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Shifting Seasonality and Acidifying Oceans as a Result of Climate Change: a Meta-analysis

Abstract

Anthropogenic activity has caused an increase in atmospheric CO_2, which in turn has shifted the equilibrium of marine chemistry causing a decrease in pH. Ocean acidification (OA) has the potential to negatively impact the development of sensitive early life stages of many marine organisms by reducing and calcification rates and increasing mortality. Warming temperatures have also influenced life events, such as spawning and migration, since many organisms rely on environmental triggers, such as water temperature or solar irradiance, to initiate these events. As climate change impacts both marine pH and phenology, there is a potential for interactions between the two as organisms have evolved seasonal behavior to optimize the success of their offspring based on water conditions, food availability, and presence of predators. Unfortunately, little research has been done on the potential interactions between impacts of OA and shifting phenology on marine organisms, raising the question as to how life stages can adapt to differences in pH due to seasonality and ocean acidification. This meta-analysis reviewed nearly 3,000 papers from Google Scholar on OA and phenology, selecting papers with quantifiable information on changes in phenology and organismal development due to OA among the early life history stages of marine organisms. Following review, 70 papers were selected based on the species overlap between searches on OA and phenology. These papers are being scored to extract quantitative relationships between the impact of ocean acidification on marine organisms and relationships between warming temperatures and phenological events. Once information on these relationships has been extracted, the data will be plugged into climate change models to project the potential impacts of OA and changes in seasonal spawning, development, and migration. A total of 22 species representing 5 phyla (Arthropoda, Cnidaria, Chordata, Echinodermata, and Mollusca) will be examined for their potential response to changing seasonality and pH due to climate change. In doing so, this meta-analysis has the potential to project changes that could prove useful to both fishery management of popular fish, such as cod and tuna, as well as coral conservation efforts.

Background

With the rise of deforestation and fossil fuel consumption in the past two centuries, atmospheric levels of carbon dioxide (CO_2) has risen by 40 percent. While this reduces climate change symptoms on land it alters the chemical balances that many forms of marine life rely on (Doney et al., 2009). This chemical balance consists of a series of chemical reactions occurring from where the atmosphere meets the ocean to the interaction between those products and minerals dissolve in the water. Due to imbalances caused by the increase in atmospheric CO_2, oceanic pH levels are dropping while the concentration of carbonate ions.

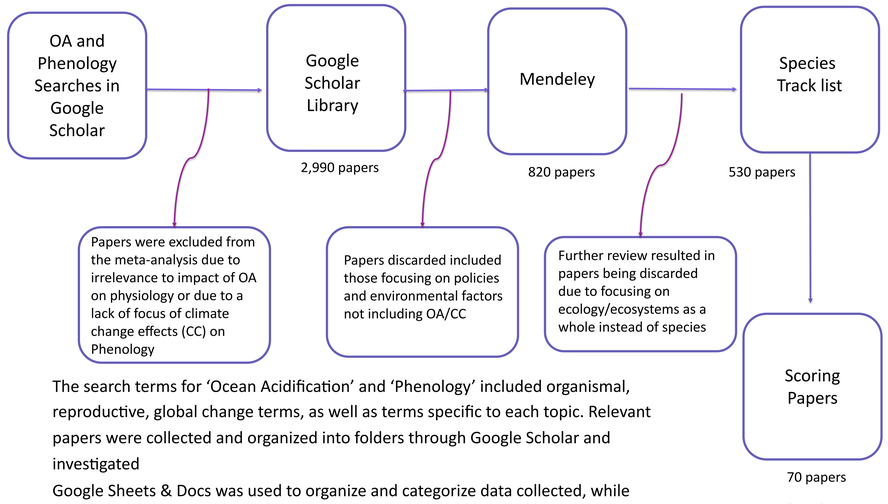
$$CO_{2\,(atmos)} \rightleftharpoons CO_{2\,(aq)} + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^{2-}$$

Ocean acidification (OA) is a relatively predictable consequence of climate change due to the stoichiometric nature of the chemical reactions and saturation rates of the involved compounds. Invertebrates and marine vertebrates face different challenges considering decreasing pH, such as reduced shell integrity or increased strain on the physiology of larval fish.

These changes in physiology have implications for the timing of spawning, recruitment, and other phenological events. The timing of these events help structure ecological interactions and ensure the survival of the next cohort of organisms in certain environmental conditions.

While global warming is shifting organism phenology in a variety of taxa, from blue mussels to loggerhead sea turtles, ocean acidification will further impact seasonal pH cycles, especially in higher latitude oceans. (Fitzer et al., 2014; Monsinjon et al., 2019).

Methodology



The search terms for 'Ocean Acidification' and 'Phenology' included organismal, reproductive, global change terms, as well as terms specific to each topic. Relevant papers were collected and organized into folders through Google Scholar and investigated

Google Sheets & Docs was used to organize and categorize data collected, while Mendeley's desktop application was used to organize papers during the tracking and scoring processes.

Following the second revision, each paper was downloaded to Mendeley and reviewed with relevant information (phylum, species name, life stage studied) recorded in a Google Sheet.

Once all species had been recorded in a Google Sheet, papers were grouped together according to species and those for which there was information available on both ocean acidification and phenological changes for a given species were retained and used as the basis for the meta-analysis.

Each of the papers from the final meta-species track list will be scored by recording information on the article itself and the data gathered including study site coordinates, quantitative relationships, equations, and non-environmental factors. Authors are contacted if raw data is needed for the modelling part of this study.

Figure 1. Flow chart illustrating the process in which papers were collected, reviewed, and scored, as well as a track of the total number of papers at that point in the process.

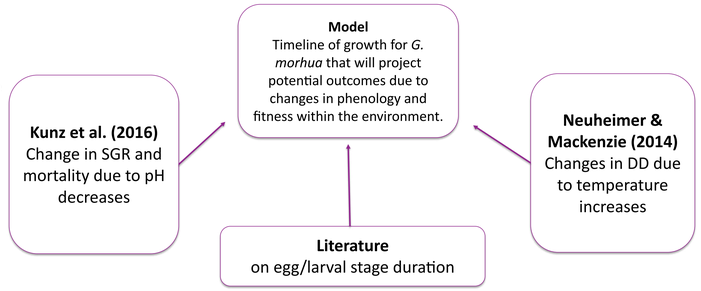
These graphs visualize not only where research is concentrated in areas, but also where it is lacking. Figures 1 and 2 show the stark contrast in the phylums observed in OA and phenology studies, respectively.

- OA focused more on shell-building phylums (Arthropoda, Mollusca, Echinodermata)
- Phenology is centered around chordates (fish) and arthropoda (copepods)
- Majority of papers that will be included in OA/CC modelling are on fish and copepods

These charts, while only representing a small portion of research done regarding CC and OA, point to areas of potential research regarding how the physiology and phenology of understudied organisms will change as the climate changes as well.

Moving Forward

In the process of scoring papers, *Gadus morhua* was identified as 'test' species to experiment with modelling potential interactions between OA impacts on organism physiology and phenology shifts due to warming temperature. A study done by Kunz et. al (2016) examined the specific growth rates(SGR) and other characteristics of *G. morhua* and *Boreogadus saida* when raised in different temperature (3, 8, 12, and 16 Celsius) and pCO_2 conditions (390 or 1170 ppm), while Neuheimer & Mackenzie (2014) examined changes in *G.* morhua's mean spawning time in Degree Days (DD) in relation to thermal history. Data from these studies will be quantified in relation to environmental factors such as changes in pH and temperature and then integrated into climate change models to project potential outcomes for larval growth and mortality due to changing pH and phenology.



Preliminary Results

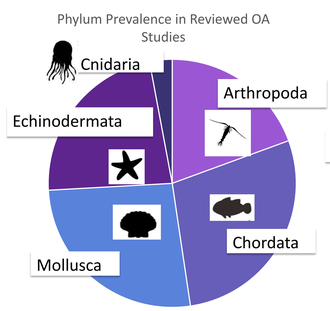


Figure 2. Pie-chart of phylum prevalence as seen across 340 total studies on OA.

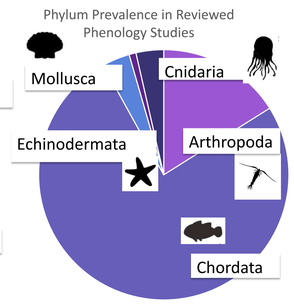


Figure 3. Pie-chart of phylum prevalence as seen across 190 studies on phenology

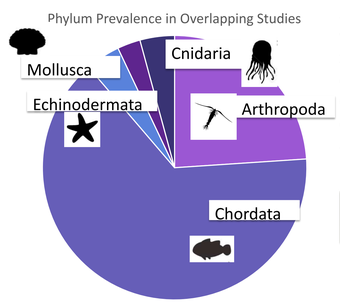


Figure 4. Pie-chart of phylum prevalence as seen in the 70 papers that will be used in modelling.

Conclusion

The literature review and meta-analysis revealed two key aspects of current studies on OA and phenology. Most literature available tends to focus on either OA or phenology without considering the potential for interactions between these two climate stressors. Studies focused on these stressors also tend to focus on different phyla of marine organisms. There is far more literature available on the phenology of chordates, whereas OA literature reveals an even distribution among phyla, with some focus on shell-building organisms. As a result, the modelling aspect of this study will focus primarily on chordates and arthropods but will have at least one species representative from the major phyla represented in a review of both OA and phenology literature.

Citations

Doney et al. (2009) Ocean Acidification: The Other CO2 Problem. *The Annual Review of Marine Science*, 1, 169-92. doi: 10.1146/annurev.marine.010908.163834

Fitzer et al. (2014) Ocean acidification impacts mussel control on biomineralisation. *Scientific Reports*, 4(6218). doi: 10.1038/srep06218

Monsinjon et al. (2019) Effects of temperature and demography on the phenology of loggerhead sea turtles in Brazil. *Marine Ecology Progress Series*, 623, 209-19. doi: 10.3354/meps12988