What are the socio-economic and ecological effects in reefs of ocean-temperature rise and ocean-acidification in the 21st century?

[Dominik Bieri, Vittorio Bizzozero, Anna Ingwersen, Alena Kvapil, Andrei Marti, Lea Schmutz]

e 2:https://www.br.de/nachrichten/wissen/co2-bedroht-korallenriffe-
o-den-natuerlichen-kuestenschutz,RBvHEGA

Figure 1:https://www.wissenschaft.de/umwelt-natur/keine-schnelle-erholung-fuer-korallenriffe/

Abstract:

There are several effects that occur on reefs due to climate change which are known to science. Global warming increases sea-surface temperatures (SST). Coral bleaching events – loss of calcifying coral's symbionts - become more frequent and more intense[1]. The temperature-rise affects the reef's microclimates. Some coral species adapt better to such altered conditions than others, leading to shifts in species composition, which cannot assure todays functionality of reef ecosystems[2,3].

Ocean acidification can also shift reef-species composition up to a complete loss of calcifying organisms[4]. Calcifying corals and their symbionts act as key species in reef ecosystems[5]. The skeleton of corals is contained of aragonite which is built by calcification. With decreasing pH, the saturation values for aragonite are decreasing which leads to less calcification of corals and other organisms in the ocean[8]. The saturation state of aragonite will be changing so much that we will be observing net sediment dissolving ecosystem by 2085[7,8]. It's unclear, if any corals could calcify at this stage[9]. Such conditions would favour macroalgae-based ecosystems[9]. Looking at the history of ocean chemistry, there have never been pH values, temperatures, or CO_2 ppm values like we see them today or will see in the future[10].

Single-stressor analysis shows mostly negative impacts on most taxa in reefs[3]. To sustainably adapt management in the future factors like SST, geographic indicators and more with their complex interactions need to be investigated to understand how reefs react to the multi-stressor-situation under climate change[11–13].

Reefs are also an essential livelihood for local people[14]. Through climate change and its impact on reef ecosystems financial damages - estimated to be in a range between 3.95 to 23.78 billion US$ annually[15] Reefs also deliver substantial amounts of goods and services that are essential to our society like fish regeneration and reef mining[16]. The tourism value of the reefs has been mapped[6].

Partial research:

What are the socio-economic impacts of the decline in the number of functional reef ecosystems?

Author: Dominik Bieri

Summary:
One of the often-overlooked aspects of the sinking numbers of functional reefs is the economic impact it has on our society[16]. Reefs are not just pretty to look at, they're an essential livelihood for the people living around it[14]. They deliver a substantial amount of goods and services to us that are essential for our marine society to function[17]. Through climate change a huge amount of financial damage has been delivered all over the world which can be in a range from 3.95 billion US$ to 23.78 billion US$ annually[15]. A huge part of this comes from the tourism sector which has been mapped and evaluated[6].

The economic impact of ocean acidification on coral reefs [16]
Estimates the economic impact of ocean acidification. Therefore, it simulates different scenarios and evaluates the results. The calculations include economic factors like fishery, tourism, real estate prices etc. The study concludes that the economic impact is not that big but rapidly escalates and could be a problem in the future.

Coral reef livelihoods [14]
Explains the different livelihood benefits that are offered by coral reefs. It concentrates on two general topics. The non-material benefits that coral reefs fisheries provide. And the role of livelihood diversity to solve the problem of overfishing. In both cases the coral reefs have an essential role. It concludes that the role of reefs as shaper of job structures is not researched enough and can generate 375 $ billion worth of goods and services.

Ecological goods and services of coral reef ecosystems [17]
Identifies the ecological goods and services of the coral reef ecosystem. The goods include renewable resources and reef mining. Physical structures and their function are a part of the ecological services. As well as seafood, wave buffering and cultural impacts. It concludes that the loss of this unique ecosystem would be a great tragedy for future generations. Therefore, international policies and arrangements are needed dearly.

Evaluating the economic damage of climate change on global coral reefs [15]
Calculates and evaluates the global and economic damage arising from the effects of climate change on coral reefs. It makes regional analysis and combines them into a global scenario. It concludes that the loss of coral reef coverage leads to a decline in tourism and recreational value. The lost value ranges from 3.95 billion US$ up to 23.78 billion US$ annually. The reason this has not been discovered yet is, that the analysis usually is only made regionally.

Mapping the global value and distribution of coral reef tourism [6]
Collects regional data and uses them to create a map with the most important coral reefs and their tourism value. These maps show that for example 44% of egypts coastal tourism value is based on the coral reefs. Moreover, over 9% of all coastal tourism is created by reefs. Regions with reefs usually have a very high density of tourism use. Which means that the tourist sector in coastal areas with reefs rely heavily on the tourism generated by the coral reefs. Therefore, the loss of this tourism generators would be catastrophic to these regions.

What are the spatial patterns of coral bleaching events and how can we predict future habitat suitability for a sustainable reef ecosystem management?

Author: Lea Schmutz

Summary

With global warming and increasing sea-surface temperatures (SST), global coral bleaching events have become more frequent and more intense[1]. Reefs, where strong temperature anomalies occurred, have been particularly affected in the last two decades[18]. For sustainable ecosystem management, reliable predictions of future habitat suitability are essential. In addition to the SST[11], geographic indicators are also of great importance when we try to predict the resistance of corals to thermal stress[19]. In addition, complex algorithms can be used to identify potential areas, where herbivore management could build coral reef resilience[20].

A global analysis of coral bleaching over the past two decades[18]

Synthesis of field observations of coral bleaching on a global scale from 1998 to 2017. Together with data on various environmental factors and temperature metrics, bleaching patterns were analyzed. Results show, that bleaching was significantly more common in localities with high thermal-stress anomalies and less common in localities with a high variance in SST.

Spatial and temporal patterns of mass bleaching of corals in the Anthropocene[1]

Compiled history of bleaching events from 1980 to 2016 to examine patterns in the timing, recurrence and intensity of bleaching episodes on a global scale. The results show a significant increase in frequency and intensity of bleaching events with increasing SST anomalies, where the decrease in time between two bleaching events is particularly significant.

Large geographic variability in the resistance of corals to thermal stress[19]

Predictions for the future of coral reefs not just based on thermal exposure but including geographic variability of coral resistance to thermal stress. The variability was evaluated as the ratio of thermal exposure and sensitivity for 226 sites in 12 countries during the 2016 global-bleaching event. Coral resistance was evaluated using generalized linear mixed models to identify the influences of geography, historical SST variation, coral cover and coral richness. Geographic faunal provinces and ecoregions were the strongest predictors and thus underline the importance of environmental history and geographic context in future predictions.

Prioritizing reef resilience through spatial planning following a mass coral bleaching event[20]

Mapping and prioritizing potential areas where local herbivore management in Hawaii could build coral reef resilience. The computer software program Marxan was used identify potential areas by synthesizing regional data of habitat, ecologically critical areas, life history, and social considerations. The analysis of the top results showed that a subset of characteristics were significantly different from surrounding areas and could thus be potential drivers for selection.

Future habitat suitability for coral reef ecosystems under global warming and ocean acidification[11]

Modelling the future habitat suitability for shallow coral reef ecosystems as a function of ocean surface temperatures and ocean acidification. Instead of assumptions of physiological tolerances or fixed thresholds, statistical Bioclimatic Envelope Models with different modeling approaches and levels of complexity were used. The models project a marked decline in habitat suitability driven by temperature, while ocean acidification plays a minor role.

What are the effects of rising temperatures on coral and fish populations, how will they respond to increasing SST and what changes will occur in species composition?

Author: Vittorio Bizzozero

Summary

Climate change, of all consequences, has most notably rising sea temperatures and coral bleaching. To better understand these influences, it is first necessary to know what species make up the different reef types and their interactions.[21] The increase in temperature will change the environmental conditions of the many microclimates, making them better for some species and worse for others. Habitat loss and changes to the physiological functions of some species may occur[12]. It is also possible that there will be a real shift in coral populations[22] to favorable areas and that the species composition of an ecosystem at a location will be altered[23], often due to algal overgrowth. Especially in the latter case, it is important to recognize the role that herbivorous fishes can play in keeping an ecosystem in balance under increasing stresses[24].

The implications of recurrent disturbances within the world's hottest coral reef[23]

Analysis of coral ecosystem structure in extreme environments (Persian Gulf and two adjacent regions). Observations of abundance and tolerance of different coral taxonomic groups during a three-year period (2008-2011). Hypotheses on the possible evolution of coral communities in a more disturbed future: decrease in some stress-sensitive taxa, and increase in abundance of more tolerant ones, with possible loss of biodiversity.

Climate change and the future for coral reef fishes[12]

Analysis of the impact of increased water temperature and coral bleaching on fish community dynamics and composition. Loss of habitat and coral-dependent fish, influence on physiological functions. Considerations of acidification, ocean circulation, extreme weather, sea level rise, future range change, interaction with other stressors, climate change adaptation, fisheries, and future management.

Coral Reefs of the Eastern Tropical Pacific[21]

The structure and composition of coral communities in the eastern Pacific is reviewed. Quantitative and qualitative data are collected in order to better understand which taxonomic groups make up which coral reefs and how. It is also pointed out which animal and plant species have reduced coral populations after warming/bleaching events and how they have recovered in different locations in recent years.

Escaping the heat: range shifts of reef coral taxa in coastal Western Australia[22]

Reef corals comprising Late Pleistocene reef assemblages exposed at five different locations along the coast of Western Australia were surveyed and the results were compared with published coral occurrence data for modern reefs off each location. Hypotheses on the response of reef coral communities to future climate change.

Spatial variation in the functional characteristics of herbivorous fish communities and the resilience of coral reefs[24]

This study aims to highlight spatial variations in the functional characteristics of herbivorous fishes and how they can prevent coral-macroalgal phase shifts (large coral mortality will follow) through grazing. Over the 15-year study period, we can find long-term stability in the distribution and abundance of herbivorous fishes in the Great Barrier Reef (GBR). In addition, there is a difference in the number and diversity of herbivorous fish communities between different regions of the reef (inshore, mid shelf and outer shelf). There is a strong positive relationship between water clarity and the diversity and abundance of herbivorous fishes on GBRs. This shows how important reef conservation and herbivore grazing are.

What are the effects of temperature rise and ocean acidification on coral species composition and diversity and competition with other species?

Author: Alena Kvapil

Summary:
Due to ocean warming and acidification coral reefs and its inhabitants are under constant stress. Some coral species are fitter to survive in the new conditions, but this shifts in species assemblage can't ensure keeping the functionality of the reef[2]. An example for the species shift is the coral-macroalgae competition whit climate change macroalgae become a stronger competitor and establish in places where corals were before[25]. Although, high diversity can provide functional redundancy, this will not save the coral reefs[26]. Extremely important for the survival of the corals is the microbiome it could be a management strategy to manipulate fast evolving bacteria, as the microbiome might be able to prevent coral bleaching[27]. Corals themselves also have strategies to survive in different conditions. One strategy is tissue fusion. Tissue fusion can increase survival of recruits under temperature stress[28].

Tissue fusion and enhanced genotypic diversity support the survival of Pocillopora acuta coral recruits under thermal stress[28]
Tissue fusion is an early life history strategy to increase survival of coral which are important for reef persistence. The study's aim was to figure out if tissue fusion can be advantageous under thermal stress. They did a laboratory experiment by manipulating parental genomic richness and number of recruits involved. As results it was found that parental genomic richness had no effect on fusion probability, but fused groups had a much higher survival. However, temperature did not influence the occurrence of fusion. Under temperature stress parental genotypic richness and fusion status were important to survival whereas the fusion is the more important factor.

Defining Coral Bleaching as a Microbial Dysbiosis within the Coral Holobiont[27]
The microbiome consisting of dinoflagellate algae and microbiota plays a fundamental role in the holobiont. The coral host provides a well-protected living space. However, the stability of the holobiont is fragile and depends on various environmental factors. Temperature stress can lead to coral bleaching which is the breakdown of the symbiosis between the coral and its microbiota. Functional activity of microbes may mitigate or even prevent bleaching responses by supporting the internal equilibrium between the host and Symbiodiniaceae, and by maintaining stable rates of photosynthesis. Manipulations of rapidly evolving bacterial communities associated with the coral host might be one strategy to enhance coral tolerance to stress and bleaching.

Shifts in coral-assemblage composition do not ensure persistence of reef functionality [2]
Although many reef-building corals are likely to decline some opportunistic species might increase in abundance. Aim of this study was to examine if reshuffling can maintain ecosystem functioning. They showed that shifting assemblage will result in rapid losses in calcification. Dominance patterns seem to be most important for the functioning of a coral reef and it is therefore essential to maintain keystone species. As a method different theoretical models were used.

Coral-macroalgal competition under ocean warming and acidification[25]
The study looks at combined effects of ocean warming and acidification on competition between coral and on macroalga. As a result, they found, that net photosynthesis of the coral decreased, and that dark respiration increased in contact whit the algae. The coral host was negatively affected by ocean warming and acidification whereas the productivity of its symbiont was enhanced. On a healthy reef, corals are superior to macroalgae but whit changing environmental conditions, macroalgae become the stronger competitor.

Confronting the coral reef crisis [26]
A review that looks at the ecological roles of critical functional groups that are fundamental to understanding resilience and avoiding phase shifts from coral dominance to less desirable, degraded ecosystems. Anthropogenic influences are leading to a resilience loss of reefs. High diversity undoubtedly provides the potential for functional redundancy. However, even in high-diversity systems redundancy in critical functional groups can be limited.

What are the effects of temperature rise and ocean acidification on key species in reef ecosystems and are there any specific thresholds or tipping points?

Author: Andrei Marti

Summary:
Calcifying corals and their symbionts act as key species in reef ecosystems[5]. Increasing temperatures and acidification can lead from a shift in reef composition up to a complete loss of calcifying organisms[9] leaving the stage for macroalgae-based ecosystems to move in, which could become negatively affected by climate change too though[4]. Single stressor analysis already shows mostly negative implications with most taxa in reefs [3]. However, understanding the dynamic effects of multiple and steadily increasing anthropogenic stressors is going to be key in preserving reef functions[13].

Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations[9]
Analyses reef-communities next to submarine volcanoes to estimate effect of higher pCO_2 on species structure Acidification causes shifts in dominant coral taxa and gradually lowers coral diversity. Below pH of 7.7 coral development ceases. Seagrasses and macroalgae increase in biomass but decrease in diversity. Sponge cover decreases as well as calcareous biota like foraminifera, small gastropods and calcareous spicules.

Effects of climate change on global seaweed communities[4]
Seaweeds form the base of the food web hosting many ecosystems-services. Multiple stressor situations of changing climate that seaweeds are faced with are understudied. Rising temperatures tend to accelerate metabolism up to a certain point above which the systems collapse very quickly, affect reproduction negatively and make seaweeds more prone to infections and disease. Taxa that cannot convert HCO to CO_2 (CCM) profit from higher CO_{2aq}. Crustose coralline algae (CCA), which lay a foundation for many coral species to grow on, are affected very negatively. Very nice illustrations.

Impacts of ocean acidification on marine organisms: Quantifying sensitivities and interaction with warming[3]
Looks at effects in multiple stressor and multiple species scenarios where reactions differ a lot from laboratory studies on single organisms. Acidification negatively impacts reef fish habitat and mollusks growth. Some populations may adapt better than others and nutrient accessibility can offset negative impacts of climate change. Has detailed plots on different taxa about survival, calcification, growth, photosynthesis and abundance under acidification-scenarios going towards 2100.

Coral reef ecosystems under climate change and ocean acidification[5]
Identifies recent changes in anthropogenic stresses on coral reefs at all latitudes and differs between shallow water, mesophotic and deep-sea reefs. Examination of biological responses under fast environmental changes such as mass coral bleaching. Corals, being habitat framework builders, are very sensitive to change. Identification of corals role in the ecosystems as food and shelter. For example, a mucus they produce acts as food for molluscs, crustaceans, worms, ciliates, fish, etc. Stating future projections and possible adaptations.

Coral reefs in the Anthropocene[13]
Argues that ecosystem functions are of most importance and should be examined and preserved. Claims, in contrary to other sources, that reefs can shift to higher latitudes. They are more dynamic and patchier than expected and one should not preserve strictly existing reefs but consider taking the dynamics into account. Moreover, reef communities have already been altered past a reversible point and preindustrial conditions are never to be brought back again. Multiple anthropogenic stressors are increasing in diversity and corals are adapting to their new environment. Science should provide insight on new management and governance opportunities.

How is ocean chemistry changing with climate change and what are its influences on coral reefs?

Author: Anna Ingwersen

Summary:
The coral cover at coral reefs in the Caribbean today (approximately 30%) will decrease until the end of the century[29]. The skeleton of corals is contained of aragonite. With decreasing pH, the saturation values for aragonite are also decreasing which leads to less calcification of corals and other organisms.[8] Even if corals are still able to calcify, they are likely not to be healthy[30]. When looking at the history of ocean chemistry, there have never been pH, temperature or CO_2 ppm values like we see them today or will see in the future[10]. The saturation state of aragonite will be changing so much that we will observe net sediment dissolving ecosystem by 2085. It is not yet clear, if any corals will be able to calcify at this stage. [7]

Dissolving Before End of Century [7]
This article investigates the Calcification and dissolution dynamics of aragonite with decreasing pH and thus decreasing aragonite stability (Ω). The authors measured $CaCO_3$ sediment dissolution by incubating said sediments with different CO_2 pressures and various initial water column $CaCO_3$ saturation states. They also highlight, that some corals will still be able to calcify, even when $CaCO_3$ sediments will be net dissolving. They also show that is quite difficult to make clear predictions at this stage, since pH is decreasing at different paces at different reefs and the calcification/dissolution rate is highly dependent on the composition of the reef community.

History of seawater carbonate chemistry, atmospheric CO_2, and ocean acidification[10]
This Article investigates the history of changes in the CO_2 ppm and tries to show, how the ocean chemistry has changed, and the ecosystems adapted/or did not adapt to it. With the aid of geologic records, the authors can investigate the changes in ocean chemistry in the last 100’000 + years. They find that what we see now in terms of changing ocean chemistry is unprecedented. The paper is also great for understanding the ocean chemistry with changing CO_2 ppm and pH and how it is connected to temperature, salinity, $CaCO_3$ precipitation and dissolution and weathering of carbonate and silicate rocks.

Why corals care about ocean acidification uncovering the mechanism[30]
Covers the influence of ocean acidification on corals. It shows how the lowering availability of the carbonate ion [CO_3^{-2}] negatively affects the skeletal growth of corals. Reason for this is the increasing amount of the bicarbonate ion which is formed due to a decreasing pH. With the aid of SEM images, they show that those corals who build a $CaCO_3$ skeleton under undersaturated conditions, are not healthy. It also shows that calcifying is highly energy consuming for the coral. The study shows the opportunity to improve the corals resilience to climate change by “feeding” the corals the nutrients they need to have enough energy for calcification.

Modelling regional coral reef responses to global warming and changes in ocean chemistry:[29]
With the aid of the COMBO model, this study tries to investigate the coral reef responses to global warming and changes in the ocean chemistry. Several different scenarios are calculated with this model. These scenarios also consider the chance of corals adjusting to changing temperatures and chemistry. These scenarios also consider the chance of corals adjusting to changing temperatures. All these models estimate that the coral cover of today (~30%) will decrease to about 0-5%. At this point it is not clear whether these ecosystems could still be called “coral reefs” since they do not accrete CaCO.

Risks to coral reefs from ocean carbonate chemistry changes in recent earth system model projections[8]
This study focuses on the chemical stress on corals by using geochemical projections from ESM (earth system models). It focuses on the saturation state of aragonite (mineral form of $CaCO_3$, material of coral skeletons). The study shows the aragonite saturation state at different amounts of CO_2 ppm. In any case, if anthropogenic CO_2 emissions are not drastically reduced, reef surrounding water will go outside the bounds of the saturation state which surrounded all coral reefs before the industrial revolution. Regions which are high in aragonite saturation (and stability) are likely to disappear by the end of the century.

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