Zeitschrift: Bulletin de la Société Vaudoise des Sciences Naturelles
Band: 100 (2021)

Artikel: What is the most effective way of preventing corals from extinction?
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DOI: https://doi.org/10.5169/seals-953546

What is the most effective way of preventing corals from extinction ?

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LESER S., 2021. What is the most effective way of preventing corals from extinction ? ***Bulletin de la Société Vaudoise des Sciences Naturelles*** **100 : 181-188.**

Abstract

Corals nowadays are under serious stress from environmental threats, most notably from anthropogenic climate change. Therefore, restoration and conservation efforts have risen in popularity, but their real effectiveness remains uncertain and controversial. The coral conservation strategies fall into four different categories : (i) coral restoration or coral gardening which tries to rebuild damaged reef structures ; (ii) helping corals and their algae adapt to warmer temperatures through assisted evolution or genetic engineering ; (iii) reducing the light and heat that reaches them with the help of geo-engineering ; or (iv) reducing the threats through systemic changes that aim to do so. Some strategies (i-iii) are more short term oriented whereas the (iv) is more for the long term.

The chemical bases of one of the restoration strategies in group (i), Mineral Accretion Technology (MAT), were tested out in lab experiments. MAT is a method using electrolysis to assist the corals in the production of their $CaCO_3$ structures, so that they can save energy. The goal of this study was to see if the MAT strategy would still have the same level of support in future, more acidic, ocean conditions. We found that the more acidic the environment was, the less $CaCO_3$ was produced. This shows that it would probably still aid the corals, but likely to a lesser degree if we continue to emit CO_2 exponentially, since the more we emit, the more acidic the oceans get. This shows the importance of reducing CO_2 emissions, which was supported by the three experts interviewed for this project. To do this we need to act together to obtain systematic changes, but local stress factors such as local pollution and overfishing need to be diminished as well.

Key words: Assisted evolution, Conservation, Coral gardening, Coral reef, Geo-engineering, Mineral accretion technology, Reducing emissions, Restoration.

LESER S., 2021. Quel est le moyen le plus efficace d'empêcher l'extinction des coraux ? ***Bulletin de la Société Vaudoise des Sciences Naturelles*** **100 : 181-188.**

Résumé étendu

Avec une pollution en constante augmentation et des températures record, les coraux sont de plus en plus menacés. Au niveau planétaire, environ 70 % des coraux ont blanchi au moins une fois pendant le blanchissement mondial de 2014 à 2017. De plus, le monde a déjà perdu environ 50 % de ses coraux au cours des 30 dernières années et le Groupe d'experts intergouvernemental sur l'évolution du climat prévoit que tous les récifs pourraient avoir disparu d'ici 2070. Cette destruction ou disparition pourrait à son tour avoir un effet néfaste sur les humains, notamment parce que les coraux servent d'abri à un grand nombre d'animaux marins, essentiels à un écosystème fonctionnel. Ce dernier est très important pour la survie d'environ 400 millions de

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 CODEN : BSVAA6 ISSN : 0037-9603

personnes qui en dépendent pour leur alimentation et leurs revenus. De nombreux scientifiques tentent de trouver des moyens pour sauver ces écosystèmes et les espèces qui y sont associées. Quatre solutions principales sont actuellement à l'étude : (i) la restauration ou le jardinage des coraux, qui tente de reconstruire les structures endommagées des récifs ; (ii) l'aide aux coraux et à leurs algues pour qu'ils s'adaptent à des températures plus élevées par le biais de l'évolution assistée ou du génie génétique ; (iii) la réduction de la lumière et de la chaleur qui les atteignent à l'aide de la géo-ingénierie ; ou (iv) la réduction des menaces par des changements systémiques visant à y parvenir. Les stratégies se différencient dans le cadre temporel de leur efficacité. Les stratégies (i-iii) sont plutôt focalisées sur le court terme, tandis que la stratégie (iv) est davantage axée sur le long terme.

Mon objectif dans ce projet étendu était d'obtenir une vue d'ensemble des différentes stratégies qui existent, en m'intéressant à leur utilité. Ensuite, les bases chimiques de l'une des stratégies de restauration du groupe (i), la technologie d'accrétion minérale (TAM), ont été testées dans quelques expériences de laboratoire. La TAM est une méthode où l'électrolyse est utilisée pour aider les coraux à produire leurs structures de $CaCO_3$, afin qu'ils puissent économiser de l'énergie. L'objectif de cette étude était de voir si cette stratégie TAM aurait le même niveau de soutien dans des conditions océaniques futures, plus acides. Enfin, trois experts ont été interrogés afin d'avoir un aperçu de leur savoir-faire.

Les résultats des expériences ont montré que plus l'environnement était acide, moins la production de $CaCO_3$ était importante. Cela montre que la TAM pourrait encore faciliter la création des exosquelettes des coraux, mais probablement à un degré moindre si nous continuons à émettre du CO_2 de manière exponentielle, puisque plus nous émettons, plus les océans deviennent acides. Cela montre l'importance de la réduction des émissions, ce qui est soutenu par les trois experts interrogés pour ce projet, non seulement pour éviter l'extinction des coraux, mais aussi pour notre propre survie. Pour ce faire, nous devons agir ensemble pour obtenir des changements systématiques, mais les facteurs de stress locaux tels que la pollution locale et la surpêche doivent également être diminués.

Mots-clés : barrière de corail, conservation, évolution assistée, géo-ingénierie, jardinage de coraux, réduction des émissions, restauration, technologie d'accrétion minérale.

Introduction

With increasing pollution and record setting temperatures, corals are under constant threat. About 70 % of corals worldwide have bleached at least once during the 2014-2017 global bleaching event. In fact, the world has lost approximately 50 % of its corals in the last 30 years and the projections of the Intergovernmental Panel on Climate Change forecast that all reefs could be gone by 2070 (Morrison *et al.* 2019). However, coral reefs are a quintessential part of the biosphere, as about 400 million people rely on them for food and income around the world (Morrison *et al.* 2019). They create 30 billion dollars of net benefit worldwide each year in goods and services, including tourism and recreation. They also play an important role in protecting coastal communities from storms and hurricanes since they absorb up to 97 % of the waves' energy (Ferrario *et al.* 2014).

Corals are a group of genetically identical cnidaria polyps only a few millimetres wide, which live in endosymbiosis with unicellular algae, called *zooxanthellae*. The polyps need the algae for nutrition and energy, and the algae need the polyps for a place to stay, a safe shelter where they can live. As for the structure, the skeleton of the corals comes from the calcium carbonate ($CaCO_3$) secreted by the polyps near their base. When they are broken into different pieces, these pieces regrow thereby multiplying the amount of coral.

Nowadays, corals face numerous threats, but we can distinguish three main ones. The two first ones are local stressors, i. e., the quality of the water and overfishing, and the last one is global, anthropogenic climate change. The latter poses two threats to the corals. The first is ocean acidification caused by the oceans ability to absorb CO_2. This decreases the pH of seawater which is corrosive for the calcium carbonate structure, which forms the coral's skeleton (Cornwall 2019). The second is global warming. In fact, oceans have absorbed more than 93 % of the extra heat in the atmosphere (United Nations 2017). This leads to increasing ocean temperatures, putting corals under heat stress which causes corals to bleach and even be "cooked". Coral bleaching is the process in which coral polyps expel their algae due to physiological stress from factors such as heat and light. This causes the corals to become white, but more detrimentally, without the algae, they do not get the energy and nutrients they need (Muscatine 1990). If the water temperatures cool down, the coral will find new algae in as little as a couple of weeks or months depending on the species and how severe the bleaching was. However, if there is prolonged, repeated or severe bleaching, the corals are more likely to die.

There are many different coral reef conservation methods but most of them fall into one of four groups (Reef Restoration and Adaptation Program 2020): (i) coral restoration or coral gardening which tries to rebuild damaged reef structures; (ii) helping corals and their algae adapt to warmer temperatures through assisted evolution or genetic engineering; (iii) reducing the light and heat that reaches them with the help of geo-engineering; or (iv) reducing the threats through systemic changes that aim to do so. My first goal in this extended project was to get an overview of the different strategies that exist.

Coral restoration

Coral restoration or gardening is the most widely used method to help save corals, because of its simplicity and low cost compared to other methods. In essence it's breaking corals into pieces, or taking broken pieces, and then letting them grow back in aquaria before moving them into offshore nurseries where they can slowly readapt to their natural habitat and finally outplanting them back onto degraded reefs.

Mineral accretion technology (MAT) is a method to boost restoration. It is a strategy where an electrical current passes through the metal structures the corals are on. This creates seawater electrolysis which causes dissolved minerals in the seawater, such as the Ca^{2+}, to crystallize on the structures, thus forming calcium carbonate, which is the same material as the one that constitutes the corals' exoskeleton. This in turn is beneficial for the corals because it means they can use their energy on growth, metabolism and resisting environmental stress instead of having to pump protons out of the calcification sites to maintain the internal pH homeostasis since this is already done by the cathode (Goreau *et al.* 2013).

Assisted evolution

Assisted evolution is giving evolution a hand so that it can keep up in these rapidly changing conditions. As Van Oppen *et al.* (2015) explain, there are four types of assisted evolution: stress exposure to induce acclimatization; active modification of the coral-associated microbes; selective breeding also known as cross fertilization; and finally genetic engineering. These approaches are in order of increasing human intervention and therefore the risk of having unwanted consequences increases as well.

Geo-engineering

As Shepard (2012) explains: *"Geoengineering is deliberate intervention in the climate system to counteract man-made global warming. There are two main classes of geoengineering: direct carbon dioxide removal and solar radiation management that aims to cool the planet by reflecting more sunlight back to space."* Knowing that corals bleach because of an excess in heat and light, the latter could directly benefit corals.

One way to block sunlight and heat is through spraying microscopic sea water droplets into the air to make clouds brighter so that they reflect more sunlight (Latham *et al.* 2012), therefore protecting the corals underneath (Reef Restoration and Adaptation Program 2020). This, however, is only a short-term strategy and not feasible in the long term, but it could provide the extra amount of time needed to help save corals.

Reducing emissions

Since anthropogenic climate change is the main problem facing corals, reducing it will highly benefit them. Climate change is mainly caused by anthropogenic emissions of greenhouse gases, mostly coming from the burning of fossil fuels for electricity and transportation.

An effective strategy would be to switch towards renewable energy sources such as solar or wind energy and away from fossil fuels. There are many obstacles to such rapid transition, whether technological, social or economic, but the current situation is not only detrimental to corals as it affects the whole planet and all of the species living on it, including us humans.

Now that I have produced an overview of the different strategies used to protect and restore corals, the second part of this study was to test the MAT in laboratory conditions. The MAT is one of the methods commonly used to restore corals, and our goal here was to experimentally test if it would still aid the corals to restore in future, more acidic environments. For this, I used seashells as they are also, like corals, primarily composed of calcium carbonate. Finally, three experts in the field were contacted to gather their opinion and analysis of the current situation and future development paths.

Methods

At room temperature, the pH of the water is the most important factor in calcium carbonate formation (Aghajanian *et al.* 2019). We conducted an experiment to answer four questions. Firstly, (i) see the impact of water's absorption of CO_2 on its pH. This will show us what will happen in the future if we continue to emit greenhouse gases. Secondly, (ii) quantify pH impact on calcium carbonate structures, in order to predict the stress coral structures will face in the future. Thirdly, (iii) investigate how the MAT influences the local pH and thus the accretion, meaning the formation, or destruction of calcium carbonate, and lastly, (iv) examine whether the same effect can be obtained in future, more acidic, seawater conditions.

When looking at the reactions that can take place, we are able to make the following hypotheses. Firstly, CO_2 probably decreases the pH since:

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

thus by definition, having more H+ ions means a lower pH. Secondly, as the pH decreases, the availability of carbonate, CO_3^{2-}, decreases since some of the hydrogen ions get attached to carbonate ions:

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

So, when looking at the whole equation:

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

the more CO_2 is absorbed by the water, the less $CaCO_3$ there probably is and can be made.

CO_2 absorption

CO_2 was bubbled in 200 ml of seawater with the use of balloons and Pasteur pipettes. The water was mixed to have equal pH in the whole cup which was measured using a pH meter.

pH impact on calcium carbonate structures

We used seashells as they are also, like corals, primarily composed of calcium carbonate and thus sensitive to ocean acidity. Each seashell was placed in 200 ml of seawater of different pH – one with CO_2 bubbling and one without - for approximately 5 hours. Their masses were measured before and after being placed into the water, in order to see the increase or decrease in calcium carbonate.

Influence of MAT on the pH of water

A standard electrolysis montage was used (figure 1): an anode, a fondue sieve serving as a cathode since it represents the structures used with corals and a salt bridge, seawater or the simulated future seawater and a generator to provide a 5 Volt current. The pH around the cathode was measured. The mass of the cathode was measured before and after each experiment, once dried, to see how much had accreted to the cathode. To determine the nature of accreted material, accretions were first placed in pure water for about a minute, as $CaCO_3$ is not soluble in water contrary to other salt like NaCl. They were then placed in acidic conditions, about pH 3, in which $CaCO_3$ should dissolve.

Two experiments were done to simulate future seawater conditions. In the first CO_2 was bubbled during the electrolysis and in the second CO_2 was injected before the electrolysis.

Results

CO_2 absorption

The bubbling of CO_2 decreased the pH of water from 8.4 to 5.1 in approximately 15 minutes.

pH impact on calcium carbonate structures

The mass of the seashell which was put in normal ocean water pH stayed relatively constant (3.825 to 3.826 grams), whereas the one put in acidic water lost a little over 1 % of its original mass (4.271 to 4.224 grams) during the 5-hour experiment.

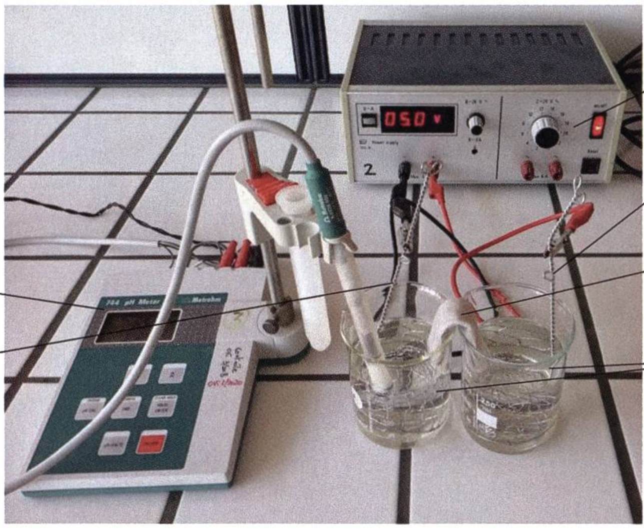

Figure 1: Experimental setup to study the effect of MAT on pH. This exact setup was used.

Influence of MAT on the pH

MAT increased the pH at the cathode and led to accretion in all three scenarios (table 1). However, it is interesting to see the differences between the different scenarios: the lower the pH, the less accretion occurred. The scenario where CO_2 was bubbled during the electrolysis had the lowest amount of weighable and visible accretion, whereas the current seawater condition had the highest amount.

When placed into pure water, 100 % of accretions stayed, meaning that it was likely $CaCO_3$ since it is not very soluble in water unlike other salts. When put in an acidic environment, 83 % of the accreted material dissolved within seconds, giving us yet another reason to believe it was $CaCO_3$.

Discussion

The increasing anthropogenic emissions of CO_2 make the oceans more acidic and jeopardise the functioning of marine ecosystems. In this study, I showed that the MAT, a method commonly used to boost coral restoration, might become less efficient in more acidic water conditions. This shows the importance of reducing CO_2 emissions, which was supported by the three experts interviewed for this project.

Table 1. Mass of accretion to a cathode during electrolysis in waters of different pH. The initial and final pH levels are indicated, as well as the difference between the two. The higher they are, the more they increased in alkalinity and the more accretion occurred.

Seawater Type	Initial pH	Final pH	ΔpH	Δm [g]	CaCO3
Normal	8.4	9.91	+1.51	+0.06	a lot
CO2 Injected before	6.24	7.65	+1.41	+0.03	intermediate
CO2 Injected during	5.57	6.25	+0.68	+0.01	a little bit

Acidic environments are corrosive to $CaCO_3$ structures, and thus to corals' exoskeleton. The more CO_2 is absorbed in the water, the less $CaCO_3$ there is and can be made. Our results show that the mass of the seashell put in normal ocean water stayed relatively constant (+0.026 %), whereas a slight decrease was measured for the one in acidic water (-1.1 %), suggesting an effect of the water pH on the seashell mass variation. In future studies, it would be interesting to repeat this experiment with larger sample size, to be able to statistically evaluate the effect of water acidity conditions. In addition, due to time and experiment constraints, we exposed the seashells to extreme pH levels that are unlikely to exist in nature. Thus, in a future experiment, the pH used could be that predicted by ocean acidity evolution models. Nevertheless, we showed that the experimental set-up developed here worked and could be repeated in future research projects.

We observed that MAT can help produce $CaCO_3$ locally at the cathode and works in more acidic water conditions, although it becomes less effective. Indeed, we saw an increase in pH and the formation of $CaCO_3$ three times, in different conditions, meaning that the MAT is likely to work in all sorts of different ocean conditions. We also showed that the accretion varied depending on the scenarios, and this would need to be repeated to estimate these values more precisely. It would also be interesting to study how corals would react to these different pH environments. M. Allahgholi, one of the three experts interviewed, argued that MAT is a solution that will help maintain and regrow corals over very harsh periods of times until the chemistry of the oceans or the climate stabilizes itself again. But he also says that it is only a temporary solution and that they will have to adapt themselves.

Finally, the different conservation strategies developed so far are only a means of slowing down the observed decline of corals while waiting for an improvement in the global situation of the oceans. Prof. Hughes, who's director of the ARC Centre of Excellence for Coral Reef Studies, wrote me that he does not support most coral conservation strategies. First of all, because they do not address the causes of reef decline, and secondly, because corals are themselves responding to very strong natural selection, to a vastly larger extent than what can be done artificially using assisted evolution (Maynard *et al.* 2008, Hughes *et al.* 2018). Instead, he focuses on strategies that do, most notably reducing emissions and other stress factors including pollution. Although, the conservation strategies might be needed in the short to mid-term, corals' protection in the long-term is dependent on the reduction of anthropogenic emissions of CO_2. In parallel, local stress factors, such as overfishing and pollution, should be diminished to increase the water quality and release the local pressures on corals.

Acknowledgments

First of all, I would like to thank all of the people who have made this project possible. A huge thanks to Matteo Pluchinotta, my biology teacher, for following and supporting me during the whole project and Hughes Jaccard, my chemistry teacher, for all the experiments involving chemistry. Furthermore, I wish to express my deep gratitude towards all the people I have interviewed: Professor Anders Meibom, Professor of Biological Geochemistry at the EPFL and director of the Red Sea Coral Institute, for giving me some insight into his knowledge, Ahmad "Aki" Allahgholi, founder and managing director of coralive.org, for giving me a glimpse of the great work he does and Professor Terry Hughes, Professor at the James Cook University in

Queensland, Australia, and director of the Australian Research Council Centre of Excellence for Coral Reef Studies, for sharing some of his world-renowned expertise. Finally, I am very grateful to all the people who supported and motivated me to do the best I can, by showing real interest in and taking the time to read and discuss my project.

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