Systematic Map Protocol

Title
What is the evidence for the impact of ocean warming on subtropical and temperate corals and coral reefs?

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Background
Ocean warming has intensified in recent decades (Frölich et al.,2018) and its impact on tropical coral reefs has been well documented across biological, ecological, and oceanographic processes (Hoegh-Guldberg, 1999; Hoegh-Guldberg et al., 2007). However, the impact of ocean warming on subtropical and temperate corals and coral ecosystems has been explored to far lesser degree despite the negative impacts on these ecosystems (Cant et al., 2020). Subtropical and temperate reef systems host a diverse array of benthic habitat formers, fishes and invertebrates, which together have the similar socio-economic value as their tropical counterparts (Bennett et al., 2015) While some studies have hypothesised that these ecosystems (widely referred to as marginal, high latitude as well as subtropical and temperate) could become climate refugia (Beger et al., 2013) and other studies report that these regions are at risk of climate-driven regime shift (Wernberg et al., 2016; Evans et al., 2021). Coral bleaching (Brown, 2016), mortality, disease (Garren et al., 2016), reductions in growth, loss of reproductive output and ecosystem phase shifts, species losses are shown to be a consequence when ambient ocean temperature exceeds their upper thermal thresholds (Ainsworth et al., 2021). Subtropical and temperate reefs were seldomly scrutinised, despite having reports of bleaching from different geographical locations. Here we propose a systematic map protocol of research since 2010 investigating the impact of ocean warming to subtropical and temperate corals and coral reef ecosystems globally. We aim to collate the current knowledge on these ecosystems and provide means to comparatively assess future evidence revealing the trajectory of climate impacts regarding ocean warming for these ecosystems. Intended users of this systematic map include researchers in climate science, invertebrate biology, and environmental policy makers. Systematic map of research effort will provide foundation to future studies into coral systems in the subtropical and temperate regions globally.

Theory of change or causal model
Research investigating subtropical and temperate corals and coral reef ecosystems has revealed events of temperature extremes (Gupta et al., 2020; Yao et al., 2021). These extreme climate events will impact the subtropical and temperate coral systems by introducing macroalgae, mortality of corals, phase shift in these regions, etc. (Beger et al., 2013) Additionally, these ecosystems are also

hypothesised as regions of climate refugia (Beger et al., 2013) as their tropical counterparts are affected by extreme temperature events as well. These theories explain the importance and impacts on the subtropical and temperate coral systems.

Stakeholder engagement

Stakeholders are not engaged in the systematic map.

Objectives and review question

Primary Question: What is the evidence, since 2010, within scientific literature on the impact of ocean warming to subtropical and temperate corals and coral reefs? Secondary Questions: - How has sea surface temperature data been recorded in subtropical and temperate coral reef locations? - Are the studies using MHW (marine heatwaves) and/or DHW (degree heating weeks), as their metrics of evaluation of climate events? - How are the levels of mortality and bleaching defined in the research locations? - Where, and how, has coral biological responses and coral reef ecological impacts been recorded in subtropical and temperate coral reef locations?

Definitions of the question components

Population: Subtropical and Temperate Coral Systems and Coral Reefs Exposure: Ocean Warming Comparison: Time-trends, including before-after studies Outcome: Mortality and bleaching, changes in coral habitat, acclimatisation measured by population growth.

Search strategy

10 benchmark articles were selected for the development of the search string. A series of search string were trialled to test their capability on capturing the benchmark articles. The Boolean operator search string was developed on Scopus and translated to Web of Science database after it successfully captured all 10 benchmark articles and returned a total of 846 articles for screening. To better capture recent studies, the search results are limited to publication on and after 2010 and limited to English only. There are four main areas the search string is designed to capture, which match the PECO criteria. Upon using the same search string in Web of Science, 1189 articles were found on Web of Science. The search string is as follow: TITLE-ABS-KEY ((coral* OR "coral reef*")) AND TITLE-ABS-KEY (("ocean warming" OR "marine heatwave*" OR "marine heat wave*" OR mhw* OR "degree heating week*" OR dhw* OR "heat stress*" OR stress OR tropicali?ation OR temperature* OR "climate change")) AND TITLE-ABS-KEY ((mortal* OR surviv* OR health* OR diseas* OR grow* OR reprodu* OR cover* OR tropicali?* OR shift* OR habitat* OR increase* OR declin* OR decreas* OR impact* OR threat* OR bleach* OR acclimati?* OR respons*)) AND TITLE-ABS-KEY ((marginal OR "high latitude" OR temperate OR subtropic* OR extratropic*)) Grey literature will be searched on the OATD database: coral AND (subtropical OR temperate) AND "ocean warming" Please see Section 8.2 for result inclusion types.

Bibliographic databases

Scopus: TITLE-ABS-KEY ((coral* OR "coral reef*")) AND TITLE-ABS-KEY (("ocean warming" OR "marine heatwave*" OR "marine heat wave*" OR mhw* OR "degree heating week*" OR dhw* OR "heat stress*" OR stress OR tropicali?ation OR temperature* OR "climate change")) AND TITLE-ABS-KEY ((mortal* OR surviv* OR health* OR diseas* OR grow* OR reprodu* OR cover* OR tropicali?* OR shift* OR habitat* OR increase* OR declin* OR decreas* OR impact* OR threat* OR bleach* OR acclimati?* OR respons*)) AND TITLE-ABS-KEY ((marginal OR "high latitude" OR temperate OR subtropic* OR extratropic*)) Followed by a removal of articles published prior to 2010. Web of Science: (All Fields) ((coral* OR "coral reef*")) AND (All Fields) (("ocean warming" OR "marine heatwave*" OR "marine heat wave*" OR mhw* OR "degree heating week*" OR dhw* OR "heat stress*" OR stress OR tropicali?ation OR temperature* OR "climate change")) AND (All Fields) ((mortal* OR surviv* OR health* OR diseas* OR grow* OR reprodu* OR cover* OR

tropicali?* OR shift* OR habitat* OR increase* OR declin* OR decreas* OR impact* OR threat* OR bleach* OR acclimati?* OR respons*)) AND (All Fields) ((marginal OR "high latitude" OR temperate OR subtropic* OR extratropic*)) Followed by removal of articles published prior to 2010.

Web-based search engines
Grey literature will be searched on Open Access Theses and Dissertations (OATD) database, with the following search string used, which in pilot testing has yielded 8 results: coral AND (subtropical OR temperate) AND "ocean warming" The included results will be limited to articles and reports published since 2010 to cohere with the rest of the searches. Grey literature included will be limited to research theses, pre-review reports, and open access scientific studies (herein defined as grey literature selected for inclusion in systematic mapping) while government reports will be excluded due to the inconsistency in availability of these reports between regions.

Organisational websites
Not Applicable. Organisational websites will not be inluded.

Comprehensiveness of the search
We have selected 10 benchmark articles for developing the search string, all 10 manually collected benchmark articles were returned in the Scopus search, ensuring the search string to be sensitive enough for this systematic mapping study. These 10 articles were selected based on their relevance to the topic, covering both climatology, and subtropical and temperate coral systems under the influence of ocean warming.

Search update
An update on the search strings would be performed if the time between the original search and publication submission exceeds two years.

Screening strategy
The first screening will be conducted including and excluding articles by titles and abstracts using Rayyan and will be undertaken by two reviewers independently. Articles that are included in the first round of screening will be screened again in the second phase of the screening by full text. If the full text does not meet the selection criteria, they would be excluded from the data extraction. Articles where there is uncertainty will be included but flagged for a third independent reviewer and excluded if identified by 2 reviewers for exclusion. A pilot screening was performed by two of the authors to check the coherence of articles screening agreement. Articles on Rayyan were selected at random for reviewers to quickly screen through the titles and abstracts. 123 titles and abstracts were screened within an hour, and inclusion decision was made on 13.8% of the screened titles and abstracts. An initial testing yielded an agreement rate of 63.4%.

Eligibility criteria
Articles from the databases will be screened manually according to the following PECO criteria: Population: Subtropical and Temperate Coral Systems and Coral Reefs • All subtropical and temperate coral systems and coral reefs will be included; this includes marginal, high latitude coral systems. • Studies focused solely on tropical, polar and/or deep sea corals, kelp forests and fishes will be excluded. Exposure: Ocean Warming • We will include studies focused on the effects of exposure to ocean warming, specifically empirical ocean warming studies that utilise degree heating weeks and the definition of marine heatwaves as defined by Hobday et al. (2016), meaning cases where: - SST exceeds the bleaching threshold of 4 degrees Celsius. - SST exceeds the 90th percentile of the ongoing and continuous 30 years climatological data, subjected to 30 days moving window (Hobday et al., 2016). • Ocean acidification and its interaction with ocean warming will be excluded from this systematic map. Comparator: Effects before and after recorded event/exposure.

Outcome: Mortality and bleaching, habitat changes, threats, acclimatisation of subtropical and temperate coral systems. • We will include all literatures that address the physiological effects and ecological effects ocean warming have on the coral systems and reefs – this includes mortality, bleaching, changes in habitats (E.g., destruction of reef structures), threats (E.g., increase in species that pose threats to corals and coral reefs). Topics addressing the acclimatisation of species will also be considered. Other eligibility criteria are listed in supplementary file "ocean_warming_data_extraction.docx".

Consistency checking

For the first stage of the screening, articles will be allocated to the two reviewers. To ensure the consistency of the decisions between reviewers, 30 articles will be chosen at random to be screened in duplicate as a training set first. Same procedure will be followed for the second stage of the screening. A third reviewer will review and assist in resolving the disagreement in decision between the reviewers. For each stage of screening, a Cohen's Kappa coefficient (Cohen, 1960; McHugh, 2012) will be calculated to examine the degree of agreement between the reviewers. For reviews using Cohen's Kappa test as a matrix for evaluating the degree of agreement, a kappa value of 0.60 (McHugh, 2012) is suggested to be acceptable level of agreement between the reviewers both in terms of inter-reviewer reliability and disagreement arising from each stage of screening. If the kappa value is below 0.60, it would be classified as general disagreement between the reviewers. In the case of a kappa value below 0.60, the eligibility and exclusion criteria will be reviewed, discussed, and amended accordingly by the review team members (McHugh, 2012). This process would repeat until the kappa value from the review agreement reaches 0.60 or above.

Reporting screening outcomes

During the full-text screening, studies that are rejected from the process will be recorded with the respective reasons recorded. A ROSES flow diagram will be used to record and visualise the number of studies assessed and rejected at each stage. It will be uploaded, and all supplementary materials will be provided. If deviations from the ROSES flow diagram exist, they will be discussed in the systematic map.

Study validity assessment

The aim of the systematic map is to provide a visual layout of where the research is conducted, and hence no study validity assessment will be conducted.

Consistency checking

Not applicable

Data coding strategy

Data extraction will be done collaboratively by two researchers using a questionnaire in the form of a Google Form from the articles included in the full text screening. A list of questions from the Google form can be found in the supplementary section of this protocol.

Meta-data to be coded

The data extraction variables are recorded in the additional file "ocean_warming_data_extraction.docx". The document describes all the variables used in the Google Form.

Consistency checking

A random subset of 20% of studies will undergo duplicate data extraction by reviewers. Disagreements between reviewers regarding outcomes will be resolved via discussion. In the case where disagreement persists, a third reviewer will be introduced and mitigate the discuassion until

the disagreement is resolved. If the conflict rates between extraction outcomes are over 10%, another 10% of studies will be extracted in duplicate for validation.

Type of mapping
A written report will be produced to accompany the systematic map to document all methodology, results, discussion, and other supplementary details during this mapping exercise. Details and information regarding the literature search, screening and data extraction will also be provided to facilitate the reproducibility of this study.

Narrative synthesis methods
The data from the review will be presented in the form of narrative review, descriptive tables, and graphical presentations. Data-generated figures will be created in R (R Core Team, 2021).

Knowledge gap identification strategy
By creating this systematic map, we aim at achieving the following three major outcomes: Firstly, the studies will be classified into subtropical or temperate, based on their geographical study location as defined within the ecoregions of Beger et al. (2013) and Spalding et al. (2007). This will improve our understanding of the research effort for these coral systems. Second, we are also interested in the keywords used, time period of studies, study durations, locations and authors of the primary research included in this systematic map. We will be able to map the relationships of these criteria using a series of bibliometric analysis on R based on data collected from the Google Form questionnaire. Third, following this classification, we identify gaps and clusters of topics in the reviewed articles on ocean warming impact on the subtropical or temperate coral systems. The gaps identified could guide further research.

Demonstrating procedural independence
As some of the authors of this proposed review may have been authors of some of the studies to be reviewed in this work, their studies will be independently assessed by other study reviewers without discussion with the study authors to ensure the independence of the review.

Competing interests
The authors do not have competing interests to declare.

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