptation of animals to be able to occur. If adaptation can occur then it is likely that the threats posed will not be as great as initially thought.

In our worm case study, we see evidence that the species has adapted over a number of generations to live under ocean acidification conditions. However, it is also apparent from that study that there were some negative consequences as a result of this adaptation, such as reduced survival, fecundity and population growth rate.

Preparing for Your Final Assignment



Having now covered all of the content in this course, it is time to focus on the preparation of your final assignment. You will now be provided back your draft assignments with annotations from your tutor. Take a moment to read through the general comments and make sure you understand them.

Remember, this activity was used to allow you to improve your final assignment so that you can achieve the best grade possible. As a result, if you have a lot of corrections and constructive comments then view these as a challenge and try to achieve the best grade you can by responding to them for your final assignment.

Activity 1 – Talking About Your Assignment:

You will each now get the opportunity to talk to the rest of the class for 2 minutes. The person sitting next to you will be your presentation partner. Throughout your talk your presentation partner will fill out a feedback form about your presentation. You will then do the same for your presentation partner's talk. These forms will be provided to you by your tutor.

The feedback you provide should be focussed on the content over the presentation style and should be constructive. By this, I mean something that your presentation partner can improve upon. This way it can be used as a peer review exercise to improve the quality of your final assignment.

If neither you nor your presentation partner is talking, feel free to make notes of any good content or ideas that any of your other classmates have.

Activity 2 – Responding to Feedback:

You have now received feedback from both:

1) Your tutor about your draft assignment.

2) Your presentation partner about your 2-minute talk.

Using this feedback, in the space below create a checklist of things that you are going to do to your assignment between now and the final deadline to improve your work:

✓

✓

✓

✓

✓

✓

Using the Mark Scheme:

The mark scheme for you final assignment is provided for you on page 6 of your course handbook. Mark schemes are not just there to assess you. They are provided for you in order to aid you and help you understand what is expected from you for the piece of work that is being marked.

The mark scheme has grade descriptions for 1st's and 2:2's. A 2:1 grade would have elements of both criteria or fall between them both. As you are provided with this mark scheme in advance of submitting your final assignment you can try and ensure that your work covers all of the criteria listed in the 1st category. Below is a list of the grades that can be achieved (in university style), and the quality of work that this equates to:

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at AS-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
Did not submit	DNS	No assignment received by The Brilliant Club

The following penalties apply for either late submission or plagiarism. For advice on avoiding plagiarism, see the 'Referencing Correctly' appendix on page 52:

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Activity 3 – Using the Mark Scheme:

Take some time to read the mark scheme and read the draft assignment that you submitted. What grade would you give yourself based on this? In the space below, make a note of the mark scheme criteria that you feel you need to improve upon and comment on how you will achieve this:

Notes

Homework Assignment 5 – The Final Assignment

You are now in a position to write your final assignment. Use the activities from this tutorial and the hints and tips from the draft assignment to help you.

The word count for this will be **2500 words** (± 10 %). The big question to debate for your final assignment will be:

'How Might Ocean Acidification Affect Marine Organisms by the Year 2300?'

See the draft assignment on page 41 for more information on structure and what to include in your assignment.

The final deadline for this assignment is: 5th April 2017.

Submit your assignment through the Final Assignment tab on the VLE. Please contact you tutor if you have any issues. More advice on the VLE can be found on page 53 of your course handbook. Good luck!

Things to Remember:

1) Try to include sources you have found on your own in addition to those provided.

2) Remember to use PEARL to justify opinions in your work.

3) Use the mark scheme to help you achieve the higher grades.

Writing to a Word Limit:

1) In the first instance, do not worry about your word limit.

2) Reduce your word count afterwards as it helps you remove unnecessary words.

3) The word count is a guide and you are given a range to work within – it does not need to be exact.

Tutorial 6 – Feedback Tutorial

What is the Purpose of Tutorial 6?

- To receive feedback on final assignments.
- To share examples of best practice with the other pupils in your group.
- To write targets for improvement in school lessons.
- To reflect on the programme including what was enjoyed and what was challenging.

Final assignment feedback

What I did well…	What I could have improved on…
• • •	• • •

My target for future work is…

Reflecting on The Scholars Programme

What did you most enjoy about The Scholars Programme?
•   •   •

What did you find challenging about the programme?	How did you overcome these challenges?
• • •	• • •

Appendix 1 – Referencing Correctly

When you get to university, you will need to include references in the assignments that you write, so we would like you to start getting into the habit of referencing in your Brilliant Club assignment. This is really important, because it will help you to avoid plagiarism. Plagiarism is when you take someone else's work or ideas and pass them off as your own. Whether plagiarism is deliberate or accidental, the consequences can be severe. In order to avoid losing marks in your final assignment, or even failing, you must be careful to reference your sources correctly.

What is a reference?

A reference is just a note in your assignment which says if you have referred to or been influenced by another source such as book, website or article. For example, if you use the internet to research a particular subject, and you want to include a specific piece of information from this website, you will need to reference it.

Why should I reference?

Referencing is important in your work for the following reasons:

- It gives credit to the authors of any sources you have referred to or been influenced by.
- It supports the arguments you make in your assignments.
- It demonstrates the variety of sources you have used.
- It helps to prevent you losing marks, or failing, due to plagiarism.

When should I use a reference?

You should use a reference when you:

- Quote directly from another source.
- Summarise or rephrase another piece of work.
- Include a specific statistic or fact from a source.

How do I reference?

There are a number of different ways of referencing, and these often vary depending on what subject you are studying. The most important to thing is to be consistent. This means that you need to stick to the same system throughout your whole assignment. Here is a basic system of referencing that you can use, which consists of the following two parts:

1. A marker in your assignment: After you have used a reference in your assignment (you have read something and included it in your work as a quote, or re-written it your own words) you should mark this is in your text with a number, e.g. [1]. The next time you use a reference you should use the next number, e.g. [2].
2. Bibliography: This is just a list of the references you have used in your assignment. In the bibliography, you list your references by the numbers you have used, and include as much information as you have about the reference. The list below gives what should be included for different sources.
    a. Websites – Author (if possible), title of the web page, website address, [date you accessed it, in square brackets].

    E.g. Dan Snow, 'How did so many soldiers survive the trenches?', http://www.bbc.co.uk/guides/z3kgjxs#zg2dtfr [11 July 2014].

    b. Books – Author, date published, title of book (in italics), pages where the information came from.

    E.g. S. Dubner and S. Levitt, (2006) *Freakonomics*, 7-9.

    c. Articles – Author, 'title of the article' (with quotation marks), *where the article comes from* (newspaper, journal etc.), date of the article.

    E.g. Maev Kennedy, 'The lights to go out across the UK to mark First World War's centenary', Guardian, 10 July 2014.

Appendix 2 – Using the VLE

VLE username	
VLE password	

Please remember the following key details…

- You are able log into the VLE either through the link on our website (www.thebrilliantclub.org) or going directly to the VLE site at (https://portal.thebrilliantclub.org/sign-in).
- Please update your profile with your full name and email address- this will allow you to retrieve forgotten passwords or usernames
- If you forget your log-in details you can request them to be emailed to you by clicking the link on the VLE home page. (If you are still having problems you can email: schools@thebrilliantclub.org)

What is the VLE?

The VLE is a virtual learning environment for all pupils on the Scholars Programme it is used for:

- messaging your tutor
- submitting homework
- submitting your final assignment
- accessing resources for your tutorials
- finding out more information about university and careers

How should I use the VLE?

The VLE is a professional academic environment in which pupils are able to message their PhD Tutor. Here are a few things to consider:

- Ensure you keep a professional tone in the messages you send to your tutors.
- Ensure you always reply to your tutors in a timely manner.
- Thank your tutor for the effort they are putting in to give you your feedback etc.
- Submit all homework to your tutor on time.

IMPORTANT: Final assignment

- When you submit your final assignment, please remember that you need to do so through the 'My Activities' tab and not as an attachment to a message.

Appendix 3 – Reliable Sources

Information can come from a variety of sources. Most of the time, sources will be reliable but sometimes it may be biased or have an agenda that calls in to question the reliability of the source. Furthermore, it may not be written by someone who fully understands the subject and therefore could make mistakes. Use the following information and questions to help you determine what makes an unreliable or reliable source:

Relevance	Does the information match my needs?
Provenance	Is it clear where the information has come from? Can I identify the authors or organisations responsible? How was it published? Has it been peer reviewed?
Objectivity	Is the author's position or interest made clear? Does the author declare any connections that might compromise their independence? Is the language emotive? Are there hidden vested interests?
Timeliness	Is it clear when the information was produced? Does the date of the information meet my requirements?
Presentatio n	Is the information clearly communicated?
Method	What research methods were used, and how are results reported? Do I need to check how significant the results actually are?

Factors to consider	*Least reliable*	*Possibly reliable*	*Most reliable*
Type of source	Unfamiliar website	Published material	Official websites, institutional sites, academic journals
Author's background	Uncredited	Educated on topic	Expert in the field
Date published	None	Outdated	Recently revised
Depth of review	Controversial reviews	Good public response; general approval	Peer-reviewed by reliable sources
Sources cited	None	Credible sources	Citations referencing other well-cited works
Objectivity	Clearly biased	Sponsored source	Balanced, neutral

Appendix 4 – Useful Sources

Information can come from a variety of sources and you should always check the reliability of your sources as described and outlined in Appendix 3. The following is a list of useful sources that you can use in your work to gather information:

1) Google Scholar: https://scholar.google.co.uk/

This is a useful source for finding journal articles and case studies. You may not have access to any of the full journal articles but usually the abstract that is available to you is enough to provide the information that you need.

2) UKOA: http://www.oceanacidification.org.uk/

This is a website for a government body that was set up to study ocean acidification. The information included has almost all come from university researchers and there are a lot of diagrams that help to explain important concepts of ocean acidification.

3) PMEL: http://www.pmel.noaa.gov/co2/story/Ocean+Acidification

This is another organisation similar to UKOA that studies ocean acidification, this time on a more global scale. Again, there are a number of articles and diagrams that can inform you of the current state of ocean acidification.

4) Nature: http://www.nature.com/scitable/knowledge/library/ocean-acidification-25822734

Nature is an academic journal and one of the most important journals in biological sciences research. This article is designed to provide any non-experts with an overview and understanding of ocean acidification and how it works.

5) See what you can find…

There is a lot of information available. Check it matches your reliability criteria and then use it. If you are unsure of the validity of a source then feel free to ask your tutor.

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