Table of Contents

POSTERS

Theme A: Changing carbonate chemistry in coastal to open ocean waters

Influence of the Amazon River plume on the carbonate system parameters in the Western Tropical Atlantic Ocean

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The Tropical Atlantic Ocean is the second largest source of CO_2 from the ocean to the atmosphere. However, the western portion of the Tropical Atlantic is a complex region in terms of oceanic dynamics and biogeochemistry, leading it to act as both a source and a sink of atmospheric CO_2. The spatiotemporal estimates of the carbonate system parameters are important to understand the role of the western Tropical Atlantic Ocean (WTA) in the sea-air CO_2 exchanges, given the increase in atmospheric CO_2. Therefore, here we investigate the temporal variability (1991-2019) of the carbonate system in the WTA. We observed that the Amazon River Plume reduces the partial pressure of CO_2 (pCO_2) by approximately 27 µatm (7.3%) in the WTA, directly influencing sea-air CO_2 exchanges in this region. Moreover, the waters from the Amazon River plume also reduce the sea surface salinity in 2.91 as well as total alkalinity in 190.99 µmol/kg and total dissolved inorganic carbon in 159.68 µmol/kg on the surface of the WTA. Despite the intense input of riverine waters rich in organic matter, the waters from the Amazon River plume have a relatively higher pH (8.09 ± 0.03) than the surrounding waters in 0.01 due to the pCO_2 drawdown by photosynthesis. The total alkalinity and total dissolved inorganic carbon were the main drivers of seasonal changes in pCO_2 in the ARP and WTA region from the dry season to the wet season, the sea surface salinity showed a secondary influence on seasonal changes in pCO_2. Our findings reveal that the Amazon River Plume is one of the main drivers for the biogeochemical dynamics in the surface waters of the WTA.

Key words: Biogeochemical, Amazon River Plume, Total Alkalinity, Total Dissolved Inorganic Carbon

Ocean acidification monitoring begins in Colombia: offshore carbonate system measurements

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The analytical capabilities for the measurement of the carbonate system with "Weather" quality obtained by regional projects funded by the International Atomic Energy Agency (IAEA), allow INVEMAR from 2021 to initiate the collection of offshore information of the carbonate system in Colombia through oceanographic cruises. This paper presents the results of 5 oceanographic cruises, 3 blocks of the Colombian Pacific and 2 blocks of the Colombian Caribbean. The national strategy for the inclusion of the parameters Total Alkalinity and Dissolved Inorganic Carbon measured at different depths and the other variables of the carbonate system derived with CO2Sys, is based on the commitment to report indicator 14.3.1 of SDG 14. Three of these oceanographic cruises correspond to marine environmental baseline studies funded by the National Agency of Hydrocarbons (ANH) of Colombia and two to cruises whose objective is the declaration of offshore protected areas funded by the Ministry of Environment of Colombia. Water column profiles of carbonate system variables and nutrient variables, salinity, dissolved oxygen, dissolved organic carbon and chlorophyll a, show changes in carbonate system variables associated with biological processes including phytoplankton photosynthesis, organic matter remineralisation and calcification.

Key words: Offshore monitoring, Ocean acidification, SDG14.3., Carbonate chemistry, capacity building.

Estimation of aragonite saturation state using satellite data in the Pacific off Mexico

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The aragonite saturation state (Ω_{arag}) is an indicator of ocean acidification (OA). This work aimed to calculate Ω_{arag} with daily 4x4 km temperature (SST) satellite data, using its temperature and omega aragonite relationship (in-situ data); with a correlation coefficient of 0.93, in the Mexican Pacific (PM). We found that Ω_{arag} presented spatiotemporal variation in the PM: In the area of influence of the subarctic water (>22° N) Ω_{arag} had values less than 3; while in the Mexican tropical Pacific region, the range of values was ~3 - 4. It is important to highlight that the coastal zone of the Mexican tropical Pacific in summer presented the highest Ω_{arag} values (3.8); while in winter its value was reduced (~3.4). This methodology allows us to know different scenarios to determine the influence of temperature change on different ecological and commercial importance species over time, such as coral reefs that are affected both by changes in SST and by the decrease in Ω_{arag}.

Key words: aragonite, correlation, ocean acidification, satellite data

The impact of a Southern Ocean quasi-stationary anticyclonic eddy on the net sea–air CO2 fluxes

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Oceanic eddies are mesoscale features that play an important role in ocean circulation and in the redistribution of biogeochemical properties among the different regions of the globe. Despite this, there is no consensus on the expected behavior of cyclonic/anticyclonic eddies being either a sink or source of CO_2 to the atmosphere nor whether they enhance or reduce the sea-air CO_2 exchanges. Thus, this work aims to contribute to the understanding of the processes that govern CO_2 fluxes in an eddy located in the Bransfield Strait, Southern Ocean.

In this sense, we sampled an anticyclonic eddy quasi-stationary located south of Clarence Island, north of the Antarctic Peninsula. Eleven hydrographic stations were carried out along the eddy. Thus, hydrographic data (i.e., temperature, salinity, and dissolved oxygen - O_2), and discrete samples (i.e., phytoplankton pigments, total alkalinity- Alk, and total dissolved inorganic carbon-DIC) were collected.

The anticyclonic eddy has a cold and salty core, as indicated by the surface maps of physical. That it is due to the Weddell Sea waters trapped inside the eddy at the moment of its formation. Additionally, our analysis indicated a higher concentration of DIC, Alk, $p$$CO_2$, Apparent Oxygen Utilization, and lower concentration of O_2 and chlorophyll in the eddy's core in relation to the adjacent waters. Thus, we hypotheses which our results indicate that the eddy retained organic matter and zooplankton (due to its foraging behavior caused by high phytoplankton biomass in surrounding waters of the eddy), which leads to the ammonification (i.e., ammonia formation due to remineralization process) and the nitrification processes, which consists of the transformation of ammonia to nitrate by nitrifying bacteria. Finally, we observed that the eddy becomes a regional source of CO_2 due to increased DIC in this area.

Key words: Southern Ocean, Northern Antarctica Peninsula, eddies, CO_2 fluxes, phytoplankton

Long-Term Trends in River Alkalinity Loading and Freshwater Inflow to Northwestern Gulf of Mexico Estuaries

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The world's oceans have absorbed vast quantities of CO_2 from the atmosphere. This uptake has significantly mitigated build-up of this greenhouse gas. Absorbed CO_2 dissolves in water and dissociates into carbonic acid, reducing pH and carbonate saturation states in the ocean. This acidified ocean water may advect into estuaries, leading to decreased estuarine pH. Estuaries in general are highly sensitive to acidification due to low buffering capacity. Because estuaries provide many important ecosystem services, alterations in the carbonate systems of estuaries can have vast consequences on ecosystems, organisms, and economies.

Despite their importance, little is known about the carbonate systems of subtropical estuaries. In the subtropical northwestern Gulf of Mexico (nwGOM), estuaries demonstrate a long-term decline in alkalinity and pH. This study investigates the role of freshwater inflow on alkalinity reduction in this region. It is proposed that reduction in alkalinity load delivered to nwGOM estuaries through rivers is the primary cause of the observed decline in alkalinity. Results of this study will improve management of freshwater resources in the south-central United States and other subtropical regions of the world.

Data on alkalinity and instantaneous stream flow, spanning from 1972 to 2013, were provided by the Texas Commission on Environmental Quality (TCEQ) for nine major rivers that empty into nwGOM estuaries. The United States Geological Survey (USGS) Fortran Load Estimator program (LOADEST) was used to calculate annual load estimates for these rivers. Preliminary analyses suggest that some rivers are experiencing decreased alkalinity concentration or total load for this region. Freshwater diversion is likely one of the contributing factors to the loss of alkalinity loading in estuaries of the nwGOM. These multidecadal changes will be examined in the context of changing precipitation and increasing freshwater consumption as a result of population expansion.

Key words: estuary, alkalinity, freshwater inflow, pH

Carbon dioxide fluxes in the ocean - atmosphere interface in the Western Tropical North Atlantic.

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The objective of this study was to estimate partial pressure of CO2 values as well as to evaluate the CO_2 fluxes between the ocean and the atmosphere in the Western Tropical Atlantic Ocean. The values were estimated by continuous underway measurements of CO_2 from an infrared gas analyzer system installed on board RV Vital de Oliveira (Brazilian Navy). The PIRATA XVII campaign took place between October 2017 and January 2018, but the data being used in this study corresponds to the transect between the equator and 15 ° N along 38 ° W. Mean SST was 28.0 ± 0.04 ° C, mean SSS was 35.63 ± 0.55, and the lowest SSS values was 34.2. The corrected mean values of *p*CO2 were 404.70 ± 4.24 µm ($pCO2_{atmosphere}$) and 455.98 ± 22.99 µm ($pCO2_{ocean}$). Salinity (SSS) and pCO2ocean had a significant linear correlation (R = 0.84, pCO_2 = (35.62xSSS) - 811.34). The mean of ΔpCO_2 was 45,81± 21,09 µatm. The lower pCO_2 values corresponded to the area under influence of the ITCZ and the Amazon River plume, which is transported by the NECC to oceanic regions. As for the calculated CO_2 fluxes, we noticed a diurnal variation with mean peaks of maximum and minimum 6.89 mmol CO_2 $m^{-2}day^{-1}$ (at 14 hours) and 2.72 mmol CO_2 $m^{-2}dia^{-1}$ (at 2 hours), respectively. The positive flux values in this region suggest that the ocean plays the role of CO_2 source to the atmosphere, as shown for the Western Tropical Atlantic Ocean by previous studies. Due to the complex regional circulation, one expects a large seasonal variation in the sea-air CO2 fluxes, mainly influenced by the ITCZ position and the Amazon plume intensity.

Key words: CO2 fluxes; partial pressure of CO_2; PIRATA.

Coastal carbonate system offshore two Eastern Mediterranean cities

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The coastal carbonate system regulates the pH of the coastal waters and controls the circulation of CO_2 between land-sea interfaces and open sea system. In the context of the ELME (Evaluation of the Lebanese Marine Environment: A multidisciplinary study) project, a seasonal survey of the carbonate system has been started in 2019 through the sampling of three different transects starting from the coast towards the open sea, to evaluate the spatio-temporal variations and main drivers of this system offshore two Lebanese cities: very urbanized Beirut and less urbanized Tyre. The carbonate chemistry is being studied by measuring both total alkalinity (A_T) and total dissolved inorganic carbon (C_T), together with other critical parameters in coastal ecosystems such as temperature, salinity, pH, dissolved oxygen, nutrients (phosphates, nitrates, nitrites, silicates), chlorophyll-*a* and fecal bacteria (indicator of domestic pollution). Average A_T and C_T were equal to 2579 ± 39 and 2288 ± 54 µmol kg^{-1}, respectively. All carbonate system parameters showed significant seasonal variability, together with other parameters (T, S, silicates, pH, DO, Chl-*a*). In addition to their expected significant correlation with chemical parameters (phosphates, nitrites, S and T), A_T and C_T were also very positively correlated to fecal bacteria only in Beirut. Whereas in Tyre, A_T and C_T were predominantly derived by the conventional parameters (T, S, nitrites, silicates, pH, DO). These results reflect the role of human pressures (here discharges of dumpsite and domestic pollution) in modifying the coastal biogeochemistry near urbanized areas and shows the complexity of constraining acidification trends in heavily anthropogenically-influenced waters. The continuity of this project will help to assess the relationship between land-based anthropogenic pressures and the coastal biogeochemistry in a changing Eastern Mediterranean Sea.

Key words: Carbonate system, ocean acidification, human pressures, Mediterranean Sea, Lebanon.

An empirical projection of ocean acidification in southwestern Japan during the 21st century

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We evaluate the progress of ocean acidification in southwestern Japan from 1995 until 2019 with SOCAT database. There are many subtropical islands (e.g., Okinawa, Ishigaki, Miyako, and Amami) surrounded by shallow waters where coral reefs grow in the study area. Many people living in this area benefit from coral reefs through food supplies and tourism. Therefore, the effects of ocean acidification on coral reefs are not only limited to ecosystem but also to socioeconomy. The progress of acidification can be traced back to the 1990s with the database of $p\mathrm{CO}_{2\mathrm{sea}}$. Using these data, we created an empirical regression to reconstruct ocean acidification up to the present. Furthermore, by applying this equation to the scenario of atmospheric CO_2 concentration, temperature, and salinity under RCP4.5 and RCP8.5 scenarios, we project ocean acidification in the study area by 2100 only with a commonly used lap-top computer. Under RCP8.5 scenario, aragonite saturation (Ω_A) will seasonally drop below 3.0 at 27°N 128°E in the winter of the 2030s. Furthermore, such a low Ω_A will last throughout the year in the 2060s. Annual mean pH and Ω_A at 27°N 128°E in 2100 will range from 7.73 to 7.75 and from 2.04 to 2.10, respectively. This projection was comparable with the results from ESMs. Although our empirical prediction limits the areal extent, it may accurately reflect the seasonal and long-term variations in our study area. Comparing our local projection with the global scale ESM products is meaningful for verifying the results from both approaches.

Key words: acidification, empirical projection, coral reefs, RCP8.5

Seawater Carbonate System Variability in the Virginia Coast Reserve LTER

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The carbonate system in the coastal zone is an essential component of the global carbon cycle, and its characterization enhances understanding of critical climate issues like carbon burial, ocean acidification, and carbon connectivity between ecosystems. This research aims to assess carbonate system dynamics in the Virginia Coast Reserve (VCR) LTER, a back-barrier lagoonal system located on the East Coast of North America, by creating a water column Dissolved Inorganic Carbon (DIC) inventory and characterizing seasonal and spatial carbonate system trends. Water samples were collected in conjunction with long-running quarterly water quality sampling at 13 survey sites and were later analyzed for DIC and total alkalinity. From these measurements, pH and pCO_2 were estimated using the CO2SYS MATLAB 1.1 package. Across all water quality sites, the average DIC concentration was 2028.8 ± 25.1 μmols/ kg in the summer of 2021 and 1970.9 ± 22.7 μmols/ kg in the fall of 2021, culminating in an estimated inventory of 1.2 ± 0.04 Gmol C for the entire volume of the VCR lagoons across surveyed seasons. DIC concentrations were significantly elevated at sites close to the marsh edge relative to inlet sites, with spatial variance of summer values exceeding the seasonal variance between summer and fall. Upcoming analysis of samples from winter and spring of 2022 will provide a more comprehensive understanding of seasonal shifts in the VCR carbonate system.

Key words: Dissolved Inorganic Carbon (DIC), Carbonate System, Carbon Connectivity

Coastal acidification in Mazatlan Bay and its relationship with upwelling

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Ocean Acidification, another consequence of the anthropogenic emission of carbon dioxide into the atmosphere, is caused by carbon dioxide exchange between the ocean and atmosphere. In coastal areas, pH variability might be caused by other drivers, such as excessive nutrient loadings, organic matter decay and upwelling events. Upwelling favors seawater pH decrease because of the higher levels of carbon dioxide in deeper waters. The coastal zone of Mazatlan City (~0.5 million inhabitants), in the NW Mexican Pacific at the entrance of the Gulf of California, is associated to the largest oxygen minimum zone (OMZ) in the world. During the winter-spring season, coastal waters are affected by intense northeastern winds that induce upwelling events. In this work, we compare an approximately monthly time-series of pH_T, pCO_2, and Ω_{Ar} versus temperature and dissolved oxygen concentration to study its relationship with upwelling conditions. During this season, pH_T and pCO_2 values were abnormal owing to the intrusion of CO_2-rich upwelled waters. Although Ω_{Ar} usually showed supersaturation levels, under upwelling conditions the values decreased to ~1. We qualitatively identified upwelling events that promote the presence of acidified waters in the Mazatlan coastal area.

Key words: Northeast Pacific, oxygen minimum zone, upwelling, coastal acidification

Seasonal Variability of Net Sea–air CO_2 Fluxes in the Northern Antarctic Peninsula

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Abstract

Several studies have been conducted in the Southern Ocean to investigate the net sea–air CO_2 fluxes (FCO_2). However, the Antarctic coastal regions are still poorly sampled and the majority of the studies are restricted to the austral summer, which difficult the better understanding of the natural variability due to high seasonality in coastal areas. Here, we joined the datasets from SOCATv6, High Latitude Oceanography Group and the World Data Center PANGAEA to construct a temporal series (2002-2017) of hydrographical and biogeochemical data in Gerlache Strait, a hotspot for climate change that is ecologically important in the northern Antarctic Peninsula. Thus, we show for the first time a detailed annual overview of the FCO_2 and primary drivers in the Gerlache Strait. In autumn and winter, episodic upwelling events increase the remineralized carbon in the sea surface, leading the region to act as a moderate or strong CO_2 source to the atmosphere of up to 50 mmol m^{-2} d^{-1}. During summer and late spring, photosynthesis decreases the CO_2 partial pressure in the surface seawater, enhancing ocean CO_2 uptake, which reaches values higher than –50 mmol m^{-2} d^{-1}. Therefore, the autumn/winter CO_2 outgassing is nearly balanced by an only 4–month period of intense ocean CO_2 ingassing during summer/spring. Hence, the estimated annual FCO_2 from 2002 to 2017 was 1 ± 17 mmol m^{-2} d^{-1}. The main drivers of changes in the surface CO_2 system in this region were total dissolved inorganic carbon and total alkalinity, revealing the dominant influence of both physical and biological processes. These findings demonstrate the importance of Antarctica coastal zones as carbon sinks and emphasize the need to better understand the sensitivity of the local/regional Southern Ocean carbon cycle to the impacts of climate change.

Key words: Biogeochemistry; Carbon cycle; Southern Ocean; Antarctic coastal region.

Increasing CO_2 Partial Pressure and Implications for Sea-Air CO_2 Exchanges in the Western Tropical Atlantic Ocean

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The Western Tropical Atlantic Ocean is a region of complex biogeochemistry, largely due to the structure of the surface current system and the large freshwater input from the Amazon River. Several studies have been conducted to identify the processes that control the carbon cycle in this region, but they are usually limited in time and/or space. We investigated a time series (1993-2019) of sea surface CO_2 partial pressure (pCO_2) and sea-air CO_2 exchanges over a vast area of the Western Tropical Atlantic Ocean. The waters of the Amazon River plume exhibit high interannual variability but no trend in pCO_2, whilst we found a significant increasing trend in pCO_2 in the waters of the North Brazil Current (NBC, 2.27 µatm year^{-1}) and the North Equatorial Current (NEC, 2.23 µatm year^{-1}). Such trends had already been observed in both regions until 2009, but they were smaller than the increase in atmospheric pCO_2. However, in the last decade there has been an 89% and 42% increase in sea surface pCO_2 in NBC and NEC waters, respectively, and currently trends are more pronounced than the increase in atmospheric pCO_2 (1.93 µatm year^{-1}). Hence, if the current rates of increase of both atmospheric and sea surface pCO_2 persist, these trends suggest that it will take around 50 years for NEC waters may shift from a CO_2 sink to a CO_2 source to the atmosphere, while NBC waters may double the current magnitudes of CO_2 release from the ocean to the atmosphere. Both cases indicate potential direct effects on the carbon cycle in this region and further into the Atlantic Ocean. These findings reveal the sensitivity of carbon dynamics in the Western Tropical Atlantic Ocean to global climate change, with implications for feedbacks on the drivers of this change.

Key words: Carbon cycle; Amazon Plume; Northern Brazil Current; Equatorial Current, sea-air CO_2 fluxes.

Near-Shore Carbonate Measurements in the Gulf of Mexico. Insights on OA drivers

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Most of the recreational fishing, aquaculture and tourism occur in near-shore estuarine and coastal regions. The effects of land-side processes such as river discharge and run-offs, and ocean-side processes on these regions are often not well known. In an attempt to fill this gap for coastal waters of the US East coast and Gulf of Mexico, we have increased coastal measurements of the carbonate parameters in critical regions by entering into a collaboration with the US National Park Service in 15 US National Parks as well as augmenting our carbonate measurements on bi-monthly cruises around the West Florida Shelf. Here we show preliminary results of our efforts. Due to the low frequency of the measurements, the results are not conclusive yet but hint at possible trends of the Ocean Acidification (OA) drivers in these coastal regions, notably those related to the occurrence of the Harmful Algal Blooms in the Gulf of Mexico.

Key words: ocean acidification, near-shore, carbonate system, Harmful Algal Bloom, Gulf of Mexico

A Matlab® software to ease, speed up and improve surface *p*CO_2 data processing and submission.

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In 2005, NOAA AOML hosted a workshop aimed at improving the surface *p*CO_2 measurements made by the community at large. The workshop produced two results: it gave recommendations on how to build the best automated surface *p*CO_2 instrument to be installed on ships, which gave birth to the "Gold Standard" General Oceanics system now used worldwide. The second action item from the workshop was the production of data reduction programs to help users process the *p*CO_2 data collected by the automated instruments. Data processing is a complex task which involves detection and manipulation of bad data, correction of data using regular calibration of the analyzer, fairly complex calculation of fugacities from mole fraction measurements and last, but not least, production of a data and metadata package for submission to the scientific community. Uniform quality data and metadata is essential for the community's effort to constrain the global carbon cycle. This work presents the resulting Matlab® program which has the following essential functions: it allows for a visual inspection of the data and makes detecting and salvaging bad data easy, which not only improves the final data quality but also helps in the troubleshooting of the instrument. It makes the standardization and fugacity calculations easy and uniform throughout the community. Finally, it promotes uniform data and metadata formatting for easy data submission to national data centers and synthesis projects such as SOCAT. The program code, or the compiled version for PC or Macs, is free and already used largely in the community.

Key words: *p*CO_2, data processing, software, data quality

Changes in the carbonate chemistry and the buffer capacity in the central layer of the South Atlantic Ocean due to anthropogenic carbon uptake.

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The global ocean has played an important role mitigating the effect of the increase in the CO_2 atmospheric concentrations by soaking off 30% of the anthropogenic carbon released. However, this uptake induces critical changes in the seawater chemistry that could lead to big impacts on the biological ecosystem in the upper layer of the ocean, a phenomenon known as Ocean Acidification. Previous studies showed that the South Atlantic Ocean has a large inventory of anthropogenic carbon (C_{ant}) because of the intense water mass formation, affecting the pH and the carbonate chemistry mainly in the South Atlantic Central Water (SACW). Here, we investigate the changes in the carbonate chemistry and the buffering factors due to C_{ant} capture in the South Atlantic since the pre-industrial epoch to 2018, related to the contribution of the Subtropical Mode Water (STMW) varieties in the SACW. To do this, we calculated the influence of the C_{ant} (from TrOCA approach) in the carbonate parameters, using data from the GLODAPv2.2019. We adjust the total dissolved carbon and C_{ant} observation to a common reference year (2018), assuming a transient steady state. Then, these results were compared with the contribution of the STMW varieties filling the SACW. We find that the C_{ant} is distributed almost uniform between the isopycnals of 26.3 and 26.4 kg m^{-3}, associated with the STMW varieties formed in the eastern side of the South Atlantic basin ($STMW_{18}$), and along the southern edge of the gyre ($STMW_{12}$) in this region. Despite that, the effect in carbonate chemistry are more linked to the $STMW_{18}$, where the decrease in pH, Ω_{Ar} and the increase in the Revelle factor are higher. These results suggest that the high buffer capacity of the STMW varieties in the southwestern side is mitigating the C_{ant} alteration in the South Atlantic Ocean.

Key words: Ocean Acidification, South Atlantic Ocean, Mode Waters, Anthropogenic Carbon, Carbonate Chemistry

Caracterización estacional del sistema de carbonatos en la Isla Foca, región Piura.

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El objetivo principal de este estudio es caracterizar la variación estacional del sistema de carbonatos en la Isla Foca, la cual se encuentra en una zona de transición entre dos grandes regiones biográficas, Pacífico Oriental Tropical y el Pacífico Sur Oriental Templado, lo que sustenta su alta y endémica biodiversidad. De acuerdo a la comisión ENFEN el periodo de estudio marzo-octubre 2019 presentó condiciones normales, durante el cual se realizaron 12 muestreos en 8 estaciones alrededor de la isla, registrando temperatura, salinidad, oxígeno disuelto, pH y alcalinidad total en superficie y fondo, además se estimó los valores de CID, pCO_2 y Ω usando el programa CO2SYS.

Los valores más altos de pH (7.88-8.04) estuvieron asociadas a temperaturas altas como lo observado en verano y en un periodo de primavera, este último con predominante presencia de aguas ecuatoriales superficiales donde además se registró las concentraciones más bajas de CID y AT (2092 y 2284 µmol/kg, respectivamente) y valores altos para los estados de saturación de la aragonita (Ω Ar >2) siendo más resaltante en las muestras de fondo. En contraste, en los meses con temperatura más baja, correspondiente a mediados de otoño e invierno, se encontraron la mayor concentración de CID y AT y valores bajos de pH (2290 µmol/kg, 2367 µmol/kg y 7.63). Asimismo durante este periodo los valores del estado de saturación de la aragonita alcanzaron valores cercanos y por debajo a 1.

Los resultados sugieren que la variación temporal del pH, CID, AT y Ω_{Ar} se encuentran asociados a los cambios estacionales y más aún ante la presencia predominante de alguna masa de agua donde se observan las fluctuaciones más definidas.

Seasonally recorded pH values at fixed stations 10 miles offshore from the Ecuadorian coastal during 2013 and 2014

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This document aims to show reference pH values obtained during monitoring carried out on the Ecuadorian coast between 2013 and 2014. The purpose is to expose the changes that have been recorded during the dry and wet season. For data collection *in situ*, the SEABIRD - CTD 25 Plus with pH sensor was used. Sea temperature, salinity and pH were considered and the mixed layer (ML), the depth of the 20°C isotherm (Z20) and water masses were calculated. For the processing of the data and the elaboration of temporality graphs, the oceanography techniques commonly used in the region were used. Superficially, the results were separated by seasonality (i) dry and (ii) wet for both years. (i) 2013 presented an average pH of 8.3337, with a minimum of 8.1182 and a maximum of 8.4107. The sea surface temperature (SST) was on average 24.7°C, finding the ML at a depth of 27.4m and Z20 at 34.8m. In 2014, it had an average pH of 8.7847, with a minimum of 8.5963 and a maximum of 8.9178. The SST was an average of 26.6°C, finding the ML at a depth of 23.6m and Z20 at 63.3m. (ii) 2013 presented an average pH of 8.5891, with a minimum of 8.5697 and a maximum of 8.6001. The SST was on average 23.2°C, finding the ML at a depth of 7.7m and Z20 at 18.4m. In 2014, it had an average pH of 8.2442, with a minimum of 8.0392 and a maximum of 8.5529. The SST was on average 25.5°C, finding the ML at a depth of 7.1m and Z20 at 32.6m. It was concluded that, although 2014 presented lower values superficially during the wet season, between both years the pH did not show seasonal variation.

Key words: SST, ocean acidification, pH.

Utilizing stable Ca and Sr isotopes to understand marine carbonate dynamics through time

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The oceans have absorbed ~30% of the anthropogenic CO_2 emitted since the industrial revolution began (Gruber, 2019). The dissolution of CO_2 in seawater causes ocean acidification, which has potential to adversely impact biocalcification and ecosystem services. Model predictions of future effects largely rely on short-term incubation experiments conducted under elevated CO_2 conditions. Utilizing the past, we can gain further information on climate dynamics, as atmospheric CO_2 levels have widely fluctuated throughout Earth history. Studies of the geologic record can offer key insights into long-term mechanisms and feedbacks that cannot be easily simulated in the laboratory.

Here, we analyzed the stable calcium and strontium isotope composition ($\delta^{44/40}$Ca and $\delta^{88/86}$Sr) of marine carbonate rocks deposited during three dramatic carbon cycle perturbations in Earth history. These include limestones deposited prior to the Sturtian Snowball Earth Event (~742 Ma), a dolostone deposited after the Marinoan Snowball Earth Event (~635 Ma) (Wang, 2022), and limestones deposited before and across Oceanic Anoxic Event 1a (~120 Ma) (Wang, 2021). The Sturtian and Marinoan samples are inorganically precipitated calcium carbonate, as they were precipitated before the advent of multicellular life, while the OAE1a samples are biogenic in origin. Interestingly, in each case, $\delta^{44/40}$Ca and $\delta^{88/86}$Sr values define lines with slopes of 0.19, which is the theoretical value expected for kinetic mass-dependent isotope fractionation (Bohm, 2012). The same value has been detected in inorganic calcite precipitated in the laboratory (Bohm, 2012).

We postulate that geologic preservation of kinetic isotope effects is significant because carbonate mineral precipitation rates are proportional to the partial pressure of CO_2. Thus, the "$\delta^{44/40}$Ca-$\delta^{88/86}$Sr multi-proxy" may offer a novel tool for constraining past changes in marine carbonate chemistry and climate, thereby improving future predictions. More research is needed to understand controls on the Ca and Sr isotope composition of inorganic and biogenic marine carbonate.

Key words: paleoclimate, isotopes, carbonates, Neoproterozoic

References: Gruber et al. 2019; Bohm et al. 2012; Wang et al. 2022; Wang et al. 2021

Testing a portable infrared CO_2 gas system for the coastal region

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Despite their reduced area (7%), the biogeochemical processes that controls the CO_2 system are more intense in coastal oceans compared to open ocean regions, due to the continental influence or physical processes. Such interactions contribute with the spatial and temporal variability, leading to controversy the role of coastal oceans in the global carbon budget as a net sources or sinks. To determine the latter, a common practice is to derive the partial pressure of the CO_{2gas} (pCO_2, µatm) from discrete sampling of dissolved inorganic carbon (DIC, µmolkg^{-1}), total alkalinity (TA, µmolkg^{-1}) and/or pH. However, in order to obtain to obtain a continuous sampling, the most reliable way to quantify the partial pressure of this gas is to measure it directly in the field. In this work we propose two objectives: (1) evaluate the precision of an portable system using an infrared CO_2 gas analyzer (LICOR 840-A, ± 2 ppm, MBARI) to measure the molar fraction of CO_{2gas} (xCO_2, ppm), and (2) define if Bahia de los Angeles, a Mexican coastal region influenced by upwelling, as a CO_2 source or sink. In order to evaluate the performance of the portable system, the xCO_2 measured values were contrasted with discrete samples of DIC (± 3 µmol kg^{-1}), TA (± 3 µmol kg^{-1}) and pH (±0.001 pH units). Our results showed that the internal calibration using dry standard gases (475 ± 0.3 ppm and CO_2-free air) worked properly to match discrete samplings, showing a discrepancy of ± 11.6 ppm (± 2.3%) with xCO_2 values derived from TA-DIC, while the use of pH showed a offset around 100 ppm. Finally, the pCO_2 transect measured with the infrared portable system along the bay showed that the study area was a source of CO_2 (3.15 to 4.73 mmol C m^{-2} d^{-1}).

Key words: pCO_2, NDIR Sensor, Bahía de los Ángeles.

Determining The Drivers Of Long-Term Carbon Change Using Coastal And Open Ocean Time-Series Data

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Research in ocean carbon change has expanded dramatically over the past decade resulting in increased access to data, instruments, and scientific social networks. Using the wealth of increased time series data, I aim to answer the question: What are the drivers of carbon change at various locations throughout the globe? I hypothesize that at most open ocean locations surface ocean pCO_2 concentrations are primarily driven by atmospheric CO_2 concentrations. Preliminary findings at open ocean locations are consistent with this hypothesis. Coastal areas may face additional drivers such as changes in circulation and increased biological production. To test this hypothesis, I will start by characterizing trends in deseasoned time series and determine which time series have statistically significant trends. Once a significant long-term trend is identified I will use various analyses, such as the first order Taylor expansion of the carbonate system, to determine the drivers of the trend. Some locations may incorporate feedback loops or multifaceted drivers; for example, a long-term increase in seawater temperature will impact the solubility of CO_2 and oxygen. I predict that coastal waters will experience more variable rates of ocean acidification in the future compared to their open ocean counterparts due to multifactor drivers of carbon change that are specific to coastal regions.

Key words: ocean acidification, time-series, long-term change

Theme B: Organism responses and consequences of living in a high CO_2 world in a multi-stressor framework

Long-term monitoring of net calcification of secondary calcifiers and CO_2 system in coral reefs of the East Tropical Pacific Ocean

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The increase of CO_2 has caused changes on seawater such as acidification and warming; both means a threat for calcifier organisms. Secondary calcifiers such as calcareous algae, briozoans, serpulids worms, bivalves, gastropods, barnacles and others, contribute to store carbon, reinforce coral structures and stabilize patches of the substrate, and allow other organisms to settle. High calcification rates are commonly associated to healthy coral reef ecosystems and it predict a decrease of calcification rates. Therefore, it is necessary to monitor the calcifier communities, as well as the environmental variables related to CO_2 (pH, pCO2 and saturation of carbonates) to assess the influence of environmental changes (climate change, acidification and climatic events ENSO on net calcification. Net calcification rate and coverage of secondary calcifiers were determined in two coralline ecosystems (Las Monas [LM] and Bahía Tiburón [BT]) by Calcification Accretion Units (CAUs) in periods of 12 months (since 2014 to 2019); also, the study area was characterized by environmental parameters (pH, temperature, light and salinity), and parameters related to CO_2 system (pCO_2, ΩCa and ΩAr). Calcification and coverage varied temporal and spatially. The overall calcification (mean ±SD g of $CaCO_3 \cdot m^{-2} \cdot day^{-1}$) was 1.3 ± 1.1. Calcareous algae dominated in both reefs, whereas bryozoans also dominated in LM. Calcification in LM (1.5 ±1.3) was higher than in BT (1.0 ±0.8), because the diversity of taxonomic groups in LM is higher than BT. Also, was observed a pattern of low calcification rates during ENSO events: from 1.7 ± 1.2 in 2014 to 1.0 ±1.0 in 2015 and from 1.5 ±1.1 in 2018 to 1.0 ±0.8 in 2019. Longer time-scale studies are required to detect the effects of acidification or warming under natural conditions; however, this study show that anomalous high seawater temperatures affect to the calcification rates of the secondary calcifiers.

Key words: calcification, secondary calcifiers, CAUs, ENSO

Comparison of carbon uptake strategies between *Chara aspera* and *Chara tomentosa* in the brackish Baltic Sea and in the freshwater lakes of Estonia

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The carbon acquisition strategies of aquatic photosynthetic organisms play a key role in the growth and survival of a species. There is much research indicating that the predicted changes (e.g., the balance between carbonate species: CO_2, HCO_3^-, CO_3^{2-}) in the oceans carbonate chemistry, due to Ocean Acidification (OA), could affect benthic primary producers and their communities. However, considerably less is known about brackish water (e.g., Baltic Sea), and even less about the possible effects of acidification on freshwater biota. This study focuses on charophytes, which are a globally widespread group of submerged algae. The aim of this study was to compare the carbon uptake strategies of the two charophyte species: *Chara aspera* Willd. and *Chara tomentosa* L. growing in freshwater lakes and in the brackish Baltic Sea of Estonia. This could indicate how they might respond to increasing CO_2 concentration. Carbon use strategies in macroalgae were determined by analysing natural carbon isotope signatures (δ13C), pH drift experiments and photosynthesis vs. dissolved inorganic carbon (P vs. DIC) curves. Our results showed that freshwater and brackish water *C. aspera* and *C. tomentosa* probably have the mechanism to use HCO_3^-. However, they use different carbon uptake mechanisms in brackish water and freshwater environments, likely due to their local acclimatization to different growth environments. Also, freshwater *C. tomentosa* and *C. aspera* are likely carbon saturated and probably will not gain photosynthetic advantages from OA. However, the predicted increase in CO_2 concentration may positively affect the growth of the charophytes in the brackish Baltic Sea.

Key words: charophytes, carbon physiology, ocean acidification, macrophytes, increasing CO_2

Emiliania huxleyi – bacteria interactions in a changing ocean

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The interactions established between marine microbes, namely phytoplankton-bacteria, are key to the equilibrium between nutrient and carbon sink and recycling. Still, their role on phytoplankton's response to rising CO_2 concentrations is poorly understood. Here we show that the response of the cosmopolitan *Emiliania huxleyi* (*E. huxleyi*) to increasing CO_2, is affected by co-existence with the two bacteria tested. Decreased growth rate at enhanced CO_2 concentrations was amplified at higher abundances and with co-existence. The effect of CO_2 on *E. huxleyi's* cellular contents was magnified by the presence of *Idiomarina abyssalis* (*I. abyssalis*), but not *Brachybacterium* sp.. At the same time *I. abyssalis* abundances increased in the presence of *E. huxleyi* at both CO_2 concentrations while in *Brachybacterium* sp. this was only true under high CO_2. Species or group-specific responses to the projected CO_2 rise, together with the concomitant effect on *E. huxleyi,* might impact the balance between the microbial loop and export of organic matter, with consequences for atmospheric carbon dioxide.

Key words: *Emiliania huxleyi*, CO_2, coccolithophores, phytoplankton-bacteria interactions, and changing ocean.

Assessing vulnerability of the U.S. Atlantic sea scallop fishery to ocean acidification and warming

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The U.S. Atlantic sea scallop (*Placopecten magellanicus)* fishery is valued at more than $500 million per year, making it the second highest valued fishery in the country and the largest wild scallop fishery in the world. While the fishery is currently considered to be well-managed, managers and industry stakeholders are concerned that changing ocean conditions driven by climate change will cause declines in scallop availability, harvest, and revenue. Subsurface scallop habitats in the Northeast and Mid-Atlantic already experience suboptimal temperature and carbonate chemistry conditions episodically. Regional ocean model projections indicate that conditions in the Gulf of Maine will begin to surpass suboptimal thresholds persistently by the year 2050. Based on a literature synthesis, we found that all sea scallop life stages are sensitive to OA and warming individually, but multi-stressor experiments have only been conducted for juveniles and suggest nonlinear interactive effects on energy allocation. Our assessment will combine life stage sensitivity scores with estimates of exposure to conditions exceeding stress thresholds based on regional models of ocean conditions, pelagic larval transport, and benthic adult distributions under present and future conditions. This novel combination of approaches will allow us to quantitatively relate changing ocean conditions to changes in the sea scallop population vulnerability. By including key variables like size structure and spatial distribution, our results will help identify vital life stages and areas that are candidates for future fishing zones. Furthermore, our methods and results will be presented to industry stakeholders at a series of workshops, and feedback from participants will be incorporated into our final recommendations to fishery managers.

Key words: multi-stressor, bivalve, management, synthesis

Response of Adult Krill to Global Change

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Changes in how energy transfers from phytoplankton through zooplankton can affect the structure of marine food webs in ways that alter their ability to support fish, seabird, and marine mammal populations. Pacific krill (*Euphausia pacifica*) is a key trophic link to the California Current Ecosystem, especially for many harvested fish species. Environmentally driven, short-terms declines in krill abundance have been linked with die offs of seabirds, salmon, and other krill-dependent species. We assessed the sensitivity of adult *E. pacifica* to ocean acidification, warming, and oxygen loss. The objective of this project is to inform how these three physical ocean changes may affect trophic transfer in the California Current Ecosystem in the future. We used a scenario approach to design this mesocosm experiment, and selected three condition sets: *current* approximated current conditions throughout the diel cycle, *marine heat wave* had the same pH and oxygen as *current* at 2^{o}C warmer temperature, and *future* had 2^{o}C warmer temperature, a 0.15 unit decrease in pH, and a 1mg O_2/L decrease in oxygen content compared to the *current* treatment. We conducted the experiment at the end of the summer 2019, when local waters in Puget Sound, Washington, USA are stratified. We used an experimental system at the NOAA Northwest Fisheries Science Center that controls pH, oxygen, and temperature dynamically. Krill were allowed to acclimate to the laboratory for 10 days, and the experiment lasted an additional 7 weeks. We will present results on survival, respiration rate, and lipid content. Information from this project could be used for single-species and ecosystem-based modeling and management efforts, assessments of the vulnerability of North Pacific communities to ocean acidification and climate change, and interpretation of patterns in krill population abundance.

Key words: krill, survival, multi-stressor, ocean acidification, thermal stress, deoxygenation

Comparison of the environmental tolerance of different populations of *MYTILUS CHILENSIS* seeds against different environmental gradients of temperature, salinity and pH/pCO$_2$

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The increase in aquaculture activity requires interdisciplinary work to improve the manage adaptation strategies against the effects of Climate Change. Although there are studies related to the response of organisms to some environmental variable, there are no studies describing the response of different populations to different environmental variables (temperature, salinity and pH/pCO$_2$). We use time series data collected by autonomous sensors in a variety of ecosystems, ranging from fjord to coastal sea, of three important sites for the capture of *Mytilus chilensis* seeds (Caleta El Manzano - Hualaihué, Reloncaví Fjord and Reloncavi Sound) to expose them to the experimental conditions of five pH, five temperatures and five salinities for 24 hours and evaluate through performance curves rates of physiological importance such as respiration and clearance, and attributes of importance to the industry such as mortality and survival of the seeds.

After comparing the results between the sites, it is evident that populations of *M. chilensis* seedlings that have lived throughout their juvenile development stage in geographical areas with greater variability, present performance curves with a wider physiological range of different environmental conditions such as temperature, salinity and pH/pCO$_2$, constituting seed populations physiologically more tolerant to current and future scenarios, mainly acidification and warming.

Key words: climate change, marine invertebrates, performance curve, *Mytilus chilensis*

Short-term pH Variability by Seagrass meadows: A hidden cost in marine calcifiers in future OA conditions

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Seagrass stores large amounts of dissolved inorganic carbon, which could play a key role to mitigate the impacts of ocean acidification (OA). This ecosystem comprises high variability in pCO2/pH as result of photosynthetic activity and respiration rate over the day/night cycle, and that can modulate the response of marine species. However, it is still critical to understand how ocean acidification can modify this short-temporal variability (intensity) of the carbonate chemistry, and thus the magnitude of buffering capacity driven by seagrass. We measured for 2 weeks the diel carbonate chemistry variability driven by the seagrass *Zostera marina* in flow through mesocosms fed with seawater under 4 different pCO_2 treatments, and we evaluate the biological responses (growth and net calcification) of sea urchin larvae imposed by pCO2/pH variability. As predicted, high variability in the carbonate system was observed with low pCO_2 during the day and high pCO_2 during the night (ΔpH= 0.4, Δ ΩAr=0.6, and ΔO_2=3 mg/l). The results also suggested that net calcification of sea-urchin larvae is modulated throughout day/night cycle (high net calcification during day). Consequences of this short-term natural variability, and thus the role of seagrass as ocean acidification refugia for marine calcifiers will be discussed.

Key words: Ocean acidification, Variability, Seagrass, Buffering capacity, Larvae

The role of an INTENSE DIATOM BLOOM on the local OCEAN CO_2 UPTAKE along the northern Antarctic Peninsula.

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Diatoms are considered the main base of the Southern Ocean food web as they are responsible for more than 85% of its annual primary production and play a crucial role in the Antarctic trophic structure and in the biogeochemical cycles. Within this context, an intense diatom bloom reaching >45 mg m^{-3} of chlorophyll *a* was registered in the northern Antarctic Peninsula (NAP) during a late summer study in February 2016. Hydrographic data profiles and seawater discrete samples were collected using a combined Sea-Bird CTD/Carrousel 911+system® equipped with 24 five-litre Niskin bottles. The phytoplankton data was measured through HPLC-CHEMTAX. Given that nutrient concentrations and grazing activities were not identified here as limiting factors on the bloom development. The aim of this study was to evaluate the effect of water column structure (stability and upper mixed layer depth) on the phytoplankton biomass and consequences of it on the carbon dioxide uptake in the NAP. The diatom bloom, mainly composed by the large centric *Odontella weissflogii* (mostly >70 µm in length), was associated with a local ocean carbon dioxide uptake that reached values greater than –60 mmol m^{-2} day^{-1}. We hypothesize that the presence of a vertically large water column stability barrier, just below the pycnocline, was the main driver allowing for the development of the intense diatom bloom, particularly in the Gerlache Strait. Contrarily, a shift from diatoms to dinoflagellates (mainly Gymnodiniales <20µm) was observed associated with conditions of a highly stable thin layer. The results suggest that a large fraction of this intense diatom bloom is in fast sinking process due to water column structure, associated with low grazing pressure, showing a crucial role of diatoms for the efficiency of the biological carbon pump in this region.

Key words: Southern Ocean, phytoplankton, diatoms, carbon dioxide uptake, water column stability.

OCEAN ACIDIFICATION impact on calcifier SERPULID POLYCHAETES: Adult stage and Reared offspring

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Anthropogenic carbon dioxide emissions are modifying seawater chemistry through a process known as ocean acidification, which can negatively affect calcification in marine invertebrates. Serpulid polychaetes are benthic annelids distributed worldwide, they produce calcareous tubes composed of aragonite, calcite or high Mg-calcite that make them vulnerable to acidified conditions.

The objectives of this study were to examine the effect of ocean acidification on the growth of tubes of *Spirobranchus triqueter* and *Spirorbis* sp., and to test for effects on offspring development of *S. triqueter*. Organisms were collected from the Bay of Villefranche, NW Mediterranean Sea and maintained for 30 and 90 days at three pH_T (total scale) levels: 8.1 (control), 7.7 and 7.4 Offspring were reared in the same pH conditions the parents experienced.

Results indicate *Spirorbis* sp. tube elongation was affected by pH. Tube growth was reduced at the two lower pH levels and tubes grown at the lowest pH were thinner and broke more easily. Tube growth of the parental generation of *S. triqueter* was also affected by low pH conditions: at 36 d and 90 d, animals maintained at ambient pH had the fastest rates of tube growth 0.23 ± 0.02 ($\pm$ SE) mm d-1 over 36 d. *S triqueter* exposed to to pH 7.7 and 7.4 presented significantly reduced tube growth compared to individuals grown at pH 8.1. At 90 d, animals exhibited further reduced growth rates. Lowered pH conditions negatively affected larval (trochophore) density and growth but, most competent larvae from the 3 pH treatments settled (89 to 93%). At 38 d after settlement, juvenile tubes at pH_T of 7.7 and 7.4 were half the size of those at pH_T 8.1. Fracture toughness was greatest for tubes maintained at the intermediate pH level 7.7. The lowered pH appeared to alter tube integrity in both species. Reduced tube growth and the lower number of trochophores produced at the lowered pH conditions are likely to affect serpulid recruitment.

Key words: Ocean acidification, benthos, polychaetes, calcification, larvae

Effects of interacting climate change stressors on polyps of two scyphozoan jellyfish: Cotylorhiza tuberculata and Rhizostoma luteum

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Ocean acidification and warming caused by the increasing CO_2 concentrations in the atmosphere are challenging marine organisms and ecosystems around the world. The effects of climate change drivers of impact have been well studied on calcifying organisms due to the direct effects of acidification on carbonate chemistry. However, little is still known about the synergic effects of seawater acidification and warming on non-calcifying animals, such as jellyfish, and particularly on their early life stages. Here, we examined the concurrent effects of decreased pH and elevated temperature predicted for the end of the century on the survival, asexual reproduction, ephyrae generation and statolith formation of the polyps of two scyphozoans jellyfish occurring in two different oceanic areas: *Cotylorhiza tuberculata* (Mediterranean Sea) and *Rhizostoma luteum* (Atlantic Ocean). Two experiments mimicking the current and predicted future winter (Experiment 1) and summer (Experiment 2) conditions were conducted considering three temperature levels (winter 18ºC, current summer 24ºC and, future summer 30ºC) and two pH levels (current (~8.0) and future (~7.7)). Polyps of both species survived the future winter and summer conditions (36 days each) but rates of asexual reproduction were significantly higher in C. tuberculata, especially at lower winter temperatures and summer temperatures increased polyp mortality. Our results show that C. tuberculata and R. luteum polyps could cope with concurrent warming and acidification. However, the wider tolerance limits and elevated rates of asexual reproduction of the Mediterranean jellyfish suggest that this species is likely to thrive in a future scenario, whereas the occurrence of the oceanic species will be reduced.

Key words: asexual reproduction, survival, ocean acidification, Scyphopolyps, warming

Lessons from Spiny Lobsters: Multi-stressors and pH Variability in OA Laboratory Experiments with Two *Panulirus interruptus* Life Stages

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Increasingly, it is recognized that the single-stressor, stable ocean acidification-like conditions oftentimes employed in laboratory studies do not comport with the realistic changes marine organisms are likely to face in the next century. The California spiny lobster *Panulirus interruptus* has a complex life cycle, consisting of pelagic larvae that spend up to 9 months offshore and benthic juveniles/adults that inhabit kelp forests with dynamic carbonate chemistry. In two experiments, we exposed larvae to ocean warming and acidification-like conditions and juveniles to fluctuating pH conditions. In the first experiment, we studied the survival and development of newly-hatched larvae exposed to ambient pH and T (mean±sd: 8.05±0.04, 18.5±0.6 °C), increased T (8.05±0.04, 22.2±0.6 °C), reduced pH (7.66±0.02, 18.4±0.6 °C), and combined (7.67±0.04, 22.4±0.5 °C) conditions. After 5 weeks, there were no differences in survival among treatments. Yet, by this time, 100% of larvae in both increased T treatments reached Stage III of XI, whereas just 0-4% reached this stage in the ambient and reduced pH treatments. These findings indicate that increased temperature, but not reduced pH, affects the developmental rate of early-stage larvae, with warming oceans potentially reducing larval duration and bolstering settlement. In the second experiment, we exposed juveniles to three months of reduced pH conditions with three levels of daily pH variation (mean±variation: ambient/stable, 7.97±0.01; reduced/stable, 7.67±0.01; reduced with low fluctuations, 7.67±0.05; reduced with high fluctuations, 7.67±0.10) and studied the exoskeletal mineralization and material properties. Notably, the carapace was less mineralized in reduced, fluctuating pH treatments but without an effect on material properties, while the rostral horn had lower hardness in reduced/high fluctuating conditions yet no corresponding difference in mineralization. Here, diurnal pH variability significantly modulated responses. Together, these experiments underline the importance of multi-factorial studies and mimicking environmental variability to further our understanding of potential future organismal responses.

Key words: ocean warming, calcification, crustacean, fluctuations

Acidification and High Temperature Impacts Energetics and Shell Production of the Edible Clam *Ameghinomya antiqua*

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Warming and ocean acidification are currently critical global change drivers for marine ecosystems due to their complex and irreversible effects on the ecology and evolution of marine communities. Changes in the chemistry and the temperature of the ocean impact the biological performance of marine invertebrates by affecting their energy budget and thus imposing energetic restrictions and trade-offs on their survival, growth, calcification, reproduction, and phenology. In this study, we evaluated the interplaying effects of acidification and temperature on the economically relevant clam *Ameghinomya antiqua*, a species inhabiting a wide distributional range along the coast of Perú and Chile. Juvenile clams were exposed to a 90-days experimental mesocosm emulating the current and a possible future scenario for both acidification and temperature projected for the coast of south Chile. Clams showed physiological plasticity to different environmental scenarios with no mortality registered in any experimental condition. Nevertheless, our results show that the high energetic requirement of this species in acidic conditions was not achieved when the environmental temperature impose high energetic costs to the organism maintenance, consequently showing metabolic depression. Indeed, although the decalcification rate was significantly higher in the acidification scenario regardless of the temperature, only in the warmer condition the growth rate was negative during the experimental period. These results indicate a useful strategy to face environmental change for short-term periods modifying energetic allocation on maintenance and growth processes, but with probable long-term population costs, endangering an important benthic artisanal fisheries resource.

Key words: *Ameghinomya antiqua*, energetics, shell production, metabolic depression.

Ocean Acidification Induces Distinct Metabolic Responses in Subtropical Zooplankton Under Oligotrophic Conditions and After Simulated Upwelling

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Ocean acidification (OA) is one of the most critical anthropogenic threats to marine ecosystems. While significant ecological responses of plankton communities to OA have been revealed mainly by small-scale laboratory approaches, the interactive effect of OA-related changes on zooplankton metabolism and their biogeochemical implications in the natural environment still remains less well understood. Here, we explore the responses of zooplankton respiration and ammonium excretion, two key processes in the nutrient cycling, to high $p\mathrm{CO_2}$ levels in a 9-week *in situ* mesocosm experiment conducted during the autumn oligotrophic season in the subtropical northeast Atlantic. By simulating an upwelling event halfway through the study, we further evaluated the combined effects of OA and nutrient availability on the physiology of micro-and mesozooplankton. OA conditions generally resulted in a reduction in the biomass-specific metabolic and enzymatic rates, particularly in the mesozooplankton community. The situation reversed after the nutrientrich deep-water addition, which initially promoted a diatom bloom and increased heterotrophic activities in all mesocosms. Under high $p\mathrm{CO_2}$ conditions (>800 atm), however, the nutrient fertilization triggered the proliferation of the harmful alga *Vicicitus globosus*, with important consequences for the metabolic performance of the two zooplankton size classes. Here, the zooplankton contribution to the remineralization of organic matter and nitrogen regeneration dropped by 30% and 24%, respectively, during the oligotrophic period, and by 40% and 70% during simulated upwelling. Overall, our results indicate a potential reduction in the biogeochemical role of zooplankton under future ocean conditions, with more evident effects on the large mesozooplankton and during high productivity events.

Key words: Ocean acidification, Mesocosms, Physiological effects, Oligotrophic waters.

The impact of Ocean Acidification on respiration and growth of hybrid abalones (Haliotis rufescens x Haliotis fulgens).

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As a consequence of anthropogenic activities CO_2 has increased in the atmosphere, a third of this CO_2 is absorbed by the oceans causing ocean acidification (Zeebe et al., 2008). Ocean acidification (OA) threatens diverse marine species but particularly calcifiers and mollusks are major producers of $CaCO_3$ in marine ecosystems. Marine shelled mollusks are economically and ecologically important species in Baja California, Mexico. In the aquaculture sector there is concern about the possible impacts of ocean acidification. An experiment was designed to evaluate the effect of OA in a gasteropod mollusk.

The aim of this study was to analyze the effect of ocean acidification on growth, oxygen consumption of a key local species, the gasteropod hybrid abalone (Haliotis rufescens –Haliotis fulgens) during a two months' exposure to two acidified conditions: pH 7.5 and 7.8, and Control 8.2. The pH was controlled using Aquamedic computers, CO_2 was bubbled to the header tanks in order to maintain the desired pH values. Each week samples for DIC (dissolved inorganic carbon) and TA (total alkalinity) were taken. Three head tanks per pH condition with triplicates with 30 aquarium approximately 300 abalones. 23 abalones into each tank. Animals were fed 2-3 times/week with a mixed diet of Macrocystis pyrifera, Ulva lactuca and Gracilaria sp, Chondracanthus sp.

We measured growth per 8 weeks, in the pH 8.2 had an increment of 0.205 gr, pH 7.8 (0.257), and 7.5 (0.007) we observed the acidification effect. Also the metabolism was affected, during the 4 and 8 weeks of exposition to the three pHs we had not find a significant difference. Hybrid abalone support 7.8 and 7.5 pHs concentration without a significant increments of metabolism but the growth in the 7.5 was very slow, Kruskal-Wallis One Way Analysis of Variance on Ranks ($P = 0.141$).

Key words: Hybrid abalone, acidification, oxygen consumption, growth

Physiological response of *Imantonia sp.* to the synergic effect of low pH / low O_2

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The sustained increase in atmospheric CO_2 levels has impacted the global climate system and the carbon chemistry of the ocean. One of the effects of the increasing oceanic CO_2 is the decrease in seawater pH, a process well-known as ocean acidification. Moreover, increasing atmospheric CO_2 levels has caused an increase in ocean temperature known as ocean warming, which is considered the principal cause of marine oxygen (O_2) loss or deoxygenation. Oxygen minimum zones (OMZs) are a natural phenomenon, environments that present naturally low pH / low O_2 concentrations. Research suggests that these low-oxygen regions are expanding, get shallower and therefore exposing surface phytoplankton communities to low pH/low O_2 conditions. In the present study, we evaluate the synergistic effect of low pH/low O_2 conditions on a phytoplankton strain isolated from the Eastern Tropical South Pacific OMZ*, Imantonia sp*. The experimental setup considered a 6-days incubation microcosm experience. Our results showed that upon control conditions (pH = 8.1; dissolved O_2 = saturation), *Imantonia sp*. it grew every day sampled, generating supersaturated O_2 levels and an increase in pH values due to intense photosynthesis. Under experimental OMZ conditions (pH = 7.5; dissolved O_2 = 55.6 uM), pH and O_2 values, remained constant at all the times sampled, indicating that there was no production of O_2, nor consumption of CO_2. These results, together with the decrease until cero in the values of in vivo relative fluorescence, indicated that *Imantonia sp.* could not survive to the combination of these stressors. Future experiments with a greater number of strains could help to better evaluate the behavior of different important phytoplankton functional groups in the ocean, explaining their vertical niches in the water column of OMZ zones.

Key words: ocean acidification, deoxigenation, OMZ, phytoplankton, microcosm.

The potential effects of increasing Ocean Acidification on juvenile *Crassostrea gigas*

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Increasing ocean acidification affects calcifying fauna, including economically important species, such as the oyster *Crassostrea gigas*. This study investigates the potential effects of low pH conditions in the development of juvenile oysters cultivated in Costa Rica. The experimental set up consisted of nine 10L aquarium filled at half capacity with artificial seawater, kept at room temperature (23ºC) with natural light cycles. Eleven oysters were placed in each aquarium on top of mesh trays and feed daily with the same concentration of *Isochrysis galbana*. All aquariums were constantly bubbled with air and water flow was kept with small water pumps; 50% water was replaced twice a week. pH-stat system bubbled CO_2 into eight aquariums to achieve a pH gradient with delta values ranging from 0.0 to 0.8 (target=high pH - delta pH), target value was adjusted twice a week. This pH gradient seeks to find threshold values for development and growth patterns associated with a specific pH value. The experiment lasted three weeks (30Nov-19Dec 2019), and weight, shell length and width were measured regularly as well as total alkalinity and nutrients.

Growing patterns could not be associated with specific pH values. Preliminary results indicate a tendency of the juvenile *C.gigas* to favour axial growth over longitudinal growth. This was seen in all individuals regardless of pH treatment. The proportion of length/width growth showed small pattern differences throughout the pH gradient, but these were difficult to perceive. This points to the conclusion that a longer exposition time may be established to observe more differentiated growing patterns. All the juvenile gained weight, independently of the pH and this could be reflected on the mantle or the shell, but further analyses are needed in order to elucidate what is the energy investment and how it diverges according to the water acidity level.

Key words: pH gradient, controlled conditions, oyster development, commercial species, Costa Rica

Effects of low-pH on the Spotted rose snapper (*Lutjanus guttatus*) under aquaculture conditions

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The Pacific coast of Costa Rica holds a large number of fishing communities and most of them are located in the Gulf of Nicoya, one of the most exploited estuaries in the region of Central America. Small-scale aquaculture has gained importance in Costa Rica, representing an important economic activity that contributes to reduce the fishing pressure on natural populations and also contributes to the socio-economical growth of coastal communities. Main aquaculture in Costa Rica has been developed in inland waters but there are some efforts to farm marine species, such as the "Spotted rose snapper" (*Lutjanus guttatus*). However, there is a lack of knowledge regarding the potential impact of near-future ocean acidification in these aquaculture projects. This research project stands as the first study to evaluate the impact of low-pH conditions on a specie with local commercial value. A long-term (8-months) experiment is being performed since March 14th 2022 at the facilities of the Parque Marino del Pacífico, to test the biological response of the fish *L. guttatus* when exposed to three different scenarios: present local conditions and two low-pH scenarios relevant in the context of ocean acidification. Carbonate chemistry is being measured on a regular basis, along mortality and growth. Additionally, nutritional content and metabolomic analyses will be carried out in coming months, and a sensory evaluation test at the end of the experiment. These end-points seek to evaluate the impact of low-pH conditions on both, the production process and the commercial quality of the final products. The results from this research would benefit local seafood producers, as they can be considered within the adaptation strategies for future local aquaculture projects.

Key words: aquaculture, experimentation, local seafood, food security

PRELIMINARY STUDY OF OCEAN ACIDIFICATION EFFECTS ON CHANGE OF BIOACUMULATION OF ^{137}Cs by *Babilonia spirata*

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This study aims to determine the effect of ocean acidification concentrations on the bioaccumulation of ^{137}Cs by *Babilonia spirata*. The snail are collected from the Tanjung Pasir, Tanggerang, Banten Indonesia. Experiments were carried out using a simple single compartment model. Experiments were conducted in a controlled aquaria system between pH and CO_2 injection. During the experiment CO_2 was injected into sea water to simulate the process of ocean acidification. The simple one compartment biokinetic were used this study. The accumulated ^{137}Cs were analyzed using gamma spectrometer. These results suggested that the bioaccumulation^{137}Cs by *Babilonia spirata* may change according to decreasing of the pH.

Key words: Ocean acidification, bioaccumulation, ^{137}Cs, *Babilonia spirata*

The Impact of Climate Change on Metabolism, Hatching Success, and Viability of Lingcod Eggs (*Ophiodon elongatus*) in the California Current System

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Early life history stages are often more susceptible to physical stressors than the adult stage; however, there is little research on the sensitivity of early life stages to climate change. It is important to understand both the lethal and sublethal effects of shifting conditions for multiple life history stages to gain a full understanding of how a species may be impacted by a changing climate. Lingcod (*Ophiodon elongates*) is a commercially and recreationally important fish species in the California Current Ecosystem and one of the few species that lays benthic egg masses in the upwelling system. I determined how lingcod's earliest life history stage may be effected by climate change by collecting egg masses in the field and placing them in a flow-through experimental mesocosm that exposed the eggs to pH, temperature, and dissolved oxygen (DO) levels that are projected by 2050 and 2100 in the Central California Current. Throughout the month-long experiment, I measured the differences in metabolism, hatching success, and larval quality between treatments. This was the first mesocosm experiment that examined the impact of multiple stressors that co-vary for groundfish benthic egg masses in the eastern Pacific Ocean. Hatching success decreased between the current condition (7.85 pH units, 13^{o}C; ~270 µmol/kg DO) and 2050 condition treatment (7.7 pH units; 14.5^{o}C; ~210 µmol/kg DO). There was a more drastic decline in both hatching success and larval quality between year 2050 treatment and year 2100 treatment (7.5 pH units; 16^{o}C; ~150 µmol/kg DO), indicating there may be a tipping point in groundfish egg masses' ability to withstand shifting conditions.

Multigenerational Adaptation of Marine Biota to Ocean Warming and Ocean Acidification

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Future oceanic chemistry changes are expected to pose severe impairments to marine biota, by directly affecting their ability to regulate acid-base balance, metabolism and physiology, and through indirect effects over processes of which growth and reproduction depend upon. Concomitantly, ocean warming related events could drive to unexpected outcomes in terms of species survival, abundance and distribution, besides ecosystems structure. In this context, the combination of ocean warming and ocean acidification could dictate deleterious effects over marine biota. In a future warm and acidified ocean, marine species might be able to maintain their fitness through acclimation or adaptation processes. In this sense, the potential for species adaptive evolution towards environmental changes may represent a critical mechanism which could alleviate some of the negative consequences expected with climate change. However, projecting how climate change drivers or stressors will impair marine life, will require empyrical based knowledge on how these changes will affect organisms acclimation and how populations will respond by means of adaptive evolution. The aim of the ASCEND project is to explore the potential for adaptive evolution of marine species (the ascidian *Ciona intestinalis* and the gamarid *Gammarus locusta*), in response to climate change-related variables of ocean warming and ocean acidification, entailing a comprehensive examination of key biological responses under a developmental, physiological, genetic and neurobiological perspective. We additionally propose to develop a conceptual model of organism adaptation to marine climate change, ultimately helping to predict the impact of human activities (carbon dioxide emissions) in the oceans of tomorrow.

Key words: *Ciona intestinalis*, *Gammarus locusta*, Adaptive evolution, Climate Change,

Theme C: Ecological effects of ocean acidification and stressors in a changing ocean

Modeling the Effect of Ocean Acidification on *Crassostrea virginica* in Chesapeake Bay

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The Eastern oyster *Crassostrea virginica* provides invaluable ecosystem services to the Chesapeake Bay. Oyster harvest is also an engine of economic activity and a historic component of regional social identity for Virginia's coastal communities. Negative impacts of ocean acidification (OA) to *Crassostrea virginica* in Chesapeake Bay pose a looming challenge for Virginia's oyster restoration and aquaculture industries. To better predict future challenges, we updated *EcoOyster*, an existing model of oyster growth embedded within an ecosystem model, to account for the effect of carbonate chemistry on the calcification, respiration, filtration, and total dissolved nitrogen and phosphorus excretion rates of *C. virginica*. Using data from a review of existing literature supplemented by the results of a seven-week culture experiment that simulated current and future pH, we determined that of the aforementioned physiological rates only calcification was significantly affected by pH; therefore, it was the only pH-influenced function we parameterized and added to the model. Our experimental data suggests a potential threshold Ω calcite of 0.86 and 1.15 for 6-month-old and 2-year-old *C. virginica*, respectively. We are running the adapted *EcoOyster* model under a range of pH and associated environmental conditions, like temperature, salinity, dissolved oxygen concentration, and total suspended solids concentration, to simulate the effect of OA, alone and in combination with co-stressors, on oyster calcification and growth. This abstract complements that of Brush et al., wherein the revised oyster model is run using high frequency time series observations at sites around Chesapeake Bay. The model will ultimately be coupled with the seagrass bio-optical model *GrassLight*, in order to investigate the potential for seagrass metabolism to mitigate the negative impacts of OA on oysters.

Key words: Eastern oyster, bioenergetics model, ocean acidification, Chesapeake Bay

Planktic calcifiers in an acidifying ocean: seasonal abundances and carbon contribution in the northern Barents Sea (Arctic Ocean)

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The impact of ocean acidification has been studied in different planktic marine calcifiers, such as planktic foraminifera, shelled pteropods and coccolithophores. These organisms are considered major contributors to the organic and inorganic carbon flux to the sea floor, by mainly exporting calcium carbonate from the surface to the deep oceans when they die.

The combined effect of increasing surface water temperatures and sea-ice melting in the Barents Sea makes it crucial to obtain a better understanding of the impact of changes in ocean chemistry and climate on the faunas and their calcification to foresee future changes. The aim of the present study is to assess the seasonality in the carbon flux of these marine planktic calcifiers in the northern Barents Sea, collected in August and December 2019, and March, May and July 2021. Seven stations were repeatedly sampled along a latitudinal transect covering different oceanic regimes: both Atlantic and Arctic environments as well as shelf, slope, and basin. This study represents the first unique quantification of organic and inorganic carbon fluxes from pteropods and foraminifera in this area. The carbon flux was estimated by measuring the protein-biomass of their cells in relation to the size of their calcareous shells. Meanwhile, the carbon flux from coccolithophores was assessed through characterizing their absolute abundance and analysing the calcium concentration on polycarbonate filters. We found the highest abundances and fluxes in August 2019 along the shelf stations. In contrast, we found the lowest in March 2021, together with low abundances and sizes. Due to the remoteness and the lack of knowledge on the seasonal changes in the northern Barents Sea, these original data sheds light on the actual state of these organisms and explore the effects that ocean acidification can have on their contribution to the carbon cycle in the northern Barents Sea.

Key words: carbon fluxes, organic carbon, inorganic carbon ocean acidification.

Phytoplankton Groups Strengthening the CO_2 Uptake in the South Atlantic Ocean

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The influence of the phytoplankton groups on carbon dynamics was investigated in the surface waters of the South Atlantic Ocean (between 20°S to 35°S) in 7 occasions during spring and summer of 2009 and 2011 and in a particular study involving the Agulhas rings crossing the South Atlantic in June/July 2015 (winter) making a total of 311 sampling stations. Measurements of sea surface temperature, salinity, partial pressure of CO_2 in the ocean and the atmosphere, chlorophyll *a* and other phytoplankton pigments data (GOAL dataset) were gathered. These measurements allowed us to calculate the CO_2 net fluxes for each cruise characterizing the region regarding its ability to act as an atmospheric CO_2 sink. By using HPLC/CHEMTAX approach we determined and quantified phytoplankton chemotaxonomic groups. Based on the prevailing role of physical forcing (temperature, salinity) as a regulator of phytoplankton distribution, sampling stations were grouped into three biogeochemical provinces: Brazil, South Atlantic gyre and Africa, corresponding to the western, central and eastern basins of the South Atlantic Ocean, respectively. Our results showed significant variations in both latitudinal and longitudinal patterns of algal groups and CO_2 uptake. Diatoms and haptophytes were dominant in the coastal regions of Brazil and Africa, the open ocean was comprised mostly by haptophytes but also by *Prochlorococcus* and *Synechoccocus*. The uptake capacity increased eastwards from –7.1 mmol CO_2 m^{-2} d^{-1} in the Brazilian coast to –27.6 mmol CO_2 m^{-2} d^{-1} in the African coast. A significant relationship ($p<0.0005$) was found between phytoplankton biomass (TChl *a*) and the sea-air pCO_2 difference (ΔpCO_2), with increasing of CO_2 uptake coinciding with increasing of biomass of certain groups. Finally, we indicated the phytoplankton groups that had the greatest influence on the magnitude of carbon sequestration and encourage further investigations of their vulnerabilities to future environmental change scenarios.

Key words: carbon cycle, carbon dioxide fluxes, phytoplankton pigments, HPLC, biogeochemical provinces.

Effects of ocean acidification on the metabolic rates of Arctic calanoid copepods

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Anthropogenic stressors such as ocean acidification (OA) and ocean warming (OW) are negatively impacting marine ecosystems all over the world. Arctic ecosystems are most sensitive to these stressors: some of the fastest rates of acidification have been reported in the Arctic, warming is happening at faster rates in the Arctic than elsewhere, and the volume of sea ice is declining from year to year. These negative impacts are being exacerbated by other stressors already present in coastal ecosystems, such as pollution or freshening. Future predictions indicate that Arctic regions are expected to experience the strongest and most rapid OA and OW of all global seas and it is therefore urgent to understand how Arctic ecosystems will respond to these changes.

Calanoid copepods of the genus *Calanus* are key species in the Arctic food web and constitute up to 90% of the zooplankton biomass in Arctic shelf regions. Thus, changes in abundances or distributions of these organisms could have profound consequences for the Arctic marine food web.

This project aims at shedding light on the physiological responses of calanoid copepods when presented with environmental stressors (such as OA, alone or in combination with other stressors) at levels projected for the near future in the Arctic region. In order to assess these responses, we evaluated changes in metabolic rates, as a proxy for metabolic activity, together with changes in metabolites in *Calanus* individuals (females, copepodites and nauplii larvae) collected in the Arctic Basin during the *Nansen Legacy* cruises in 2021. Preliminary observations indicate elevated metabolic rates in nauplii larvae when exposed to OA in combination with elevated temperatures (+3°C), but not when exposed to OA alone.

The results of this investigation will advance our understanding of responses in natural populations of Arctic calanoid copepods when subjected to changing environmental stressors.

Key words: respiration rate, warming, zooplankton, polar regions

Theme D: Insights from natural ocean acidification analogues

Short-term variability of surface water pH in the Patos Lagoon Estuary

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Human activities have caused an exponential increase in atmospheric CO_2 concentrations, resulting in potential changes in natural marine systems. However, coastal ecosystems interact with other environmental processes, resulting in a much more complex spatiotemporal pH variability, with changes ranging from –0.023 to 0.023 pH units per year, as documented in past studies. This study investigated the dominant processes driven the pH variability at short-time scales in an inner region of the Patos Lagoon estuary, south Brazil. Surface water temperature, salinity, dissolved oxygen (DO), pH and fluorescence were hourly measured by sensors coupled in a moored buoy placed in a shallow area of the estuary (< 5 m). The pH sensor used was SeaFET™ and worked from April 2016 to June 2018. Data obtained by SeaFET™ was corrected from measured pH obtained in situ and potentiometrically determined from discrete surface water samples. The model established to correct the pH data has a coefficient of a determination of 0.94 with root-mean-square-error of 0.38 pH units. DO and temperature were the parameters that most resembled the diurnal pH cycle. In summer and part of autumn, the highest correlation factors between DO and pH were observed (r~0.7 and r~0.6, respectively). Moreover, the chlorophyll fluorescence also influenced the pH oscillation, especially in summer and spring (r~0.8 and r~0.7, respectively). The variability of the diurnal pH cycle presented similar pattern in all seasons, where the highest pH values occurred at night and the lowest pH values during the day. However, the drivers of pH varied over the seasons. During spring and summer, the effect of biological processes prevails to control the diurnal pH cycle oscillation. During autumn, the remineralization of organic matter together with abiotic processes stood out. In winter, the pH was less disturbed due to the attenuation of biological processes and lower water temperature.

Key words: diurnal cycle; coastal monitoring; estuarine biogeochemistry; carbonate chemistry.

Dynamics of the carbonate system in the shallow zone under the influence of both a river discharges and coastal upwelling off Chérrepe

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Studies suggest that ocean acidification has dramatic impacts on the carbonates system, especially on the coastal zone of the Pacific Ocean, where the dynamics of coastal upwelling and freshwater inlets are the main stressors affecting ocean pH as well as total alkalinity and pCO_2. The Ensenada of Chérrepe, Lambayeque, is characterized by the seasonal occurrence of coastal upwelling and fluvial discharge from the Chamán river in the southern part of it.

During 2018, water samples were obtained monthly in three shallow stations located in front of Chérrepe. The water pH and total alkalinity (TA), salinity, temperature and dissolved oxygen, were also determined. The pCO_2, Ω_{arag} and dissolved inorganic carbon (DIC) were obtained through the CO2SYS software.

The pH showed values lower than 8 during the summer, autumn-winter at site 1, and with greater variability than at the remaining sites throughout the year. pH values greater than 8 would be related to strong photosynthesis processes, while the range of pH values between 7 and 9 indicate the predominance of the bicarbonate ion. TA values were high (> 4495.954 $\mu mol.kg^{-1}$), and highly variable in the river discharge zone (site 3), especially during the summer and autumn, gradually decreasing towards the north (sites 2 and 1), until 2098.112 $\mu mol.kg^{-1}$. The DIC showed high values in the discharge zone during summer and autumn, while values less than 1800 $\mu mol.kg^{-1}$ were observed throughout the year at site 1. At site 1, Ω_{arag} values <2 were observed in summer and autumn, and > 3.45 in spring, while on site 3 values greater than 3 were observed in autumn. High values of TA observed at site 3 and to a lesser extent at site 2, indicate a high productivity associated with Chaman river discharges

Key words: carbonates, coastal upwelling, Chaman river, Chérrepe, Perú

First Investigation of the Carbonate System Parameters in the Patos Lagoon Estuary

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Estuaries, which have a surface area of only 4% of the continental shelf, generally exhibit a higher net water-air CO_2 flux than those observed over the surface ocean, for this reason we studied the carbonate system in the Patos Lagoon Estuary (PLE). From the use of several databases with a sparse/discontinuous distribution both temporally and spatially beginning in the 70s, Total Alkalinity (A_T) and Total Dissolved Inorganic Carbon (C_T) were reconstructed using the neural network, while the others were used to calculate the other parameters using the CO_2 SYS software. In general, the distribution of A_T followed the distribution of salinity and higher variation than that of C_T. The concentration of chlorophyll follows the seasonal cycle, with higher concentrations in the spring and summer months and lower for autumn and winter. Most pH values were below 7, indicating an acidic condition on the PLE waters. The concentration of partial pressure of CO_2 (pCO_2) were considered high in the studied period, only a few months showed equilibrium with the atmosphere. The PLE showed peaks of pCO_2 of up to 50,000 µatm. These values indicate that, to a large extent, these zones were major sources of CO_2 into the atmosphere at different intensities. Thus, these regions will influence carbon emissions into the atmosphere. The values found for the saturation state of calcite and aragonite (ΩCa and ΩAr, respectively) show that the environment is unsaturated in these two ions. A more acidic environment is less likely to have aragonite and calcite as it becomes more corrosive to such, since carbon uptake by the water decreases the pH, it brings some direct effects on marine organisms, making calcification hampered. This makes us believe that this estuary has been suffering long-term anthropogenic impacts over the years.

Key words: Estuary; Carbonate system; CO_2; Acidic.

pCO2 distribution in a tropical coastal lagoon adjacent to marine waters impacted by upwelling: antagonist effects of biological and thermal processes.

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Despite its modest surface area, the coastal ocean plays a fundamental role in marine carbon cycle, and global air-sea CO2 exchange. However, carbon dynamics in these regions still poorly documented, particularly in the tropics. We have studied the contribution of thermal effects, biological activity and gas exchange to the spatiotemporal variability of surface water pCO2 in a shallow coastal lagoon parallel to the coast, tidally connected to a marine region influenced by the Cabo Frio's upwelling (Brazil). Fieldwork took place in November 2019 and February 2020 and consisted in continuous in situ monitoring and discrete sampling inside the lagoon, at its mouth during 25 hours. Maximum water pCO_2 of 524 ppmv was observed at the mouth at high tide, with corresponding temperature of 16.2°C and a salinity of 34.2, attesting for the entrance of upwelling waters in the lagoon. At the same sampling point but at low tide, water pCO_2 was 194ppmv for temperature of 28.2°C and a salinity of 28.4, showing simultaneous warming, mixing with brackish waters, and biological uptake. Inside the lagoon, water pCO_2 progressively decreased down to 65 ppmv at the most internal station, at a salinity down to 16.9, a temperature of 30.0°C and a chlorophyll a concentration up to 52.2 µg L^{-1}. Our results show that biological activity inside the lagoon was able to: 1) absorb the excess CO_2 brought by the resurgence water; 2) absorb the additional excess CO_2 that comes from the heating of marine water masses; and, 3) absorb even more CO_2, generating regions of marked pCO_2 under-saturation and atmospheric CO_2 uptake in the less saline part, in contrast to the marine CO_2 source. We discuss quantitatively the significance of the thermodynamical and biological processes in the context of marine eutrophication of the region.

Key words: partial pressure of CO_2, upwelling, coastal Lagoon, eutrophication.

Intense biological, physicochemical, and meteorological controls on partial pressure of CO_2 and O_2 in Surface Waters of a Highly Eutrophic Tropical Bay (Guanabara Bay, Rio de Janeiro, Brazil)

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Eutrophication in coastal waters caused by nutrient inputs from the watershed has been considered one of most important effects of global change. Recent evidence has indicated the subsequent loss of water quality due to anthropogenic nutrient loading may also have profound implications to climate, as it could increase greenhouse gas emissions. Carbon dioxide (CO_2) is an essential metabolic gas involved in organic matter (OM) production *(e.g.*, photosynthesis) and decomposition (*e.g.*, respiration), which may show high daily and seasonal variability following changes in temperature, tide, nutrient availability, and rainfall. However, the controlling factors on metabolic gases in eutrophic estuaries are still not well understood. Based on this, we evaluated nictemeral and seasonal variability on the partial pressure of CO_2 (pCO_2) and O_2 (pO_2) in a beach of a tropical eutrophic bay (Guanabara Bay, Rio de Janeiro, Brazil). We monthly monitored gases between June of 2018 and January of 2020 in surface bay waters that receive large nutrient inputs from urban-industrial effluents resulting in high nutrient and OM concentrations. Surface waters (~25 cm depth) from Catalão beach were gently sampled over 24h using a continuous non-turbulent pump in closed system with a CO2 infrared gas analyzer (EGM-4® PPSystems) coupled to air equilibrator and a thermo-oximeter (YSI Pro ODO). As a result, high temporal variability in pCO_2 and pO_2 indicated inverse trends between both gases (*e.g.*, increases in CO_2 and decreases in O_2 overnight associated to the opposite trend over diurnal periods). Principal component analysis (PCA) showed different groups among months, in which pCO_2, salinity, and nitrate showed highest numbers in August of 2019, and pO_2, DOC, TOC, water and air temperature in December of 2019. PCA did not grouped data by hours. Our study demonstrates pCO_2 and pO_2 may show more intense biological, physicochemical, and meteorological controls over daily than monthly variability.

Key words: Greenhouse gases, Acidification, Hypoxia, Eutrophication

Glacial meltwater effects on carbonate chemistry, ocean CO_2 uptake, ocean acidification and drivers in Svalbard fjord water and sea ice

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Svalbard fjords on the west-Spitsbergen are influenced by Atlantic water in the outer parts and by glacial water and sea-ice processes in the inner parts. The fjords also have different characteristics depending on the sill depth, seasonal sea-ice coverage, and the presence of land-terminating glaciers and rivers. Here, we present the variability of the carbonate chemistry, ocean acidification (OA) state and freshwater influence in several Svalbard fjords, based on data collected at several seasons between 2012 and 2022. For the study, we used total alkalinity (AT), total dissolved inorganic carbon (DIC), pH, dissolved inorganic nutrients, salinity, temperature and calculated calcium carbonate saturation state (Ω) for aragonite and calcite. We also use freshwater fractions to investigate the seasonal and interannual variability and the biogeochemical processes driving the carbonate chemistry, Ω and air-sea CO_2 fluxes in the different fjords. Changes in the inflow of different water masses and freshwater directly influenced Ω, but also indirectly by affecting the biological drivers of the CO_2 system in the fjords. The seasonal variability showed the lowest Ω and pH values in winters coinciding with the highest freshwater fractions. The highest Ω and pH were found in fall, mostly due to CO_2 uptake during primary production. In Kongsfjorden, near the glacier front, glacial water decreased Ω by the same amount as the biological effect increased Ω. The seasonal increase in temperature only played a minor role on the increase of Ω. Overall, we found that increased freshwater supply decreased Ω, pH and AT. On the other hand, we observed higher AT relative to salinity in the freshwater end member in mild winters in Tempelfjorden, both in seawater and in sea ice. Observations of calcite and dolomite crystals in the glacial ice and sea ice suggested supply of carbonate-rich glacial drainage water to the fjord, partly mitigating ocean acidification.

Key words: Arctic fjords, tidewater glaciers, meltwater, calcium carbonate saturation, ocean acidification, sea ice

MAP OF NATURALLY ACIDIFIED PLACES IN THE WORLD

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Within the GMaRe Project in Galapagos and within the framework of the Master's Degree in Climate Change of the Escuela Superior Politécnica del Litoral (ESPOL), the oceanographic characterization of a place naturally acidified by volcanic activity was carried out, located in the Galapagos Islands to the north of the Isabela Island at Roca Redonda at position 0.26884, -91.62084. Within this context, in the search for bibliographic information it was possible to show that there is no map where all (at least those published) the leaks around the planet are presented. In order to have the seeps in a single document and be able to visualize them and later be able to build a geobase that allows us to monitor these places, which are considered natural laboratories and are of the utmost importance in order to understand how the naturally acidified ecosystems. The map was built by searching for information in documents about the leakers and placed in a geodatabase. The result of this search resulted in a map with 15 places for which there is published information and that has information on different topics.

The countries in which these places found were Iceland, Italy, Spain, Greece, Portugal, Japan, Taiwan, the Philippines, New Papua, New Zealand, USA, Mexico and Ecuador. The seeps that show the lowest pH values recorded according to what was published were the following: Spain (n = 5.1), Saint Vincent and the Grenadines (n = 6.8) and Ecuador – Roca Redonda, Galapagos (n = 6 .8). These values are below the oceanic average that is located, which is approximately 8.1. This is expected to be the beginning of the construction of a platform that allows access to data from all seeps in the world. This map has a format .gif and shapefile too, with SRC: WGS84.

Key words: Seeps, ocean acidification, pH.

Relationships between Eutrophication and Carbonate Chemistry in two subtropical estuarine canals with distinct levels of anthropic pressure (São Paulo, Brazil)

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Eutrophication has been shown to aggravate acidification in estuarine waters, in which the patterns of carbonate chemistry are highly driven by variable freshwater and nutrient inputs. We evaluated the carbonate chemistry in two estuarine canals with similar water circulation but under distinct levels of anthropic pressure. The Bertioga Canal (B-C), Santos Estuary, has received great N and P loads from sanitary sources over the last decades, whereas the Ararapira Canal (A-C), Cananéia estuary, is inserted in one of the estuaries most protected in Brazil. Under summer campaigns (February 2019), water column (temperature, salinity, oxygen, nutrients, chlorophylls, and carbonate parameters) and surface sediment (particle size, organic matter and carbonate percentages, and chemical elements by INAA) variables were gotten from five locals of the estuarine canals to verify links among eutrophication levels, carbonate system, and interface (sediment-water-air) dynamics. The B-C presented nitrogenous nutrient values up to 15 times higher than those found in the A-C. In the A-C, the fine sand predominance at sediments with low organic matter percentage reflected the higher tide dynamic observed in the water column (salinities 12.77-31.88) under higher pH (7.69-8.05) and ΩCa (1.0-3.2) values. Unlike, the water column of the B-C presented a higher freshwater influence (salinities 9.04-17.77), whereas the silt predominance associated with a higher organic matter percentage at sediments evidenced a higher interaction involving conservative elements (N, P, Fe, and Ca) with the carbonate system due to the hypoxic condition (dissolved oxygen < 2.0 mL L^{-1}) at bottom waters. Overall, the results indicated that the advanced eutrophication stage (heterotrophic metabolism) in the water column of the B-C presented a considerable influence on the high pCO_2 (936-2016 µatm) and lower pH values (6.85-7.40) that, in turn, increased the $CaCO_3$ dissolution potential (ΩCa<0.4), pointing out the nitrate reduction pathway as an exacerbating factor of alkalinity decreasing.

Key words: subtropical estuary; eutrophication; carbonate chemistry; interface dynamic.

Impact of upwelling crises on ocean acidification, Mediterranean Sea, Egypt

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Egyptian Mediterranean Coast is affected by seasonal Gyres and upwelling crises for both western area between ElSalloum and Elallameen and eastern area in front of Elarish. Carbonate Chemistry and corresponding carbon dioxide system parameters were studied in six cruses in different season during the period 2010-2021. Ocean acidification and anthropogenic carbon were also calculated with correspondence to preindustrial period. Upwelling areas showed highest oxygen and nutrient concentrations with highest carbon dioxide content. The recorded decrease in pH reached 0.18 and the highest anthropogenic carbon recorded during upwelling events.

Key words: Mediterranean Sea, Ocean acidification, Upwelling crises, anthropogenic carbon

Theme E: Ocean acidification and society

Impact of high CO_2 world on geochemical process in water of coastal regions in Bangladesh

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The increasing of anthropogenic emissions such as use of fossil fuel and automobiles, caused a result of CO_2 increase in the atmosphere. However, CO_2 enrichment in aquatic ecosystems would cause changes of pH, salinity and also changes on the mobility of certain trace elements. Climate change impacts on water resources are among the most important problems facing hydrologists today as water resource management systems have historically been designed under the assumption of climate stationarity. The impacts of carbonate chemistry change on trace metal contamination have been discussed qualitatively for marine/riverine ecosystems in literature. On the other hand, river water quality is important for environment and ecological sustainability. Therefore, objectives of the study are to evaluate the changes of trace elemental chemistry in water before and after monsoon in Noakhalikhal estuary near the Sandip channel region, which is a coastal area situated near the Bay-of-Bengal, Bangladesh. It should be mentioned here that there are many industries in the study area, and water of Sandip channel region is heavily used for irrigation, fishing, washing, aquaculture etc. Water samples were collected using Van Dorn water sampler from 8 sites in triplicate in pre-monsoon and in post-monsoon. This study revealed that mean metal concentrations of water samples in the present study area were decreased in the following trend: Cr > Zn > Cu > Pb > Cd respectively. The studied metals showed higher concentrations in respect of drinking water standard values of WHO. This study also revealed that degree of contamination for the studied metals in water samples of the study area was low to moderate. However, the studied heavy metal concentrations were significantly higher before the monsoon compared to the period after. It might be happened due to the reasons that H^+ ions concentrations were higher in pre-monsoon, which has influence on more solubility/mobility of metals from sediment into aquatic environment.

Key words*:* Coastal region, carbonate chemistry, trace element, water, ecosystems

Bivalve aquaculture in upwelling coastal zones: importance of monitoring pH and Oxygen.

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The climate-change-induced intensification of ocean upwelling in some eastern boundary systems, may lead to regional cooling rather than warming of surface waters and cause enhanced productivity, hypoxia and acidification. This will be exacerbated in coastal zones due to nutrient input from rivers, enhanced primary production and bacterial degradation of organic matter. All these stressors may affect the nearshore aquaculture productivity, specially for sessile organisms like bivalves, due to the high vulnerability of its early development stages to changes in normal ranges of pH and oxygen. Currently at the central zone of Chile, small bivalve aquaculture are developed and are therefore affected by intense seasonal upwelling. This farms can act as natural laboratories to study the effects of future expected conditions on this economic activity. For this we proposed to understand the natural variability of the oceanographic and carbonate system at one pilot aquaculture system and relate this variability to the timing of sensitive life history stages of bivalves and to local farming methods. A high frequency time serie was obtained for Temperature (T), salinity (S), oxygen (OD) and pH using autonomous sensors installed at the surface and bottom of bivalve aquaculture. In addition, manual sampling of alkalinity, nutrients and chlorophyll was carried out, for the estimation of the carbonate system parameters. Qualitative analysis methods were used to understand the productive cycle of the farm, such as field observations and semi-structured interviews. The results indicates a higher variability of T, OD and pH between October and April, reaching < 1 mg/L O2 and <7.4, that can last more than four days. We developed a proposal of biological/productive model for the aquaculture, associated with the environmental variability of the system, which indicates that the best month to place the seeds is December and this could be a good tool farmers decision making.

Key words: bivalve aquaculture, acidification, upelling, hypoxia

Theme F: Global to regional policy, actions, communication and capacity building for ocean acidification, e.g. research networks, communication, and outreach

REMARCO network: a look at the interaction between science and communication on addressing marine-coastal stressors

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The Marine - Coastal Stressors Research Network in Latin America and the Caribbean (REMARCO), was created in 2018 to establish institutional links between different countries in the region in four action lines: ocean acidification (OA), chemical and microplastic pollution, harmful algal blooms (HABs) and eutrophication.

REMARCO presents an organizational novelty: the interrelated work between scientists and communicators. For this purpose, the Network has a technical counterpart and a communicator in its 18 member countries.

Thus, there is an experience of collaborative and interdisciplinary work between scientists and communicators that contributes to making the work of the Network visible and positioning it, bringing information to the general public, decision-makers, the scientific community and other target audiences.

REMARCO currently has institutional communication pieces, a permanently updated website, a Communications Manual, monthly meetings, support for scientific presentations, a Facebook page and a YouTube channel.

In this sense, AO is the starting point for the synergy between scientists and communicators to develop: workshops to determine the key messages, press releases, videos about the stressor and work on specific dates such as the AO Day, with a massive and active dissemination in social networks.

As a conclusion, this model of work between communicators and scientists is a strength of REMARCO that demonstrates the importance of science communication in all scientific spaces to make our oceans visible as a source of life and raise awareness on relevant aspects such as AO. It also encourages the development of public policies related to the sustainability of marine-coastal environments, becoming as an example of communication management, which aims at the democratization of science taking into account the current scenarios of misinformation worldwide.

Key words: Interdisciplinary collaboration, science communication, research and communication network, marine and coastal stressors, ocean acidification

Ocean: an Interactive Exhibition Co-created among Scientists and Museum Professionals in Argentina

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Argentina has a coastline that is more than 6,000 km long and a marine platform that is twice its continental territory. However, the country is known for its agricultural activities both nationally and internationally. The Cultural Centre for Science (C3) is a public national science museum that depends on the Ministry of Science, Technology and Innovation. The C3 develops different science engagement programs using a STEAM education approach by carefully combining Science, Technology, Engineering, the Arts and Mathematics for stimulating visitors' inquiry, dialogue about science and critical thinking. Aligned with scientific policies, in 2021 the interactive exhibition "Ocean. Turning blue colour" was opened after close cooperation with marine scientists from along the country receiving 50,000 visitors to date.

The exhibition design process involved different methodologies: from visitor surveys that helped to understand their previous ideas about the ocean, to co-creation strategies with scientists that turned out to be fundamental to define the narrative of the exhibition. "Ocean" interconnects our lives with the ocean by focusing on current human activities; "Ocean" has people and human activities at its core. In order to do so, the exhibition brings together different scientific disciplines and technological developments around the ocean from a social perspective. Indeed, four topics guide the narrative: climate change, marine biodiversity, marine pollution and society. Installations that evoke personal experiences are identified as the most successful strategies since they bring up visitor conversations, memories and anecdotes. Among them, we find Patagonian Scallops, which are easily recognized by their shapes and known as traditional seafood, as a great example to show how ocean acidification affects marine biodiversity. (we performed artificial erosion with acetic acid). Observations and post-visit surveys reveal that students and families talk and reflect about their connections to the Argentinean Sea and bring back their own memories related to it.

Key words: science museum, ocean awareness, ocean literacy, interactive exhibition

Strengthening of the Argentine National Observing System for Ocean Acidification. Implementation of the Marine-Coastal Stressors Research Network in Latin American and the Caribbean (REMARCO) into the Pampa Azul Initiative

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Studies of ocean acidification should be approached from an integrative perspective between observations of the evolution of this stressor, together with the impacts that it could have on coastal-marine ecosystems and how they affect different ecosystem services. In this context, policies at the national level should be addressed and agreed upon by decision makers in order to implement observation and research systems that are sustained in the long term. Since the incorporation of Argentina in 2020 to the Regional Observatory of Ocean Acidification formed by 18 countries of Latin America and the Caribbean as part of the actions carried out by the Marine-Coastal Stressors Research Network, REMARCO, the implementation of the topic at national level is being worked on as one of the horizontal priority areas to be developed within the National Strategic Plan of Marine Sciences. Argentina has proposed the need to strengthen the capacities of the scientific-technological system to contribute to public policies related to the sea, which is implemented under the "Pampa Azul Initiative". That is, an inter-ministerial and inter-institutional program which, among other activities, promotes a systematic approach for the definition and implementation of a national observation system, that allows the development of a continuous monitoring of the conditions of the oceanic environment, including the coasts and transition zones. In this context, REMARCO is integrated into the Pampa Azul Initiative, in order to convey the OA studies in the country, allowing the transfer of training and capacity building of local researchers for the measurement of these variables received by the international network, to other institutions in Argentina, thus increasing national capacities to respond to SDG 14.3. In this way, through REMARCO Argentina, the permanent environmental monitoring stations of the carbonate system and pH in marine-coastal zones are increased, as well as the incorporation of data from the carbonate system from oceanographic vessel campaigns in the Continental Shelf that all will provide information on the indicator of SDG 14.3.1, as well as the basis for the implementation and integration with studies on key organisms of commercial importance and/or community structuring.

Key words: National OA Observing System, Pampa Azul, Science-Policy Interface, REMARCO

The State of Hawai‘i’s Ocean Acidification Action Plan

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Hawai‘i hosts some of the foremost data about changes to global water chemistry with specific focus ocean acidification parameters. The state of Hawai‘i joined the International Alliance to Combat Ocean Acidification in 2018, an organization dedicated to helping states and nations develop action plans, collaborate across regions and international networks, and collectively work on local and global implementation of planned actions. The State of Hawai‘i is dedicated to the development and implementation of a state-wide action plan that concentrated needed efforts to combat ocean acidification for our islands. The state of Hawai‘i, as part of the Pacific Islands, have different concerns for ocean acidification than many other US states, with our coral reefs particularly vulnerable. The state of Hawai‘i’s action plan has the following goals: 1) increasing scientific understanding (including formalization of a monitoring network), 2) reducing causes of ocean acidification (both CO_2 as well as land-based source of pollution for coastal acidification), 3) building adaptation and resilience (blue carbon ecosystems may be the solution, but will require collaboration) 4) public awareness, and 5) international collaboration. The State of Hawai‘i will have fully draft specific actions for each of these goals, and will be looking for collaborative ways to implement.

Key words: action plans, Pacific Islands, coral reefs, blue carbon, collaboration

Ocean Acidification Research Center: Increasing monitoring capacity

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The Ocean Acidification Research Center at the University of Alaska Fairbanks in the USA is an analytical laboratory dedicated to providing services to a wide variety of scientific objectives. Our primary goal is to conduct research to determine the intensity, duration, and extent of ocean acidification around Alaska. We observe conditions in the subarctic and Arctic by collecting seawater samples for laboratory analysis and using autonomous sensors from shoreside stations, moored platforms, and remotely operated vehicles. All data are submitted to public archives to incorporate in regional ecosystem studies, set experimental parameters that assess species-specific effects, validate biogeochemical models and forecasts, determine time of emergence, and calculate global carbon budgets. Findings from our data resources show the intrusion of anthropogenic CO_2 is one of several factors controlling seasonal carbonate mineral suppression and undersaturation in the Pacific-Arctic region with additional impacts from the biological pump, cryosphere-hydrological cycle, and sea ice. Our secondary goal is to operate a non-profit recharge facility that offers high-quality, competitively priced analytical services. The Ocean Acidification Research Center's laboratory equipment measures the total dissolved inorganic carbon and total alkalinity of discrete seawater samples and recently purchased instrumentation increased our capacity. We employ the knowledge and infrastructure to immediately assist new users and their projects such as those that monitor changing carbonate chemistry, determine organism response to change, and assess ecological effects of ocean acidification. Our ability to provide accurate and precise data for a wide variety of scientific objectives is a unique resource that may be utilized by scientific researchers, local communities, government agencies, educators, policy managers, and private organizations. There are few groups that offer similar services for hire and the Ocean Acidification Research Center is committed to capacity building for the greater ocean acidification community.

Key words: capacity building, monitoring, autonomous sensors, discrete samples

Qualitative and Quantitative Value of the Ocean Acidification Information Exchange, an Online Community of Practice

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The Ocean Acidification (OA) Information Exchange, an online community of practice for professionals working with or interested in ocean and coastal acidification, demonstrates "best-in-class" member engagement and participation rates. A community, whether in-person or virtual, is a collection of people who come together to build something beyond what they would as individuals. As a social species, communities fulfil essential needs for socialization and connection, and individuals' sense of community at work profoundly impacts their professional lives. There is growing recognition that people who are engaged in an effective community of practice in the workplace are more productive and able to solve complex problems faster. In an attempt to harness their benefits, new communities are continuously being launched, sometimes at great financial cost to organizations. How, then, does one determine the value of a community and quantify the worth of its outputs?

While informal feedback on the OA Information Exchange website has been plentiful and is valuable, since the OA Information Exchange's inception we have also employed more empirical methods with which to measure if the community is effectively meeting the OA Information Exchange's mission and is getting good return on investment. We will present nearly 30 months of data on member usage statistics, outputs, and impacts of community-driven collaboration, which have been synthetized and used to create a more complete, balanced answer to the question of the OA Information Exchange's worth. The results of our analysis suggest that several relatively low-effort activities, including individually welcoming new members and visible participation by thought leaders, influence the quantity of members' questions and answers. Additionally, we posit that efforts to encourage socialization and trust among members have large positive effects on community value.

Key words: Metrics, collaboration, community of practice, engagement, ROI

NOAA's Ocean and Great Lakes Acidification Research Plan 2020-2029

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NOAA's OA research mission is to understand and predict changes as a consequence of ocean and Great Lakes acidification; conserve and manage marine organisms and ecosystems in response to OA-induced changes; and to share OA knowledge and information with others. The 2020-2029 Research Plan builds upon OA research accomplishments made over the last decade and responds to emerging scientific requirements. In coordination with international, interagency and external academic and industry research partners, the present NOAA OA Research Plan aims to support science that produces integrated and relevant research results, tools, and products for stakeholders. The Research Plan is framed around three research themes; (1) document and predict environmental change via monitoring, analysis and modelling; (2) characterize and predict biological sensitivity of species and ecosystems; and (3) understand human dimensions and socioeconomic impacts. These research themes can collectively be used to understand, predict, and ideally reduce vulnerability to OA. The Research Plan includes regional chapters which encompass the coastal zones around the U.S. and its territories and the Great Lakes, and an Open Ocean chapter focusing on deep ocean regions extending beyond the continental shelf. The research plan also includes a National chapter, which draws upon the regional and open-ocean needs to present high-level, collectively relevant research objectives. Implementation of the Research Plan has required continued collaboration across the agency and with interagency and international partners, including the Interagency Working Group on Ocean Acidification (IWG-OA) and the Global Ocean Acidification Observing Network (GOA-ON). Since the plan's completion, NOAA has been tracking implementation of the plan's actions to help maintain progress and work towards filling existing knowledge gaps.

Key words: NOAA, Research, Environmental Change, Biological Sensitivity, Human Dimensions

DFO-NOAA Ocean Acidification Partnership: bilateral coordination to advance federal science decision-making

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Canada and the US share transboundary resources and remits on Pacific, Arctic and Atlantic coasts, each with a federal need for science-informed decision making. Despite these common concerns, there are few coordinated research and monitoring efforts between Canada and the United States. North American leadership acknowledged the potentially significant impacts of ocean acidification (OA) on the management of coastal resources, with a need for global leadership and enhanced scientific transboundary cooperation. This need led to the development of the Canadian Department of Fisheries and Oceans (DFO) and the U.S. National Oceanic and Atmospheric Administration (NOAA) joint partnership under the *Collaborative Framework for Joint DFO/NOAA Ocean Acidification Research and Monitoring* in 2017. The goals of the DFO-NOAA Ocean Acidification Coordination Committee and two Working Groups are to enhance scientific exchange and knowledge mobilization about the impacts of ocean acidification (OA) on shared marine resources, share and develop consistent research methodologies related to the effects, monitoring, and mitigation of OA, and identify opportunities for collaborative synergies between Canada and the United States while encouraging support of early career scientists. Two Working Groups were established (Monitoring Working Group and Research, Experimentation and Modelling Working Group) which have identified regional hotspots and species of mutual concern, coordinated cruises, and shared laboratory infrastructure, and identified knowledge gaps hindering biological or geochemical understandings of OA. Improved collaboration has proven to benefit both countries through increased capacity and shared knowledge, conducting joint monitoring activities and research projects, developing synthesis products (e.g. overlapping model domains, species vulnerability assessments, and publications) and linking to other OA initiatives (e.g. GOA-ON North American Hub). This partnership is ongoing, building from individual country and bilateral research to support federal science OA information needs.

Key words: Ocean acidification, government, observation, monitoring, knowledge mobilization

Pacific Islands Ocean Acidification Centre (PIOAC)

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To address the impacts of ocean acidification, Pacific Islands and Territories must understand local ocean acidification conditions, identify effective and sustainable adaptation and mitigation approaches, and develop strategies to address the changes to the ecosystems, communities, livelihoods and economies. To address this need, the Pacific Islands Ocean Acidification Centre (PIOAC) was created in 2021 to support ocean acidification capacity development throughout the Pacific. PIOAC is now working with Pacific partners to find Pacific solutions to address the impacts of ocean acidification through:

- Training to increase regional expertise in ocean acidification monitoring
- Advice on the application of monitoring to support adaptation and mitigation approaches
- Access to international networks that support monitoring, action, and policy efforts
- Assistance with ocean acidification data management and accessibility

Through support from NOAA and The Ocean Foundation, the SPC-led initiative includes partners from University of the South Pacific, New Zealand's National Institute of Water and Atmospheric Research (NIWA), and University of Otago. Through an expanding network, we are working to support Pacific Island researchers, government officials, and community members and welcome new collaborators.

Key words: Pacific Islands, Capacity Development, Training

TALKS
Theme A: Changing carbonate chemistry in coastal to open ocean waters

Ocean acidification at the crossroads: approaching unpurified and purified m-cresol spectrophotometric pH measurements

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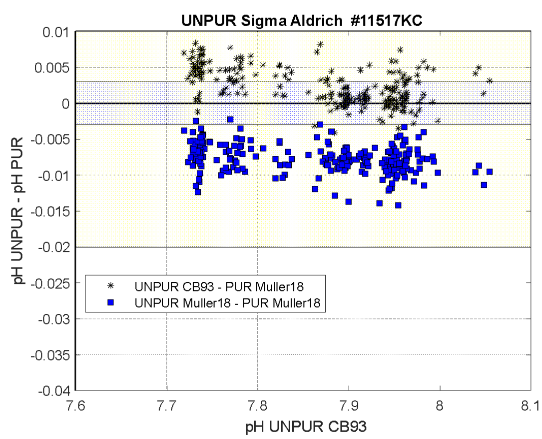
The pH spectrophotometric method is the gold standard to measure pH in the ocean and detect ocean acidification trends due to the anthropogenic carbon uptake from the atmosphere into the ocean. The pH method has an accuracy of about 0.003 and a precision of about 0.0004 pH units.



The method has evolved since the 1990s when defined using manual approaches and unpurified dyes to currently automated methods using expensive and cumbersome to obtain purified dyes. From a collection of about 300 paired measurements of unpurified and purified pH measurements along with DIC and TA from natural samples in the Eastern North Atlantic and Mediterranean Sea we find that contrary to expected, unpurified and purified pH measurements calculated with the proper corresponding functions agree to within 0.003 pH units for waters with pH >7.95, while waters with lower pH, calculated unpurified pH is higher than purified pH. Applying the purposed correction from unpur to pur pH as explained in the literature is not straight forward, the community risks for an incoherence in the pH time series. Clearly, we need a definition and evaluation of the unpur to pur correction on real seawater samples by different labs, and look for a consensus agreement on seawater pH definition (scales!, ionic model), metrology, and on the Standard Operational Procedure, where loose issues are still present.

Key words: pH measurement, unpurified dye, purified dye, time series coherence

EFFECT OF DISSOLVED ORGANIC MATTER ON TOTAL ALKALINITY AND CO_2 CONCENTRATION IN A SUBTROPICAL SHALLOW ESTUARY

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Several studies have shown that dissolved organic matter (DOM) contributions to total alkalinity (TA) can be significant, especially in riverine and coastal waters (Kulinski et al., 2014). Here, we study DOM composition, organic alkalinity (A_{ORG}) and pCO_2 distribution in a subtropical shallow estuary during five seasonal sampling campaigns along the salinity gradient (0-36). The pH and TA were measured by potentiometric titration (Metrohm 906) and DOM composition was assessed using its optical properties (absorbance and fluorescence) and dissolved organic matter (DOC) concentration. To evaluate the effect of DOM on TA, A_{ORG} was calculated following Hernández-Ayón et al. (1999), and the partial pressure of CO_2 (pCO_2) was calculated from TA and pH according to Millero (2010) using the CO2SYS program (Pierrot et al., 2006). Values of TA, A_{ORG} and pCO_2 ranged from 2378 to 5737 µM, 240 to 540 µm and 333 to 6807 µatm, respectively. On average, A_{ORG} accounted for the 8.6% ± 1.8% of TA, similar to the contribution found in rivers (Kulinski et al., 2014). Regression models showed positive linear relationships between both A_{ORG} and the excess of pCO_2 with DOC concentration, chromophoric DOM, aromatic index $SUVA_{254}$ ($R^2 = 0.50$, 0, 61 and 0.44, respectively, $p < 0.01$), and the humic-like components derived from terrestrial and microbial sources ($R^2 = 0.45 - 0.66$, $p < 0.01$). By contrary, no relationship was observed with the protein-like material ($p > 0.01$). Thus, A_{ORG} increased with increasing humic-like material from microbial or terrestrial sources, as well as with increasing aromaticity. Therefore, production of A_{ORG} should be taken into account when quantifying CO_2 in shallow estuaries dominated by humic-like material. Our results further indicate that the contribution of condensed aromatic compounds from terrestrial and/or microbial source may increase pCO_2 values in estuarine systems.

Key words: organic alkalinity, dissolved organic matter, CO_2, shallow estuary

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Ocean Acidification trends in the Gulf of Mexico: Results from the GOMECC program

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The Gulf of Mexico (GoM) is a low-latitude, semi-enclosed basin bounded by the US Gulf Coast, the eastern coasts of Mexico, and northern Cuba. The GoM is strongly influenced by the loop current and, in the northern section, by riverine inputs from the Mississippi River. The eastern section of the GoM has been experiencing devastating Harmful Algal Blooms some of which lasted 16 months (2017-2019).

Since 2007, the NOAA Ocean Acidification Program supports synoptic coastal cruises in the GoM as part of its commitment to monitor ocean acidification conditions in coastal waters of the United States. Four Gulf of Mexico Ecosystems and Carbon Cycle (GOMECC) cruises have been conducted during the summer in the years 2007, 2012, 2017 and 2021. Multiple near-shore (~15m depth) to open ocean (~3000m depth) transects are conducted during these cruises. Parameters measured include pH, total alkalinity (TA), dissolved inorganic carbon (DIC) and fugacity of CO_2 (fCO_2), as well as O_2, nutrients, salinity, temperature, and a variety of plankton sampling.

Here we present preliminary results from our most recent cruise, and we look at trends in carbon parameters over the history of the GOMECC program, exploring regional differences within the GoM. The highest decrease in saturation state is observed in the near shore region at subsurface levels, linked to a deoxygenation trend that might also be linked to enhanced HAB events.

Key words: Gulf of Mexico, coastal OA trends, carbonate system.

INTERCOMPARISON OF FOUR METHODS TO ESTIMATE CORAL CALCIFICATION UNDER VARIOUS ENVIRONMENTAL CONDITIONS

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Coral reefs are constructed by calcifiers that precipitate calcium carbonate to build their shells or skeletons through the process of calcification. Accurately assessing coral calcification rates is crucial to determine the health of these ecosystems and their response to major environmental changes such as ocean warming and acidification. Several approaches have been used to assess rates of coral calcification but there is a real need to compare these approaches in order to ascertain that high quality and intercomparable results can be produced. Here, we assessed four methods (total alkalinity anomaly, calcium anomaly, ^{45}Ca incorporation and ^{13}C incorporation) to determine coral calcification of the reef building coral *Stylophora pistillata*. Given the importance of environmental conditions on this process, the study was performed under two pH (ambient and low level) and two light (light and dark) conditions. Under all conditions, calcification rates estimated using the alkalinity and calcium anomaly techniques as well as ^{45}Ca incorporation were highly correlated. Such a strong correlation between the alkalinity anomaly and ^{45}Ca incorporation techniques has not been observed in previous studies and most probably results from improvements described in the present paper. The only method which provided calcification rates significantly different from the other three techniques was ^{13}C incorporation. Calcification rates based on this method were consistently higher than those measured using the other techniques. Although reasons for these discrepancies remain unclear, the use of this technique for assessing calcification rates in corals is not recommended without further investigations.

Key words: Calcification; Coral; Alkalinity anomaly; Calcium anomaly; ^{45}Ca incorporation; ^{13}C incorporation

Coastal acidification in the Southern Mexican Tropical Pacific: the buffering role of riverine input in upwelling-dominate regions

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Many regions of the world have been observed to have seasonal acidification derived form the natural upwelling processes. However there is still much to be understood about its variability and how the coastal processes affect it. The purpose of this work was to identify the effects of the regional proceses such as upwelling, tropical storms and river discharges on the coastal pH and aragonite saturation state in the Gulf of Tehuantepec (GOT), a wind dominated region of the tropical Mexican Pacific where intermittent wind jet events (>10 m s-1) occur from November to March, producing acidification in most coastal regions.of Oaxaca, while the summer brings the rainy season along with tropical storms. The data was obtained from water samples and a seapHOx sensor from the Oaxaca Coast during rainy, and wind seasons from 2015 to 2019. Both wind jets and summer tropical storms increased acidification levels. by lowering pH and aragonite saturation state. pH values are lower at the central GOT than compared to the western GOT, as a consequence of seasonal went jets .(as low as 7. 5 and 1.0, respectively at 30 m depth and <1 km from the coast). In contrast river runoff during the rainy season was a source of carbonate ions to the costal zone. The Copalita river alone discharges 217.804 Gg. year-1 thus modifying the carbonate system, increasing pH and aragonite saturation levels. Although acidification may affect coastal organisms, riverine input play an important role at buffering the acidification produced by the coastal and regional dynamic processes. Therefore a correct management of the watersheds from tropical rivers of Mexico is crucial, since activities such as deforestation, water take up may indirectly affect the survival of organisms sensitive to ocean acidification, and important ecosystems such as coral reefs.

Key words: Tehuantepec, Huatulco, buffering

The Role of Riverine Input in Coastal Ocean Acidification: A Case Study from Belize

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The coastal ocean is a highly dynamic, heterogeneous environment and is influenced by both open ocean and terrestrial processes. Typically ocean pH is measured in the open ocean, but the coastal ocean can have additional sources of CO_2 not included in models. It is therefore likely that the coastal ocean may by experiencing enhanced ocean acidification. In tropical rivers pCO_2 levels may be linked to land use in their catchment, with conversion of pristine forest to agricultural land potentially enhancing carbon flux to the coastal ocean. The logistical limitations of discrete bottle sampling at the coast from manned research vessels or shore-based platforms has historically served as a barrier to gaining a comprehensive understanding of coastal ocean acidification. Using sensors on autonomous platforms is a promising approach to bridge this gap.

Belize is home to the Mesoamerican Barrier Reef, which provides sources of income through fisheries and tourism, as well as offering coastal protection. Like all reefs, Belize's corals are facing a number of threats including ocean acidification. Our aim was to investigate if changes occuring inland may be enhacing coastal ocean acidification in Belize. Water samples were collected and measured for: total alkalinity; dissolved inorganic carbon (DIC); and $\delta^{13}C_{DIC}$; and were complemented by pH and pCO_2 data acquired from sensors mounted on an autonomous surface vehicle. Samples were collected from the source of the Belize river to the mouth and out past the barrier reef. $\delta^{13}C_{DIC}$ samples were taken to identify terrestrial DIC signatures and used in combination with sensor data to identify potential controls on coastal pH. Our data allows us to shed light on the complex processes controlling coastal ocean acidification not only for a country heavily dependent on their barrier reef but also as a case study for similar regions.

Key words: Coastal, Belize, Coral Reefs

Seasonal, Interannual, and Long-Term Trends in Air-Sea CO_2 Fluxes in the Northeast Pacific

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With the ocean taking up nearly a quarter of anthropogenic emissions annually, there is an urgent need to better understand variability in the marine carbon sink and how it may be shifting under climate change. Here, we use a neural network approach as a method of gapfilling sparse observations to basin wide estimates. We compiled partial pressure of CO_2 (pCO_2) observations as well as a range of predictor variables including physical oceanographic reanalysis products, and satellite based biological estimates. With the predictor variables acting as proxies for known processes affecting pCO_2, we can create non-linear relationships to interpolate observations from 1998-2020 in the Northeast Pacific. Using wind speed and atmospheric CO_2, we evaluate spatiotemporal dynamics of carbon uptake from the atmosphere. Focusing on the open ocean, distinct seasonal, interannual, and long-term patterns emerge. We see strong fluxes in the winter months dominated by higher winds due to seasonal storms, with outgassing in the north Gulf of Alaska and uptake in the south. When looking at specific events, such as recent Pacific marine heatwaves, the higher resolution product proves more accurate in investigating the impact on air-sea CO_2 fluxes compared to lower resolution global products. Over the long-term trend, surface ocean pCO_2 generally increases in parallel with the atmospheric increase due to anthropogenic input with a regional time of emergence around 2018. However, the rate of change in the air-sea CO_2 flux in the region suggests the marine sink for atmospheric CO_2 may be increasing. The insights from such a high resolution, regional look at marine carbon fluxes are just beginning to be mined, with observations across the coastal to open ocean continuum next to be resolved.

Key words: Machine learning, carbon cycle, gas exchange, biogeochemistry

A Long-term Observatory of Marine-coastal Acidification and ODS in the Upwelling System off Peru: Challenges and Opportunities

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The Peruvian upwelling system, characterized by low pH and DO concentrations, high nutrients, and organic matter, is a natural laboratory to understand coastal-marine stressors variability and impacts on biodiversity, organisms, and ecosystem functions. In fact, these characteristics can be very variable in spatial and temporal scales and can trigger the acidity sea level, hypoxic and/or anoxic events, and sulfidic events in coastal areas, which are relevant in the context of climate change. The study of ocean acidification (OA) and the impact on the coastal marine areas require high-resolution long time series. We propose a marine- coastal environmental observatory for the monitoring of total pH relevant to marine acidification and other stressors in the central and northern areas of the Peruvian upwelling system. In addition in collaboration with the REMARCO network and the IAEA contribute to submitting data to IOC/UNESCO for the Ocean Sustainable Development Goal (SDG) 14.3.1 indicator (marine acidity). The monitoring of coastal marine stressors such as total pH will contribute to fulfilling the national commitments in the context of SDG, specifically SDG 14.1. We expect the results will be useful to the Peruvian scientific community and stakeholders in general, providing tools for better management of coastal Peruvian marine ecosystems in a changing ocean and contributing to the regional and global knowledge on OA.

Key words: pH, long term observatory, SDG, coastal upwelling ecosystem, Peru.

State of the Art Autonomous CO2 System Measurements Onboard Boaty McBoatface: Results from an 8-day Mission in the Celtic Sea.

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In a world where the climatic response to human carbon emissions has reached a critical point in time, understanding the ocean's role in carbon cycling has become a major focus for scientific observation and intervention. The development of marine autonomous platforms provides observations of higher spatiotemporal resolution, which can be used to further measure, characterize, and model ocean carbon. As a part of the pioneering OCEANIDS programme, novel carbonate chemistry sensors were integrated on the Autosub Long Range (ALR) Autonomous Underwater Vehicle (Boaty McBoatface) and deployed in the Celtic Sea. The project utilized three autonomous Lab-On-Chip (LOC) sensors measuring pH, Total Alkalinity (TA), and Dissolved Inorganic Carbon (DIC). Together, these sensors enable characterization of the marine carbonate system based on direct in situ measurements. This unprecedented technology has the potential to improve our understanding of the inorganic carbon cycle in the ocean and enable ocean acidification monitoring at a higher spatial and temporal resolution than currently possible. Additionally, it presents a powerful tool for CO2 leak detection from sub-seafloor carbon sequestration and storage (CCS) sites and paves the way towards decarbonization of ocean observations. Preliminary results collected in March 2022 during a multi day ALR mission in the Celtic Sea from surface waters to 600m depth will be presented. Sensor data will be validated against discrete water samples collected along the ALR's track. The performance of the new technology and its potential as an observing tool for ocean CO2 observations will be evaluated.

Key words: Autonomous Technology, Biogeochemical Sensing, Ocean Carbon, Carbonate Chemistry.

Winter Carbonate System Properties in the South Atlantic Ocean South of Africa

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Spatial and column ocean carbon dioxide (CO_2) system was assessed during winter 2019 along a southbound and northbound return transect in the South Atlantic sector of the Southern Ocean (>30^{o}S), dividing the study area into three domains from the north to south; subtropical domain, Antarctic Circumpolar Current (ACC) domain, and the Weddell gyre domain. Four carbonate system parameters (sea surface fugacity of CO_2 (fCO_2ssw), dissolved inorganic carbon (DIC), total alkalinity (TA), and pH) were measured.

Spatial distribution of fCO_2ssw showed high variability along the transects, varying between 370 and 432 µatm with decreased fCO_2ssw in the north of 43^{o}S during the return northbound transect. Surface pH varied generally between 7.50 and 8.1 with the lower values found in the ACC domain. Surface DIC concentrations (2036 to 2175 µmol kg^{-1}) increases towards the pole with the aragonite saturation (Ω_{Ar}) (0.9 to 3.2) decreasing and reflects the influence of temperature along the latitudinal gradient. Within the water column, DIC is lowest at the surface layer with corresponding high values of pH and Ω_{Ar}. At different depths, the DIC concentration increases southward while Ω_{Ar} decreases southward both corresponding to the observed surface distribution. Given the approximate values of Revelle factor (RF) as 8 for warmer and subtropical waters and 14 for colder waters in the high latitudes, observed surface and column RF values for this study reaching 11 in the subtropics and 17 in the Weddell gyre domain is a potential indicator of decreasing ocean buffer capacity in South Atlantic Ocean. This could be linked to increased CO_2 solubility in the subtropics during winter and the effect of deep winter mixing seen in the polar upwelling zone within the ACC and the Weddell gyre domain where Winter Waters were identified with the Circumpolar Deep Waters in the near-surface depth of 200-300 m.

Key words: carbon dioxide, dissolved inorganic carbon, aragonite saturation, pH, Revelle factor

Development of a coastal observation monitoring network for carbonate system along the French coast

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Since the start of the industrial revolution, atmospheric CO_2 concentrations have risen steadily and induced a decrease of 0.1 units for the averaged surface pH of the ocean. In addition to warning, ocean acidification poses a tremendous challenge to marine organisms, especially calcifiers. The need of long-term oceanic observations of pH and temperature is a key element to project the future impact of these pressures in the coming decades. Near-shore productive environments where a large majority of shellfish farming activities are conducted, are known to present pH levels as well as amplitudes of daily and seasonal variation that are very different from those observed in the open ocean. Yet, to date, there are very few coastal observation sites where these parameters are measured simultaneously and continuously.

To bridge this gap, a French national observation network was initiated in 2021 in the framework of the CocoriCO$_2$ project (EMFF, 2020-2022). Along the French littoral, a total of six sites was chosen based on their importance in terms of shellfish production and the presence of low-frequency monitoring activities (SOMLIT/ECOSCOPA), In each of these sites, pH autonomous loggers (SeaFET pH - SeaBird) were deployed both inside and outside shellfish production areas, next to CTD probes operated through two existing networks (COAST-HF/ECOSCOPA). pH sensors were set to an acquisition rate of 15 mins and a discrete sampling strategy was designed on a biweekly basis to control the quality of pH measurements (spectrophotometric measurements) and to measure total alkalinity and dissolved inorganic carbon concentrations in order to fully characterize the carbonate system.

While this network is up and running for more than one year, the acquired data set has already revealed important differences in terms of pH variations between monitored sites related to the influence of diverse processes (freshwater inputs, tides, temperature, biological processes).

Key words: pH measurements; coastal monitoring; high frequency; carbonate cycle

A call for a community of practice for assessing ocean acidification trends

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Time-series observations are one of the most valuable tools for characterizing how the ocean carbon system is changing over time. Ocean acidification time series exist globally, covering gyre-scale biomes and biogeochemical provinces, coastal and estuarine systems, and coral reefs. While observing methods are standardized across a distributed network of investigators, there is no common set of approaches for analysing data to identify trends. Standardization of trend analysis is necessary to enable comparisons across ocean and coastal systems globally, create accurate records of change that stand the test of time, and communicate scientific results clearly and consistently to policy makers and the public. To facilitate this effort, we are developing best practices for determining multi-decadal change in ocean acidification time series. Here we provide an update on these efforts and discuss the motivation for creating a community of practice to test these and new techniques across different data sets. Additional research needed from this community include determining consistent approaches to data gap filling, characterizing exceeded thresholds or the changing frequency of extreme events, and characterizing periodic signals at frequencies other than seasonal. We recommend that the organizations supporting coordination efforts within the ocean carbon and biogeochemistry community support regular forums for sharing results and new techniques in trend analysis and modify these best practices accordingly.

Key words: best practices, time series, long-term trends

CO_2 Sink and Source Zones Delimited by Marine Fronts in the Drake Passage

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The Southern Ocean, on average, is the largest sink of anthropogenic CO_2 of the global ocean. However, recent studies show that carbon fluxes are highly dynamic over time and they respond to the interaction of different scale processes. Therefore, the objective of this work is to study the factors that modulate CO_2 fluxes (FCO_2) in the Drake Passage (DP), a transition area between the South Atlantic and South Pacific oceans.

Using the SOCAT (Surface Ocean CO_2 Atlas) database, circumpolar fronts, and physical and biological variables were used to analyze the spatial patterns of the sea/atmosphere gradient of the partial CO_2 pressure (ΔpCO_2) and FCO_2 at a climatological scale (1999-2019). In other regions of the world the fronts play a fundamental role in the distribution of carbon sources and sinks. Consequently, the monthly climatological position of the most important fronts of the DP, the Subantarctic Front (SAF), the Polar Front (PF) and the Southern Antarctic Circumpolar Current Front (SACCF), was estimated using satellite altimetry data. The results show a coherence between the FCO_2 spatial distribution and the physical front positions. The region to the north of SAF behaves as a sink ($\Delta pCO_2 < 0$ μatm); this sink weakens between SAF and SACCF and the region to the south of SACCF acts as a CO_2 source. We also analyzed the relationship between FCO_2 with thermal (TE) or non-thermal (NTE) effects. The relative importance of these processes shows that to the north of SACCF the TE dominates the CO_2 variability, whereas in the region south of SACCF the NTE dominates. This research shows that the CO_2 dynamic in the DP is not dominated by a single process, but rather responds to both thermal and non-thermal processes. Finally, the interannual variability is analyzed.

Key words: carbon dioxide, Drake Passage, circumpolar fronts, thermal and non-thermal effects.

Comparative Marine Ecosystem Modelling to Assess the Impacts of Ocean Acidification and Hypoxia in Miyako Bay and Tokyo Bay, Japan

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There is growing concern that ocean acidification, primarily caused by excessive anthropogenic CO_2, may adversely affect marine calcifying organisms. Similarly, hypoxia, the long-term decline in dissolved oxygen (DO) concentrations, has also been linked to ocean warming and acidification. We have been developing a modelling approach using the CROCO framework (Jullien et al., 2019) to evaluate the combined effects of these phenomena on calcifying organisms along the coasts of Japan. The Regional Ocean Modelling System (ROMS) is coupled with the PISCES biogeochemical model to simulate coastal processes in the relatively pristine Miyako Bay, Iwate Prefecture, and the highly eutrophic Tokyo Bay. Model grid resolutions of ~1 to 1.5 km were used with physical forcing derived from the global HYCOM GOFS 3.1 dataset. Realistic atmospheric, tidal, and river forcing were also included, as well as biogeochemical forcing for PISCES. Simulations for Miyako Bay reproduced the general features of observations, except for some rapid decreases in salinity, pH, and aragonite saturation state (Ω_{arag}), suggesting possible underestimation of freshwater inputs. However, while mostly reproducing trends in observed physical parameters, Tokyo Bay simulations failed to accurately reproduce pH and Ω_{arag} observations, particularly in deeper waters. River nutrient inputs are likely underestimated, and biogeochemical settings need adjustments. Both setups are undergoing modification and improved reproducibility is expected within the year. We have also been testing future scenarios, with physical forcing derived from the Future Ocean Prediction dataset (FORP-CGCM3; Nishikawa et al., 2021). For Miyako Bay, simulations suggest significant impacts in the 2100s for the RCP8.5 scenario, with Ω_{arag} approaching critical levels for calcifying organisms ($\Omega_{arag} < 1.1$; Onitsuka et al., 2018) year-round. DO concentrations are predicted to not be as adversely affected. Similar setups for Tokyo Bay are being developed. Overall, we highlight how such modelling approaches can help in determining proper mitigation and adaptation measures.

Key words: ocean acidification, hypoxia, biogeochemical model, mitigation, adaptation

Compound Marine Heatwaves and Ocean Acidity Extremes

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Co-occurring marine heatwaves (MHWs) and ocean acidity extreme (OAX) events, i.e., ocean compound MHW-OAX events, can have much larger impacts on marine ecosystems than the individual extreme events. Yet, the location and likelihood of these compound MHW-OAX events, their underlying processes, and their evolution under climate change are currently unknown.
Using monthly open-ocean observations, we show that globally 1.8 in 100 months (or one out of five present-day MHW months) are compound MHW-OAX event months, almost twice as many as expected for 90th percentile extreme event exceedances if MHWs and OAX events were statistically independent. Compound MHW-OAX events are most likely in the subtropics (2.7 in 100 months; 10°-40° latitude) and less likely in the equatorial Pacific and the mid-to-high latitudes (0.7 in 100 months; >40° latitude). The compound event likelihood results from opposing effects of temperature and dissolved inorganic carbon on $[H^+]$. More compound events occur where the positive effect on $[H^+]$ from increased temperatures during MHWs is larger than the negative effect on $[H^+]$ from co-occurring decreases in dissolved inorganic carbon.

Daily model output from a large-ensemble simulation of an Earth system model is analyzed to assess changes in MHW-OAX likelihood under climate change. These changes in MHW-OAX likelihood arise due to mean warming and acidification, due to changes in variability of temperature and $[H^+]$, and due to changes in their interdependence. Among these changes, it is the mean warming and acidification that has the largest effect on the number of MHW-OAX days per year, increasing it from 12 to 265 days per year at 2°C global warming relative to a fixed pre-industrial baseline. Even when mean trends are removed, an increase in $[H^+]$ variability leads to a 60% increase in the number of compound MHW-OAX days per year (from 12 to 19) under 2°C global warming. This projected increase in the occurrence of compound MHW-OAX events may cause severe impacts on marine ecosystems.

Key words: marine heatwaves, ocean acidity extremes, multivariate extreme events, ocean warming, ocean acidification

Field deployment of a new generation of carbon dioxide sensor in an underway application

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The recent advancement in ocean carbon sensors and autonomous platforms is enabling air-sea carbon dioxide (CO2) measurements to be made in regions where there are currently observational gaps. In particular, this technology can allow progress to be made in the coastal ocean where variability is high and measurements are sparse. Proven methodology from the Moored Autonomous pCO2 (MAPCO2) system was repackaged for deployment on Autonomous Surface Vehicles (ASVs). The current version of the Autonomous Surface Vehicle CO2 (ASVCO2) uses an infrared analyzer (LI-830, LI-COR Biosciences) for CO2 detection. To achieve climate quality measurements above the accuracy of the manufacturer's specifications, multiple points of the calibration process of the LI-830 were explored. The LI-830 was calibrated using a range of gases 100-2500 ppm over a temperature range of 5-35 ºC. With the best-known calibration procedure for the LI-830, the ASVCO2 was able to achieve an accuracy of ± 2 ppm in laboratory and preliminary field tests. Using information gained from these initial tests, the new generation of the ASVCO2 system was installed in an underway application on the R/V Ronald H. Brown prior to departure of the West Coast Ocean Acidification cruise in June-July 2021. The ASVCO2 was compared to the gold standard General Oceanics (GO) underway pCO2 system. Both systems captured multiple large excursions in pCO2 during the transit and provided validation for measurements that would otherwise have been identified as more questionable. This field evaluation of the ASVCO2 is further confirmation of the instrument's ability to be used in underway applications in addition to ASV platforms to improve spatiotemporal coverage of air-sea CO2 measurements and contribute to our understanding of the global carbon cycle.

Key words: Carbonate chemistry, carbon dioxide, sensor, autonomous, pCO2

A New Chemical Model to Constrain the Impacts of Ocean Acidification in Aquatic Systems: Application to pH and the Carbonate System

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We have implemented a chemical speciation model of natural waters containing the ions of seawater, and the Tris buffers defining the total pH scale that is the basis of studies of ocean acidity and its effects. Based upon the work of Millero and others, this is the first Pitzer-based model to include estimates of uncertainties in all calculated quantities, including pH and stoichiometric equilibrium constants K_1 and K_2 of the carbonate system.

Applications include clarification of the uncertainties and self-consistency of the different sets of K_1 and K_2 in seawater, and the calculation of pCO_2 and carbonate mineral saturation in natural waters differing from seawater stoichiometry. This could be used to investigate composition effects on calcite saturation to better understand influences on organismal response, for example.

Model development is supplemented by a program of measurements at U.S. National Institute of Standards & Technology (NIST) and equivalent German and Japanese partner institutions to complete the model of Tris buffer solutions. This will lead to a better defined value of hydrogen ion, and hydrogen ion concentrations, for use with conventional carbonate dissociation constants and account for different methods of pH measurement used by marine scientists. It will also improve the model for the applications noted below.

This presentation will focus on the advantages and applications of this model to ocean acidification research. We will share recent successes such as calibrating total pH for seawaters of salinity <20 (adjusting the results of the principal experimental study for composition discrepancies), and insights into the total pH scale. We will also discuss model capacity to convert between free and total pH and define the pH of buffers for novel sensors (e.g., H^+/Na^+ or H^+/Cl^- pairs) in seawater-related solutions. The model will be publicly available in late 2022.

Key words: chemical speciation, pH, carbonate constants, sensors

From short-term to interannual variability of carbonate system parameters at near-shore sites.

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Coastal ocean is affected by numerous climatic and local stressors such as atmospheric variability, El Niño-Southern Oscillation, coastal upwelling/downwelling, river influence, and precipitation between others. These natural stressors produce different temporal changes in the coastal zone where frequency may vary from hours to several years. Here, we have used five independent coastal high frequency time-series in order to estimate the most dominant factors that influence the natural variability at interannual, seasonal, intraseasonal, and daily scales in the coastal zone at the Innner Sea of Chiloé in Northern Chilean Patagonia. High variability was observed at all five coastal sites where temperature, dissolved oxygen (DO), chlorophyll-a and pH were the most important factors contributing to seasonal variability. Important signals were also observed at intraseasonal scale (30 and 14 days frequency), and at diurnal and semi-diurnal scales (24 and 12 hours). These signals were mainly represented by temperature, DO, pH, and pCO_2. The most important daily changes were estimated for DO, pH, and pCO_2 at the scale of 2.5 mL O_2 L^{-1}, 0.2 pH units, and 189.2 µatm, respectively. When observing all parameters, high variability was mostly estimated during the productive seasons (spring/summer periods) compared to more stable conditions during winter periods. Important local shifts at the "ocean weather" scale occurred within days and hours thus, our results highlight the importance to represent not only potential future changes in the carbonate system, but also the high frequency variability of the changes in experimental setups.

Key words: pH time-series, carbonate system, coastal zone, natural variability, Chilean Patagonia.

Coastal air-water carbon dioxide flux in front of a community of the northwestern Mexican Tropical Pacific, in 3 different years

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Data of the air-water CO_2 flux (FCO_2) in the coastal region of the Mexican Tropical Pacific are scarce. Oceanographic cruises were conducted in April 2017, 2018, and 2019 to obtain instantaneous point samples covering the area at five monitoring stations off Manzanillo, Mexico. Measurements and analyses were conducted for sea surface temperature (SST), salinity (SSS), total alkalinity (TA), dissolved inorganic carbon (DIC), and wind velocity, which were used to calculate FCO_2. In addition, satellite temperature, chlorophyll, and sea surface height (SSH_{sat}) data were obtained, and geostrophic velocity was calculated. Spatial and temporal changes in FCO_2 were related to multiple phenomena, such as upwelling, eddies, changing coastal currents, winds, and photosynthesis. The study region was affected by strong coastal upwelling events and mesoscale eddies. which contributed to this area being a source of CO_2 to the atmosphere in the first two years, while during the third year it behaved as a sink. The average value (± standard deviation) of FCO_2 during 2017 was 2.70 (± 1.01) mmol C m^{-2} d^{-1}, while in 2018 it was 1.55 (± 0.60) mmol C m^{-2} d^{-1} and in 2019 it was -5.29 (± 2.09) mmol C m^{-2} d^{-1}. It is possible that these differences were caused by changes in the intensity of upwelling and photosynthesis at the time of sampling. Nonetheless, a more complete dataset covering broader regions and seasonal conditions is still needed.

Key words: CO_2 Flux, Carbon System, Mexican Tropical Pacific, Interannual variability.

First registers of dissolved inorganic carbon and CO_2 ocean-atmosphere fluxes in the Baja California Sur Frontal System, Mexico.

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The Baja California Sur Frontal System (SFBCS) zone is a biologically rich region with a very dynamic oceanography. It is characterized by presenting mesoscale structures that vary in space and time, due to the confluence of water masses of different densities that induce the vertical advection of nutrients, which stimulate the growth of phytoplankton and, with it, primary phytoplankton productivity. The objective of this work is to show the first measurements of dissolved inorganic carbon and ocean-atmosphere CO_2 fluxes in the SFBCS. From July 27 to August 20, 2019, aboard the R/I "Dr. Jorge Carranza Fraser" of the National Fisheries Institute (INAPESCA), an oceanographic cruise was carried out in the SFBCS. Vertical temperature, salinity, dissolved oxygen and pH profiles were performed with a CTD, and water samples were taken for DIC determination in 58 stations. The water masses of the California Current (CCW), Tropical Superficial (TSW), Subtropical Superficial (StSW) from the surface to 200m, Equatorial Subsurface (ESsW) from 200-400m were recorded. In CCW, OD values of 150-300 µmol kg-1, DIC of 2030-2150 µmol kg^{-1}, pH of 7.85-8.25, and in ESsW of 20-70 µmol kg^{-1}, DIC of 2250-2300 µm kg^{-1}, pH 7.50-765. In the study area the ocean-atmosphere flux of CO2 varied from -7.5 mmol C m^{-2} (atmosphere to ocean flux) and 7 mmol C m-2 (ocean to atmosphere flux). The great oceanographic dynamics of the SFBCS is observed, which modulates the flow of CO_2 ocean-atmosphere. More research is required to better understand the area.

Key words: dissolved inorganic carbon, water masses, CO_2 fluxes, Baja California Sur Frontal System

A nearshore Burke-o-Lator network along the North American Pacific coast

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The US west coast shellfish industry experienced unprecedented larval Pacific oyster mortality in hatchery facilities during 2007. Ocean acidification was identified as having reduced aragonite saturation state (Ω_{arag}) to levels that impaired survival thereby leading to hatchery failures. Partnership between the shellfish industry and the research community led to select hatcheries being instrumented with Burke-o-Lator pCO_2/TCO_2 analyzers for real-time determination of Ω_{arag}. These unique analyzers measure at high frequency both CO_2 partial pressure (pCO_2) and total dissolved inorganic carbon (TCO_2), providing robust determinations of Ω_{arag} and pH for the dynamic conditions typically experienced in coastal waters. The initial effort provided critical information for hatcheries to adjust practices and "dodge the punch" of ocean acidification during periods of upwelling. Beginning in 2013, a network of shore-side Burke-o-Lators expanded along the North American Pacific coast from California to Alaska. These instruments recorded marine CO_2 system measurements at 10 sites with data portraying variability ranging from sub-hourly to inter-annual time scales and broadcast across various web-based data portals. Nearshore oceanographic settings monitored by this network include areas within the California Current System, semi-enclosed basins in the Salish Sea, and locations in the Gulf of Alaska. Until now, information on conditions across these settings has relied on periodic research cruise observations and a small number of coastal moorings, both of which provide limited information on nearshore conditions. Here we provide a synthesis of the observations from this network including an evaluation of the relative roles of physical versus biogeochemical drivers and the coherence of temporal variability along the North American Pacific coast. Our results highlight the complexity with which extreme Ω_{arag} conditions manifest across settings exposed to the influence of coastal upwelling versus semi-enclosed waterways and downwelling regions. The value of this nearshore network for both environmental monitoring and stakeholder decision-making cannot be understated.

Key words: nearshore, time-series, aragonite saturation state, shellfish

Anthropogenic Carbon Concentrations in the Pacific Ocean: Implications for Ocean Acidification Since the Beginning of the Industrial Era

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Anthropogenic carbon (C_{anth}) distributions in the Pacific Ocean and West Coast of North America have been determined from repeat hydrographic cruises as part of the Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP) and the NOAA Ocean Acidification Program (OAP). The basin-wide rate of change of C_{anth} is estimated using an approach that combines the extended multiple linear regression method with improvements to address difficulties associated with analyzing multiple occupations of sections spaced irregularly in time. C_{anth} concentrations range from 40-70 µmol kg^{-1} in surface waters, with the highest concentrations in warm high-salinity subtropical waters. The C_{anth} buildup over the top 1500m of the Pacific increased from 8.8 (±1.1) Pg C per decade between 1995 and 2005 to 11.7 (±1.1) Pg C per decade between 2005 and 2015. The pre-industrial to present-day decrease in surface aragonite saturation state (Ω_{ar}) ranged from 0.57 to 0.82, corresponding to an average decrease of 0.34% per year. Similarly, surface pH_T decreased by approximately 0.08 to 0.14 over the same period. The impacts of surface C_{anth} on pH_T are greatest in the colder waters, with as much as 0.04 larger surface pH decreases at high latitudes. Along the west coast of North America C_{anth} uptake increases at the rate of 0.8–1.2 µmol kg^{-1} yr^{-1}, with the rate decreasing from south to north in the surface waters. The rates gradually decrease with depth to values of ~0.3 µmol kg^{-1} yr^{-1} at depths near 400 m. Corresponding rates of pH decrease on average about 0.002 yr^{-1} in surface waters. In future years, acidification rates will be driven by CO_2 emissions and the changes in carbon chemistry that reduce the buffer capacity of subsurface waters, with the largest impacts on pH and CO_2 partial pressure (pCO_2) occurring in the colder waters at higher northern and southern latitudes.

Key words: Anthropogenic carbon dioxide, ocean acidification

The count-down for calcifiers to dissolve in major Atlantic and Mediterranean water masses due to ocean acidification

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The oceanic uptake of atmospheric CO_2 is driving changes in seawater chemistry that result in the decrease of both pH and the concentration of the carbonate ion, which is essential for marine calcifiers to build their hard structures and shells. Reduction in the availability of carbonate ions lowers the saturation state (Ω) for the calcium carbonate mineral aragonite in the ocean. When concentration of aragonite changes from oversaturation ($\Omega>1$) to undersaturation ($\Omega<1$), biogenic calcification is not supported, with severe impacts on marine biodiversity and ecosystem functioning. In this work, we used 17 years (2005–2022) of biogeochemical measurements collected at the Gibraltar Fixed Time series (GIFT) located at the Strait of Gibraltar to estimate temporal trends of seawater pH and Ωaragonite in major Mediterranean and Atlantic water masses that exchange in the area, i.e. the Western Mediterranean Deep Water (WMDW), the Levantine Intermediate Water (LIW) and the North Atlantic Central Water (NACW). Our analysis shows a gradual decline in pH in all water masses that is accompanied by a noticeable temporal drop of Ωaragonite. Decreasing trends in both parameters were more and less pronounced in the NACW and LIW, respectively. Estimated long-term changes of Ω under future increases in atmospheric CO_2 according to the CO_2 business-as-usual scenario (Shared Socioeconomical Pathway SSP5-8.5) indicate that critical conditions for calcifiers will be reached in Mediterranean and Atlantic waters before the end of the current century, with corrosive environment (undersaturation of carbonate) expected within the next 200 years.

Key words: aragonite; biogenic calcification; ocean acidification; Strait of Gibraltar.

Carbon dioxide fluxes and pH levels in the surface waters of the North-East Levantine basin (Mediterranean Sea)

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Since industrial revolution more than 30% of the anthropogenic CO_2 emissions have been absorbed by the global ocean. However, CO_2 is not uniformly absorbed over the globe and marginal seas might be important sink of atmospheric CO_2. In particular, the Mediterranean Sea has displayed higher ocean acidification rates in respect to the global ocean, suggesting a net air-sea CO_2 flux on a basin scale. Nevertheless, the paucity of available data prevents a final assessment of air-sea CO_2 fluxes, especially in the Levantine Basin.

In this study, we measured pCO_2 and pH in surface seawater in different seasons in the north-eastern Levantine Basin. pCO_2 was measured continuously by the CONTROS-HydroC pCO_2 sensor during eight cruises carried out between 2019 and 2021 while pH was measured by SeaFET pH sensor in two cruises (autumn 2020 and 2021).

Globally, pCO_2 and pH data ranges were 285-584 ppm and 7.98-8.14 pH units on the total scale, respectively. Air-sea CO_2 fluxes were positive (ocean to atmosphere) in spring, summer and autumn while it was neutral to negative in winter. On annual basis, the study area was a net source of pCO_2 to the atmosphere. Coastal and offshore waters displayed a different seasonal variability, being coastal waters more sensitive to temperature and primary production variations. A peculiar behaviour was observed in the Rhodes gyres which displayed negative and minimum fluxes in winter and in late summer, respectively. All over the areas and seasons, the temperature was highly correlated to pCO_2 and poorly correlated to fluorescence indicating a more important role of physical processes in respect to biological ones. The negative fluxes reported in winter in the Rhodes gyres and in the Cilician basin, both areas of Levantine Intermediate Water formation, need to be further investigated to assess their potential role in anthropogenic CO_2 invasion.

Key words: air-sea CO_2 fluxes, East Mediterranean Sea, annual CO_2 budget

New marine observations of carbonate chemistry variability and ocean acidification state in North West Africa waters

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The Canary Current Large Marine Ecosystem (CCLME) region supply very significant local and international fish resources, based largely on small pelagic fish and artisanal fisheries. Especially on the North West Africa Atlantic Sea, the fishery market contributes to economy of the region bordering this sea and provide an important food and employment to coastal communities. In 2017, the 30-year long EAF Nansen Program (FAO and Norway), began with studies on ocean acidification along the CCLME region. Here, we show the first results on the ocean acidification state from this new research theme focusing on the North West Africa waters (from Morocco (35°N) to Senegal (12°N). Between May and July 2017, samples were measured, in this region, onboard the R/V Dr. Fridtjof Nansen for total alkalinity and pH using potentiometric titration and spectrophotometric pH measurements, respectively. The other parameters describing the carbonate chemistry and ocean acidification state were derived from salinity, temperature and pressure combined with AT and pH, using the CO2SYS calculation program. The survey performed at twenty-seven sections perpendicular from the coast (the mesopelagic transect included) with a total of 110 stations in the full water column. We found large variability along the coast, connected to upwelling/mixing of water masses, primary production, temperature and biological processes. In this presentation, we present the first ocean acidification data from the North West Africa waters and discuss the variability in context of deep-water intrusions, upwelling, temperature, and phytoplankton production.

Key words: North West Africa, EAF Nansen Program, upwelling, Carbonate chemistry variability, Ocean acidification

Where Does The Extra Carbon Go? Dominant Impacts of Anthropogenically Modified Carbonate Chemistry in a Temperate Fjord System

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Recent observations have shown large spatial and temporal variations of pH and Aragonite Saturation (AS) in the Salish Sea and in other estuarine and coastal systems. These changes are significantly larger than the global anthropogenic change, which raises questions concerning potential effects on regional biogeochemistry, ecosystem health, and regional stakeholders such as shellfish farmers. In addition, to predict future changes to the global carbon cycle, it is critical to understand the role that anthropogenic carbon plays in a highly naturally variable coastal regions. Here, we use the SalishSeaCast biogeochemical model to determine dominant features of this spatiotemporal variation in the Salish Sea, a temperate, naturally carbon-rich estuary, on an annual timescale. The model resolves dissolved inorganic carbon, total alkalinity, pH, and AS at hourly and daily resolution. We first characterize dominant features of the carbonate chemistry in this fjord system and examine the influence of previously-identified drivers, including biological activity and open-ocean exchange, on this natural cycle. We then use the model to investigate the fate of the atmospheric and open-ocean anthropogenic carbon signal in this system, and compare the present-day carbon balance of the system to the preindustrial balance. We discuss the effects of anthropogenic carbon on biologically-relevant metrics, such as aragonite saturation horizon and pH shifts, and as well effects on the air-sea carbon flux balance of the system. Finally, we discuss our findings in the broader context of other coastal regions.

Key words: numerical modelling, coastal biogeochemistry, aragonite saturation

Synthesis and Visualization of Carbonate and Nutrient Data on North American Continental Shelves

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The lack of an internally consistent carbonate and nutrient chemistry data product in the coastal ocean hampers our ability to understand the societal vulnerabilities of ocean acidification (OA) in an area where most of the population reside and most of the economic activities related to commercial and recreational fisheries as well as aquaculture industries are located. In this collaborative effort, we plan to compile, quality control, and synthesize over two decades of discrete measurements of carbonate, nutrient, and hydrographic data from North America's continental shelves, with an initial focus on U.S. coastal waters and the hope of promoting and catalyzing future OA research in the area. This project will contribute to the North American node of the Global Ocean Acidification Observing Network (GOA-ON). Specifically, the objectives of this project are: (1) to generate an internally consistent coastal carbonate and nutrient data product that will be accessible in uniform formats to all users; (2) to develop climatologies (mean fields of oceanographic variables on a regular geographic grid at specific depths) for pH on total scale (pH_T), aragonite and calcite saturation states (Ω_{arag} and Ω_{cal}, respectively) and to provide a baseline for future changes and help validate or initialize regional models; and (3) to produce atlases (a collection of graphical depiction pictures of the area of interest, including climatological mean fields, etc.) for pH_T, Ω_{arag} and Ω_{cal} using the World Ocean Atlas (WOA) infrastructure at the NOAA National Centers for Environmental Information (NCEI) to help inform the general public about the OA status and its trends in each region and provide actionable information for marine resource decision makers.

Key words: Coastal synthesis, Data product, Ocean acidification, Biogeochemical data, nutrients.

Modelling ocean acidification in a rapidly changing Arctic ocean

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A coupled sea ice-ocean biogeochemistry model with pelagic and sea-ice ecosystem components including carbon cycling is applied for the Arctic. The model has been run over over recent and future time periods (1979-2080) and evaluated with respect to ocean and sea-ice changes, ocean acidification and CaCO3 saturation. The model indicates significant regional variability in carbon fluxes and ocean acidification in the Arctic with some regions already perpetually undersaturated with respect to aragonite at the surface. Including the sea-ice carbon pump shows only a small change to the total uptake of carbon but a marked decrease in the seasonal variability of both DIC and TA, as well as an offset in the summertime saturation state in the surface Arctic Ocean. The analysis highlights regional and interannual variability during the time period of strong sea-ice loss and future projections indicate a continuation of the past trend. A comparison of CMIP6 models will also be presented.

Key words: Arctic, ocean acidification, carbon cycle, modelling, biogeochemical modelling

Drivers, Variability, and Projections of pH and Calcium Carbonate Saturations in Three Distinct Regions of the Gulf of St. Lawrence.

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The Gulf of St. Lawrence is a unique semi-enclosed system. It receives one of the largest freshwater runoff in North America, and is strongly influenced by oceanic water originating from the Arctic and Atlantic Oceans. The presence of deep channels allows these waters, which remain in great part isolated from the surface, to flow far inland. The gulf is also influenced by strong tidal mixing and upwelling in particular areas. The topographic and hydrographic features of the Gulf of St. Lawrence lead to the presence of hypoxic and acidified waters at the head of the deep channels, with observed pH values as low as 7.52 near the bottom. Sampling of the carbonate system started only recently (last decade) in some areas of the Gulf, with a more spatially comprehensive sampling through the Atlantic Zone Monitoring Program since 2014. Our knowledge of the processes governing the state and the variability of the carbonate system in the various regions of the Gulf thus remains incomplete. Moreover, the system is acidifying at a fast pace and baseline conditions are needed. Here we present the results of a coupled physical-biogeochemical model and look at the processes driving seasonal and interannual changes (including sea-ice formation/melting, spring bloom, mixing, large-scale atmospheric forcing) in the different regions of the Gulf of St. Lawrence. We also show the behaviour of the system in winter, and the strong spatial variability in CO_2 fluxes between the atmosphere and the ocean. Finally, using the model in projection mode, we identify the years when calcium carbonate saturation states will reach critical values.

Key words: Modelling, coastal, drivers, variability, projections

Lower Cost and Complexity for Carbonate Chemistry Measurements: the pCO_2 to Go as a Tool for Observation and Adaptation

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High-quality carbonate chemistry measurement systems are often inaccessible to those who are most vulnerable to the effects of ocean acidification, such as shellfish hatcheries, small-scale fishers, and ocean-dependent communities. Lowering cost and technical barriers to monitoring can enable these stakeholders to better understand their local conditions and adjust their practices when events such as seasonal upwelling may be impacting the resources upon which they rely. The pCO_2 to Go is a hand-held, low-cost analyzer that allows for pCO_2 measurements to be made directly at the seawater surface as well as from discrete samples, enabling measurements in a number of environments that are not currently captured by long-term monitoring stations and at a level of accuracy that lab-grade pH meters rarely attain. One such application for the pCO_2 to Go and its associated user guide is shellfish hatcheries. With the pCO_2 to Go and included user-friendly manipulation application, staff can measure the pCO_2 of their incoming seawater, then use regional knowledge of alkalinity characteristics to calculate quantities of buffering reagents that will adjust the saturation state in specific tanks to stable, favorable conditions for sensitive larvae. The analyzer, manipulation application, and methodology are currently being tested at shellfish hatcheries that include the Alutiiq Pride Marine Institute in southcentral Alaska. Furthermore, users who pair the pCO_2 to Go with other measurements to constrain the carbonate chemistry system can collect coastal data to increase spatial coverage as well as research understudied habitats, such as clam gardens. Low-cost, portable tools such as the pCO_2 to Go are needed to provide marine resource users around the globe with the ability to understand and adapt to changing ocean conditions to limit the economic and socio-cultural impacts of OA.

Key words: technology, capacity, aquaculture, bivalve

On the causes of the seasonal dynamics of the inorganic carbon chemistry in Bahía de los Ángeles, Gulf of California (México)

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The surface waters of the Ballenas Channel, whitin in the Gulf of California, are characterized by presenting thermohaline and biogeochemical conditions that depend on the water masses present. This oceanic region is influenced by an intense vertical mixing. Since these oceanic surface waters (and its biogeochemical conditions) are subsequently transported into the interior of Bahía de los Ángeles (BLA), it is relevant to evaluate the timing and intensity of this influence, as well as it biogeochemical implications on this bay. In order to verify the later, in this study we have evaluated the seasonal and spatial variability of dissolved inorganic carbon (DIC), total alkalinity (TA), apparent oxygen utilization (AOU), and nutrient variables over 19 discrete monthly monitoring campaigns that covered 12 stations along a fixed transect in BLA from June 2017 to October 2019. This was accompanied by vertical CTD profiles to identify the water masses present and evaluating how the observed spatial gradient change seasonally. Our results highlighted the presence of spatial gradients which allowed to determine regions within the bay, each one with a particular ~~and~~ processes that controls the inorganic carbon biogeochemistry. It was found that the seasonal dynamics of DIC, AOU, nitrate, and temperature in BLA corresponded to the presence of Subtropical Subsurface Water (SSW) during winter and to Gulf of California Water (GCW) during summer. The alternating dominance of these water masses in the has important implications for the ecological processes within the bay, since they (1) define the winter (December to May) and summer (July to October) conditions and (2) enrich the bay with DIC and nitrate during winter. The proposed regionalization within the bay indicated three zones which are consistently present along the year (winter and summer) and corresponded well to the presence of intense production-remineralization processes in the interior of the bay.

Key words: seasonal variability, inorganic carbon chemistry, Ballenas Channel, Water Masses, coastal variability.

Carbonate System Reconstruction at the Western Tropical Atlantic Ocean Surface Waters

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The purpose of this study is to reconstruct the carbonate system time series at the Western Tropical Atlantic Ocean from 1998 through 2018 (20 years) using sea surface temperature and salinity data from the PIRATA (Prediction and Research Moored Array in the Tropical Atlantic) buoy at 8°N 38°W, and describe its variability through time. Two empirical models (equations), proposed by Bonou et al. (2016) and applied to several studies in this region, were used to estimate total alkalinity (TA) and dissolved inorganic carbon (DIC) concentrations using sea surface salinity data. From those two parameters we were able to further calculate other components of the carbonate system (pH, fCO_2). TA showed a slight decrease through these 20 years (around 0.3 $\mu mol\ kg^{-1}\ year^{-1}$ p-value = 0.6865), along with a more significant decrease in pH (around 0.006 $year^{-1}$ p-value $< 2.2 * 10^{-16}$). DIC and fCO_2, however, showed increasing values through time (around 0.7 $\mu mol\ kg^{-1}\ year^{-1}$ p-value$<2.2*10^{-16}$ and 0.8 $\mu atm\ year^{-1}$ p-value$<2.2*10^{-16}$, respectively). Even though the area of this study is well known for the great seasonal input of fresh water from the Amazon river plume, and rainfall from the Intertropical Convergence Zone, which results in sea surface salinity freshening, thus decreasing TA and DIC concentrations, these preliminary results showed some temporal trend besides the natural seasonality, probably related to an interplay between biological activity, induced by the Amazon River plume and increasing anthropic emissions of CO_2.

Key words: Time-series, Ocean acidification, PIRATA, CO_2

Seasonal shift in pCO_2 source and sink status in the eastern Arabian Sea

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Oceans are one of the crucial reservoirs of anthropogenic carbon. Its carbon dioxide (CO_2) holding capacity is dependent on physicochemical and biological factors, and hence any shift in them can alter the carbon dynamics of the oceans. Arabian Sea has been earlier reported as a perennial source of CO_2 to the atmosphere. To know whether the same has been maintained even after two decades this study has been carried out. The near-surface partial pressure of carbon dioxide (pCO_2) in the eastern Arabian Sea (EAS) was measured for ten months from December 2017 to January 2019. The summer monsoon (SM) showed maximum pCO_2 levels (524 ± 177 µatm, August) in the entire study period. The coastal regions exhibited considerable variation from 261 to 1222 µatm, and was mainly affected by freshwater input from the adjoining rivers/estuaries and intense upwelling. Similarly, during the winter monsoon (WM), EAS was also oversaturated with pCO_2 (494 ± 30 µatm, January) with higher values in the northern region compared to the south owing to vertical mixing driven by convective mixing. However, pCO_2 levels were undersaturated in spring intermonsoon (SIM; 431 ± 52 µatm, May) and early SM (426 ± 69 µatm; June). Our results show a rise of 126.1 µatm pCO2 in the EAS at the rate of 5.7 µatm y^{-1}. Therefore, we conclude that monsoons were a source of pCO_2, with SM higher than WM, whereas SIM was a sink of pCO_2.

Key words: inorganic carbon, Arabian Sea, pCO_2, seasonal, upwelling

Ocean Acidification monitoring project in Palau

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Coral reefs today are diminishing worldwide due to harmful human activities and natural activities. Over the next 50-100 years, significant increases in temperature, carbon dioxide, and typhoons (or hurricanes) will threaten the survival of the world's coral reefs. Detailed studies of the impacts of changing climate on corals in a range of environments are critical. We are starting our third year of monitoring environmental conditions with a highly instrumented mooring in Malakal harbor, Palau in the Western Pacific. Carbon dioxide is measured in the atmosphere and surface seawater every three hours using a MApCO_2 system. This location is a net source of CO_2 to the atmosphere because of strong coral calcification in the harbor. The range of seasonal variability in the surface CO_2 (>300 ppm) is significantly larger than typically observed in the open ocean. Through this project, managers will have new information on carbon dioxide levels and other environmental parameters in their waters that will allow them to better understand and manage the stresses facing the Palau corals.
Key words: coral reefs, ocean acidification, carbon dioxide, climate change

Short-term variation of pH in seawaters around Japan coastal areas: Its characteristics and forcings

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pH of coastal seawater varies by several local forcings such as water circulation, terrestrial inputs and biological processes, and all these forcings can change along with global climate change. Understanding of the mechanism of pH variation in each coastal area is thus important to make realistic future projection taking changes of these forcings into account. From 2020 to 2021, we carried out parallel year-round observations of pH and related ocean parameters in four stations around the Japan coast (Miyako, Shizugawa, Kashiwazaki and Hinase) to grasp general characteristics of short-term pH variation in Japan coastal area as well as their forcings. Amplitude of seasonal-scale variation for pH and Ω_{ara} was 0.4 and 1.5, respectively, for all stations, while that of short-term variation (timescale of several weeks) varied from 0.1 to 0.6 for pH and from 0.6 to 1.5 for Ω_{ara}, respectively, depending on the productivity. For all stations, main forcing of Ω_{ara} variation in seasonal scale was water temperature, while biological activity explained most of short-term Ω_{ara} variation. In addition to these variations, sporadic pH drawdown with several-days timescales associated with rainfall events were repeatedly observed. Extent and duration of pH drawdown per rainfall was roughly relative to the extent of development of the hinterland. Detailed analysis indicated that main mechanism of the observed pH drawdown was biological degradation of organic matters that was transported from rivers and estuaries by fresh water plume. Rainfall events are predicted to increase in future Japan area, and this might increase frequency and extent of short-term pH drawdown event in future Japan coastal areas. Artificial measures such as re-creation of seaweed bed and/or tideland in river mouths might be effective to suppress organic matter release to the wider coastal areas, and hence diminish the extent of pH drawdown in future rainfall events.

Key words: coastal pH, short-term variation, rainfall events

Arctic Ocean annual highs in pCO_2 and $[H^+]$ could shift from winter to summer

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Long-term trends in ocean acidification will differ between seasons as will related stress on marine organisms. As atmospheric CO_2 increases, so do seasonal variations of pCO_2 and acidity (H+]), causing summer and winter long-term trends to diverge. These trends may be further influenced by an unexplored factor, changes in seasonal timing. In Arctic Ocean surface waters, the observed seasonal timing is typified by a winter high and summer low because biological effects dominate thermal effects. Here we show that 27 Earth system models have similar timing under historical forcing but generally project a very different future. Under mid-to-high end CO_2 emission scenarios, today's broad summer minimum in each of these two CO_2 system variables eventually splits, in most models, into an early summer minimum (as NPP peaks earlier) and a late-summer maximum (as summertime SST increases). This late-summer sign reversal often inverses the chronological order of the annual high and low. The annual high shifts by up to six months, much more than seen previously for any climate variable. The main cause is physical climate change, namely sharp increases in summertime SST that occur in all models particularly in the shelf seas owing to increased loss of summer sea ice. The associated thermal effect on pCO_2 and [H+], which are linearly related, eventually overwhelms non-thermal effects (biology + circulation). Furthermore, the timing change makes this century's increase in summer pCO_2 and $[H^+]$ about 25% more than had one assumed that seasonal variations in the drivers did not to evolve. Thus the timing change worsens summer ocean acidification, in turn lowering tolerance of endemic marine organisms to increasing summer temperatures.

Key words: Arctic Ocean, pCO2, [H+], seasonal cycle

Carbonate system along the Florida Reef Tract: Long term trends, seasonality, and regional variation

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Global ocean acidification (OA), caused by increasing atmospheric CO_2, threatens the physiology of calcifying organisms including reef-building corals. Nearshore carbonate chemistry is further influenced by physical and biological processes, which may modulate an organism's susceptibility to OA. These processes vary in space and time, and remain poorly quantified despite their importance. As part of NOAA's National Coral Reef Monitoring Program (NCRMP) and South Florida Ecosystem Restoration Research (SFERR) cruises, carbonate chemistry was characterized along 10 inshore-offshore transects located along the Florida Reef Tract. Discrete seawater samples were collected bimonthly from 2015 to 2021 (n=1318). We assessed long-term trends and seasonal patterns in the carbonate chemistry of major biogeographic regions (Biscayne Bay, Upper Keys, Middle Keys, and Lower Keys) further distinguished by shelf position (inshore, mid-channel, and offshore). Significant declines in aragonite saturation state (Ω_{Arag}) and pH were detected in the mid-channel and offshore reefs in every biogeographic region. These patterns were not detected at the inshore reefs, where long-term trends were obscured by strong seasonal variations. Total alkalinity (TA) and dissolved inorganic carbon (DIC) were depleted relative to offshore signals at all inshore sites during spring and summer, indicating net calcification and photosynthesis. Conversely, TA and DIC were typically elevated on inshore reefs in autumn and winter, indicating net dissolution and respiration. Inshore DIC depletion during the spring resulted in increased Ω_{Arag} in the Upper and Middle Keys, but not in Biscayne Bay. Inshore reefs of the Florida Keys may benefit from biologically-driven refugia that buffer, obscure or acclimatize organisms to acidification stress. However, alteration in benthic community composition may eliminate this buffering capacity or lead to acidification enhancement.

Key words: Coral reefs, Florida Keys, Ocean acidification, seasonality.

CO_2 fluxes between air-water interface at SAMBAR Project

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The area of the Atlantic Ocean between 33-38 °S is an area where the flow of the Brazil current meets the Malvinas current, forming a region with a strong gradient of potential vorticity, richly populated with meanders, vortexes and filaments, and known as Brazil-Malvinas Confluence. This region has strong thermal gradients that are highly variable in time and space. The changes generated by the encounter of currents with very different characteristics, combined with the influence of the waters coming from the Prata estuary make this region an interesting area for the study of CO_2 fluxes. The data presented comes from a partnership in the SAMBAR Project, between April and May of 2018/2019, on the Oceanographic Ship Alpha-Crucis, coordinated by the University of São Paulo. Ph, temperature, salinity and pCO_2 were measured. The data on salinity, ph and surface temperature are derived from the vessel's SAD Data Acquisition System file. In order to obtain the pCO_2 data, a closed system with a water-air balance was used, coupled to an Infra-Red Gas Analyzer (IRGA – PP systems). Analyzing the data in relation to a transect perpendicular to the coast, it is observed, as expected, a CO_2 output from the water-atmosphere direction that decreases according to the distance from the coast. When moving away from the continental shelf, these values decrease, passing to an entry of CO_2 atmosphere-water. However, in an open ocean region, CO_2 concentrations vary from 400, reaching 370ppm. This variation in CO_2 concentrations also accompanies the variations observed in the temperature and salinity of these surface waters, showing that small filaments, vortexes or meanders can influence the carbon flow in this region. This fact corroborates the importance of knowing more and more about the variations in CO_2 fluxes observed in this dynamic area that is the Brazil-Malvinas Confluence.

Key words: Brazil-Malvinas, Carbon, Atlantic Ocean

Carbonate chemistry and accretion/dissolution dynamics on the southern-most coral reefs in the Western Indian Ocean

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Purpose: The southern-most coral reefs in the Western Indian Ocean are located in South Africa. These reefs are particularly interesting from a climate change perspective, but there is little knowledge on the dynamics of their carbonate chemistry and biogenic accretion and dissolution. This study investigated variation in the carbonate dynamics of the reef environment as well as biogenic accretion.

Methods: Carbonate chemistry was monitored at hourly intervals with a permanently moored SeapHOx^{TM} V2 Ocean CT(D)-pH-DO Sensor. In addition, water samples were collected from four representative sites and were analysed for total alkalinity using an automated titrator (Metrohm 888 Titrando). Accretion and dissolution of biogenic carbonate was assessed at these sites by deploying, respectively, pre-weighed polyvinyle chloride tiles and de-organified *Acropora austera* coral nubbins at three reef sites where the water samples were collected, during the austral spring-summer and autumn-winter periods.

Findings: Temperature ranged from 19.6–28.5°C with an average ± standard deviation of 25.6±1.7°C, while the pH ranged from 7.93–8.08, averaged 8.05±0.02 and showed an obvious diel cycle. Total alkalinity averaged 2287.2 ± 16.6 mmol/kgSW. Aragonite and calcite saturation states were 3.17 ± 0.46 and 4.81 ± 0.70 respectively. Most of the accretion resulted from amorphous and calcitic calcium carbonate organisms and averaged 122.8±109.8g $CaCO_3$ $m^{-1}.yr^{-1}$. Coral nubbins decreased in mass indicating dissolution rates averaging 0.13±0.16 g $CaCO_3$ yr^{-1}.

Conclusions: This study was the first to quantify the temporal and spatial carbonate dynamics associated with the southern-most coral reefs in the Western Indian Ocean. Accretion and dissolution dynamics indicated the non-net accretive characteristics of these reefs that flourish on fossilised sand dunes. This is despite the relatively high Aragonite (>3) saturation. The study will continue for at least three years to derive a more holistic understanding of the annual, seasonal, and diel variations in relevant carbonate parameters. This knowledge will be vital to assess future changes in ocean acidification in the region.

Key words: Aragonite; Biogenic accretion; Calcite; Dissolution; High-latitude coral reef

Effects of contrasting land uses on the availability of Coloured Dissolved Organic Matter (CDOM) and the carbonate system in the coastal ocean

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Changes in land use have become a global environmental problem in recent years. Recent studies show that anthropogenic uses in watersheds can further alter biogeochemical cycles in the adjacent coastal ocean. Agriculture and livestock (grassland use) have replaced native forest in most of the watersheds that drain to the inland sea of Chiloé, in southern Chile, where the core of the mussel aquaculture industry is located. These anthropogenic uses modify the flow of nutrients and organic matter, with potential impacts on carbonate chemistry in the adjacent coastal zone, with possible implications for shellfish activity in this region. To date, there are no references connecting the impact of color dissolved organic matter (CDOM) availability for carbonate chemistry in the area's coastal ocean. Here, we used a combination of land use maps, statistical analyses, and field campaigns to characterize carbonate chemistry, CDOM, nutrients, chlorophyll, in the coastal zone of an intervened and a less intervened watershed. The results show that the less intervened watershed has 82% its surface covered by forest, and in its coastal zone a low $CaCO_3$ saturation state was observed, as well as total alkalinity (A_T) and dissolved inorganic carbon (DIC). While the concentration of CDOM and humic-like compounds was high. On the other hand, the coastal zone of the most intervened watershed (with 38% its surface covered by grassland-agriculture) was characterized by high concentration of nutrients, A_T, DIC and low pH. A strong negative correlation between A_T, DIC and Ω_{Ar} with CDOM/fDOM suggested the influence of terrestrial material on seawater carbon chemistry.

Key words: Land use, Coloured Dissolved Organic Matter, mussel, carbonate chemistry

Global ocean acidification indicators: past, present, and future

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Accurate projection of future ocean acidification (OA) indicators is critical to support OA research and guide society's regional OA adaptation effort. In this study, a hybrid OA data product is produced that is based on three recent observational data products: (a) the Surface Ocean CO_2 Atlas (SOCAT, version 2021), (b) the Global Ocean Data Analysis Product Version 2 (GLODAPv2, version 2021), and (c) the Coastal Ocean Data Analysis Product in North America (CODAP-NA), and 14 Earth System Models from the sixth phase of the Coupled Model Intercomparison Project (CMIP6). The trajectories of nine OA indicators, including fugacity of carbon dioxide, pH on Total Scale, total hydrogen ion content, carbonate ion content, aragonite saturation state, calcite saturation state, Revelle Factor, total dissolved inorganic carbon content, and total alkalinity content are provided under preindustrial conditions, historical conditions, and future Shared Socioeconomic Pathways: SSP1-19, SSP1-26, SSP2-45, SSP3-70, and SSP5-85 from 1750 to 2100 on a 1˚ × 1˚ global surface ocean grid. These projections are an improvement over previous versions with respect to the quantity, recency, temporal coverage, and diversity of the underlying data; the many model simulations; and the diversity of the provided projections with respect to the properties estimated and the socioeconomic pathways considered.

Key words: Ocean acidification indicators; Earth System Models; Global surface ocean; past, present and future.

Near-Term Predictions of Ocean Acidification

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Marine resource planning has the potential to benefit from near-term predictions of ocean physical and biogeochemical state in important ecosystems. Initialized earth system models have been shown to skillfully predict the real-world evolution of physical and biogeochemical state. Here, we use the novel Community Earth System Model (CESM) Seasonal-to-Multiyear Large Ensemble (SMYLE) to quantify multi-month predictive skill of multiple ocean stressors, including ocean acidification and warming. We find that CESM-SMYLE shows high predictive skill multiple months in advance across various regions for both physical and biogeochemical tracers. The ability of the model experiment to skillfully predict important ocean tracers could provide useful information for marine managers, allowing them to potentially estimate ocean state multiple months in advance.

Key words: ocean acidification, earth system model, predictability, multiple stressors

Spectrophotometry-derived *in situ* ocean acidification time series for the Fiji Islands and Dominica: Addressing SDG 14.3 requirements

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The United Nations Sustainable Development Goal 14.3 urges countries to minimize and address the impacts of ocean acidification through enhanced scientific cooperation and monitoring; to date countries the most at risk from climate change such as Small Island Developing States (SIDS) have no baseline data on the acidification levels of their coastal waters. To address this issue, the National Oceanography Centre of the UK developed a monitoring approach using a novel, semi-integrated and autonomous microfluidic lab-on-chip system to measure pH. Using standard spectrophotometric analytical method it offers high accuracy (<0.005) and precision (<0.001) climate-quality pH measurements for ocean acidification research. We have deployed this sensor at a coastal site in the Fiji islands at a depth of 14m, producing the first continuous pH time-series for this locality and the Pacific Islands in general. Measurements were taken at 2-hourly intervals and showed a high diurnal variability, most likely the cause of biological activity of the coral reefs where the sensor was deployed. However once the background biological noise is filtered, the ability to discern long-term trends in oceanic pH variations make this technology a reliable tool to inform policy and meet the SDG 14.3 targets of SIDS.

Key words: Ocean Acidification, Time Series, Spectrophotometry, Small Island Developing States, SDG-14.3

Utilizing Planktonic Foraminiferal Morphometrics as a Gulf of Mexico Paleo-OA Proxy

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The calcium carbonate remains of planktonic foraminifera preserved in seafloor sediments have widely been used to reconstruct Earth's past climate and ocean conditions. Foraminiferal morphometrics (the geometry of fossil shells) have been shown to significantly correlate with ambient seawater carbonate chemistry, with elevated carbonate ion concentration coinciding with more robust, thicker foraminiferal shell walls. Utilizing the foraminiferal morphometrics of well-preserved shells found in recent sediment archives (short, high-resolution sediment cores and sediment trap time-series) offers an opportunity to quantify the Post-Industrial progression of ocean acidification, particularly in the absence of in situ observations. We use the calcification response of two planktonic foraminifera species, *Orbulina universa* (a surface-dwelling species) and *Neogloboquadrina dutertrei* (a thermocline-dwelling species) to quantify the reduction in calcium carbonate production by these two species and to examine dynamics of the marine carbonate system in the open-Gulf of Mexico. We estimate population shell morphometrics by using a combination of area density ($\mu g/\mu m^2$; shell thickness) and micro-CT scans (shell density). Shells analyzed as a part of this study were collected by sediment trap (27.5N, 90.3W, 2008-2010, 1,150 m water depth) and multi-core (TPA-MC03, 25.99N, 85.99W, 2021). Morphometric proxy reconstructions are compared with available in situ carbonate chemistry measurements for the Gulf of Mexico and represent the first such paleo-OA record of its kind for the region.

Key words: Planktonic foraminifera, Gulf of Mexico, Morphometrics, Area Density, micro-CT

Carbonate chemistry along the Pacific coast of Costa Rica

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Carbonate chemistry data in the Eastern Tropical Pacific (ETP) is scarce and this lack of information constrains the acknowledgement of changes in seawater chemistry, as well as the study of its impact on marine organisms and ecosystems, including reef development. This study aims to fill the knowledge gap of carbonate chemistry data in coastal areas from the ETP and disclose its role in local reef development. Physicochemical parameters were measured in situ and from discrete water samples along the Costa Rican Pacific coast over a one-year study period, during dry and rainy season. Three sampling locations were selected: Santa Elena in the north, Marino Ballena in the south and Matapalo between these two locations. The obtained results show a high variability of seawater chemistry along this coast, with pH that ranges between 7.85 and 8.04. Coastal upwelling, photosynthesis and respiration are the main drivers of the carbonate system in the north at Santa Elena. Conversely, in the south at Marino Ballena, enhanced river discharges in combination with calcification and dissolution exert a strong control on the carbonate chemistry, with dissolution occurring mainly during the rainy season. Compared to these locations, Matapalo displays a relatively low seasonality and is confirmed as a “transition location” along a gradient caused by upwelling in the north and river discharges in the south. Nutrient inputs caused by upwelling and river discharges in combination with the aragonite saturation state (omega), salinity and turbidity seem to control the distribution of key reef-building species along this coast. The dominant coral species in the north (*Pavona* spp. and *Pocillopora* spp.) are highly tolerant to low omega and nutrient-enriched cold waters. Main reef-builders in southern locations (*Porites* cf. *lobata* and *Pavona clavus*) cope better with low salinity, low omega and loads of suspended matter.

Key words: discrete samples, coastal zone, variability, Eastern Tropical Pacific, coral reefs

Evaluating Seasonal and Long-term Carbon Dynamics in the South Pacific

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Understanding the variability in the processes controlling carbonate chemistry over seasonal to decadal time scales is critical to forecasting the impacts of ocean acidification and developing effective mitigation. The Munida Time Series is a repeat oceanographic transect along the Otago shelf off southeastern New Zealand. This timeseries has documented ocean acidification in New Zealand waters, showing the decline in surface ocean pH consistent with increasing atmospheric carbon dioxide over the past two decades and it provides a unique opportunity to evaluate the physical and biological processes that control carbonate chemistry across the Otago Shelf, with its proximity to the subtropical front and regional dominance of the Southland Current (SC). We have used these timeseries observations with ancillary datasets to investigate the seasonal dynamics and long-term trends in carbon cycle of the subantarctic waters (SAW) of the South Pacific by evaluating the dissolved inorganic carbon (DIC) budget in the surface layer, assessing the contributions of air-sea gas exchange, freshwater flux, diffusive transport, vertical entrainment, horizontal advective transport and biological production, including calcification ($CaCO_3$). Monte Carlo simulations were used to assess the uncertainty of the change in DIC according to the controlling processes where the nonlinear relationships describing the system are complex. DIC is added to the region through advection of higher DIC concentrations in the SAW along the SC as well as by air-sea exchange. The region is a sink for atmospheric CO_2 and has been strengthening by 0.6 mmol CO_2 $m^{-2}y^{-1}$. The carbon budget is balanced by net community production (NCP) and calcification. NCP has increased at a rate of 0.7 mmol CO2 $m^{-2}y^{-1}$, which is also evidenced by an increase in annual chlorophyll concentrations over the last two decades. NCP is lower in this high nutrient low chlorophyll region compared to the North Pacific, while $CaCO_3$ production was higher.

Key words: carbon cycle, ocean acidification, model, uncertainty, coastal processes

Theme B: Organism responses and consequences of living in a high CO_2 world in a multi-stressor framework

Physiological and immune response of oysters to climate change as a function of diet and tidal regime

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Ocean acidification and warming caused by increased anthropogenic carbon dioxide emissions pose a tremendous challenge to marine calcifiers such as intertidal bivalves. The approach to studying acclimation potential or adaptation to climate change are often conducted under artificial conditions where food is provided *ad libitum* and do not consider tidal emersion. These limitations present problems for extrapolating results to natural ecosystems. For instance, food provisioning and regular emersion can enhance or limit acclimation capacities of marine organisms. Here we investigate the physiological response of young Pacific oyster *Crassostrea gigas* exposed for 3 months to ambient and future (+3°C, -0.3 pH unit) climate scenarios under two food regimes (*ad libitum* vs restricted) and two tidal levels (subtidal vs intertidal, emersion twice daily) under laboratory conditions. Oysters were sampled for biometric and physiological rate measurements (growth and food intake), biochemistry (energetic reserves and enzyme assay) and histology to evaluate their reproductive status. At the end of the experiment, oysters were further challenged with a viral disease to investigate the physiological cost of acclimation to these conditions and their immune response. Preliminary analyses suggest that food level was the most influential factor, followed by climate scenario and tidal level. We indeed found that growth, food intake, reproduction and disease resistance of oysters were negatively affected by food restriction. Future conditions enhanced oyster growth, physiological rates and sexual maturation, particularly at high food levels. Finally, tidal level had no major effect on these variables, suggesting physiological compensatory mechanisms during emersion. Our study suggests that the oyster is robust to future climatic conditions.

Key words: Ocean acidification, Ocean Warming, Multi-stress experiment, Bivalve, Physiological trade-offs

Impact of Ocean Acidification on Different Life Traits of the Gastropod Hexaplex trunculus

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Increased atmospheric CO_2 produced by anthropogenic activities will be absorbed by the oceans over the next century causing ocean acidification and changes in the seawater carbonate chemistry. According to IPCC (2014) a reduction of 0.3–0.5 pH units is already expected by 2100. An observed effect of ocean acidification is the lowering of calcium carbonate saturation states, which inhibits calcification rates in shell-forming organisms or may cause dissolution of the existing shell, thus reducing shell resistance and increasing predation pressure. The present study aims to investigate the sublethal and synergistic responses of long term exposure to low pH and increased temperature on the murex gastropod *Hexaplex trunculus* (Linnaeus, 1758). Adult gastropods were maintained under controlled conditions of temperature (ambient; increased +3.7°C) and pH (ambient; reduced -0.3 units) for more than two years. Effects on shell growth, density, porosity and structure thickness were investigated using micro-Computed Tomography (micro-CT) imaging technique. In addition, the results of a feeding experiment are presented in order to evaluate the feeding efficiency and performance of gastropods under the controlled treatments. Marine molluscs support community structure and ecosystem functioning, therefore their capacity to develop normally under altered environmental conditions is important. Their potential plasticity to environmental factors makes them an ideal model for the study of study of adaptation to ocean acidification.

Key words: ocean acidification, climate change, gastropods

Effect of low pH on calcification and mechanical properties of Peruvian scallop *Argopecten purpuratus*

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The uptake of anthropogenic CO_2 by the ocean modifies seawater pH and triggers the acidification process with consequences for the calcifying organisms such as bivalve molluscs. In fact, ocean acidification appears as a key stressor for organisms under the climate change scenarios. Along the Peruvian coast natural conditions of low pH occurs in the habitat of Peruvian scallop (one of the most important benthic resources) due to the nearby coastal upwelling waters. In this context, an experiment on juvenile Peruvian scallops *Argopecten purpuratus* (average size: 14 mm height) was performed in order to test the effects of low pH on calcification and the mechanical properties of their valves. During 28 days, scallops were exposed to two contrasted pH conditions: a control with unmanipulated seawater presenting pH conditions similar to those found in situ (pH_T = 7.8, which is low in comparison to other ecosystems) and a treatment, in which seawater was injected pure CO_2 reducing pH (pH_T = 7.4). Net calcification rates were reduced by about 10% respectively in the low pH treatment. The crushing force in the right valves appears higher than in the left valves. No difference between the two treatments was found for crushing force and extensibility in right and left valves. However, the microhardness was positively affected in both valves (right and left) in the low pH condition. We suggest that the organic and inorganic composition and the microstructure of the valve could be altered by low pH, modifying the mechanical properties of the valves, such as strength and hardness. Therefore, a change in crystallographic orientation could increase the microhardness of new calcite formed under low pH. Furthermore, low pH did not affect the proportion of calcite/aragonite in the whole shell. However, a detailed study of the newest parts of the shell, which would have grown in low pH conditions, is recommended, as well as the study of the ultrastructure in natural populations of Peruvian scallop.

Key words: ocean acidification, pH, *Argopecten purpuratus*, microhardness, crushing force, mechanical properties.

The Effects of Ocean Acidification on Macroalgal Physiology and Ecology and Implications for Coral Reefs

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Coral reefs are marine ecosystems of great biological diversity and immense environmental, societal and cultural value. Coral reefs undeniably depend on hard corals for their existence; however, benthic macroalgae (or seaweeds) play fundamental roles in essential ecological and biogeochemical processes in reefs. Crustose coralline algae (CCA), for example, are crucial for reef cementation and are substrate providers for coral larval settlement, while filamentous turf algae are highly productive providing food for fish and invertebrate grazers. On the other hand, species of fleshy macroalgae have been involved in reef degradation, particularly when they grow out of control and outcompete reef-building corals, contributing to reef decline. Therefore, understanding the causes and consequences of macroalgal abundance and the impacts of increased CO_2 concentrations and other anthropogenic stressors on macroalgae is of critical importance for reef resilience and conservation. In this talk, I will give an overview of the state of knowledge on the effects of ocean acidification and its interactions with other global change stressors on physiological and ecological processes of key tropical macroalgal groups. In particular, I will analyse the influence of ocean acidification and warming on the growth and calcification of CCA, the variability in responses across taxa, and the potential implications for the survival of the group in future oceans. I will also discuss the physiological responses of fleshy macroalgae to elevated CO_2 and will then explore the ecological consequences of these effects. I will dissect how the process of space competition between corals and macroalgae changes in response to elevated CO_2 and examine the evidence supporting different mechanisms that mediate coral-algal competition under ocean acidification. In this talk, I will identify knowledge gaps that should guide future research to improve our understanding of the flow-on impacts of increased CO_2 on benthic macroalgae, coral-algal dynamics and more widely on reef ecology.

Key words: macroalgae, crustose coralline algae, calcification, dissolved organic carbon, coral reefs

From Scenario to Tipping-point experiments: revisiting responses of the Pacific oyster to Ocean Acidification.

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Ocean acidification and warming are main global threats causing significant impacts on calcifying organisms such as bivalves. We addressed this issue by experimentally studying the biological responses of the intertidal and widely cultivated Pacific oyster *Crassostrea gigas*. We first conducted exposures over a full reproductive cycle in which broodstock and offspring (D-larvae) were exposed to two temperatures (1821°C) under a realistic pH offset (-0.33 pH unit). The results showed that *C. gigas* was robust to such water changes during both gametogenesis and embryogenesis, and that there was no apparent transgenerational linkage. However, the Pacific oyster is an intertidal species that thrives in a mosaic of habitats where pH varies greatly throughout the year and can exceed locally the global ocean IPCC projections, while there is a global lack of reliable long-term coastal pH monitoring. We therefore designed a framework that allows up scaling the observations to a wide range of *C. gigas* niches. In a flow-through system, juveniles were exposed for several weeks to constant pH conditions ranging from pH_T 7.8 to 6.4 and then put back to ambient pH for recovery. Tipping points have been identified for growth, lipidome and physiological rates (ingestion, respiration, calcification) at pH 7.1–6.9, beyond which detrimental effects and reshuffling in membrane lipids were observed. Shell thickness was impacted as soon as the pH dropped. Growth stunting, observed below the tipping point, seemed irreversible when the pH returned to ambient. While we show that *C. gigas* exhibits a high tolerance threshold to ocean acidification, the loss of shell integrity and lack of growth recovery capacity raise concerns about the fate of natural and farmed oyster populations. This is of particular concern in dynamic environments, such as coastal areas, where acidification events are expected to increase in intensity, duration and frequency in the near future.

Key words: Ocean acidification, Scenario, Tipping point, *Crassostrea gigas*, Macrophysiology, Growth recovery

Mechanism of local adaptation to natural variability in pH in marine calcifiers

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The role of local adaptation in biological response to ocean acidification is increasingly acknowledge in the field of ocean acidification. Monitoring and understand the ecological niche at the right spatio-temporal scale (*weather*) is key to understand the sensitivity of any organism and ecosystems. However, the role of the variability in relevant carbonate chemistry parameters as a driver is often overlooked. Biological activity on the coastal zone is often creating high level of variability. For example, the balance between respiration and photosynthesis over the night/day cycle is leading to pH/pCO_2 variability in seagrass beds. We hypothesized that (i) marine calcifiers exposed to such variability would develop some adaptive mechanisms to anticipate and respond to this variability; (ii) these mechanisms would reach their limit under ocean acidification. We used artificial seagrass beds in flow through mesocosms fed with seawater with 4 different pCO_2. The resulting variability in carbonate chemistry was monitored and biological response of a marine calcifier (sea urchin larvae) to this day/night variability was documented over 2 weeks. Growth and net calcification were measured twice a day (low pCO_2 during the day, high pCO_2 during the night). Results suggest that sea urchin larvae possess mechanisms to anticipate the variability in carbonate chemistry, downregulating their calcification during the night. These results will be discussed in the light of local adaptation, phenotypic plasticity and future response to ocean acidification.

Key words: Plasticity, Calcification, Variability, Seagrass, Larvae

Phenotypic plasticity on the sea urchin *Echinus esculentus* larvae under constant and fluctuating seawater pH conditions

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Anthropogenic activities are acidifying marine environments and increasing variability across natural mosaics of marine pH environments. Planktonic larvae of marine organisms (e.g., sea urchin) may disperse across different natural habitats and experience different levels of pH variability. This may lead to the selection of genotypes with different potential for phenotypic plasticity. We hypothesize that (1) genotypes selected under fluctuating conditions will exhibit reduced survival and growth rates when exposed to stable conditions (cost of plasticity); (2) Genotypes selected under stable pH conditions would also exhibit reduced survival and growth rates when exposed to fluctuation conditions (cost of canalisation). The sea urchin *Echinus esculentus* was used as a model species. In a cross-breeding design, sea urchin larvae were cultured for the first part of their development to either stable or fluctuating pH conditions then transferred to the stable or fluctuation pH conditions. Density, larval size and total skeleton were measured twice a day and the carbonate chemistry was monitored on a daily base. The results will be discussed in the context of local adaptation to present and future environmental variability.

Key words: Plasticity, Canalization, Calcification, Variability, Larvae

Combining MONITORING and ECO-PHYSIOLOGY to understand the response of a coastal fish to ocean acidification

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There has been an increase in global efforts to monitor local ocean acidification (OA) conditions and experimentally test the response of species to OA conditions. Many experimental studies still use open ocean averages and projections to infer experimental treatment conditions instead of conditions relevant to the organism's natural habitats. However, coastal environments are known to show greater environmental variability than the more stable open ocean and coastal organisms are often adapted to these conditions. As a consequence, open ocean scenarios are not relevant for coastal species and can lead to the underestimation of the effects of future OA. The aim of this study was to collect data on the local pH variability in a coastal embayment in South Africa and to apply this information to an experimental study which assessed the physiological performance of the larval stages of a local fish species, *Diplodus capensis,* to a range of pH treatments that exceeded the measured local variability. The monitoring data revealed that pH varied significantly over 24 hours in intertidal habitats, from a maximum of 8.35 down to 7.79 pH at night. Larvae collected from these monitored intertidal sites were exposed to a gradient of pH treatments covering present natural variability (controls) and true future conditions (OA). Routine and maximum metabolic rates and relative aerobic scope did not differ among pH treatments suggesting that *D. capensis* is highly tolerant to pH levels as low as 7.27. This suggests that this species has a well-developed acid-base regulation system and is likely to tolerate coastal variability in pH associated with OA predicted for the future.

Key words: coastal acidification; monitoring; physiology

Moving Past the Mean: The Amplitude of Diel pH Fluctuations Can Influence Coral Calcification

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Temporal variability is a ubiquitous feature of carbonate chemistry, especially in shallow-water and restricted-flow environments, where benthic organisms and coastal processes can strongly influence the chemical composition of seawater. Both the mean and magnitude of daily pH fluctuations have the potential to impact the physiology of marine organisms as co-occurring circadian rhythms result in different physiological processes taking place within different chemical settings. Here we introduce a novel system for dynamic pH manipulation, controlling both the mean and amplitude of diel carbonate chemistry fluctuations. We used this setup to expose the endangered Caribbean coral *Acropora cervicornis* to treatments ranging from static to highly variable (±0.2 pH units) under contemporary and end-of-the-century mean pH scenarios. Corals subjected to a present-day pH mean and ±0.1 pH diel oscillations calcified at a rate faster than those kept under constant conditions. These results suggest that day-time elevation in pH during a period when calcification is photosynthetically-enhanced can more than counteract the deleterious influence of nighttime acidification. In order to further explore how circadian variation in the physiology of *A. cervicornis* is influenced by pH oscillations, we built automated incubation chambers to track net production and calcification over a 24-hr cycle. As with the prior experiment, coral fragments were also assessed in both static and dynamic scenarios. Results have implications for reef persistence under ocean acidification and may help to explain some of the observed intraspecific variation in the acidification-sensitivities of scleractinian corals.

Key words: coral, temporal variability, calcification

Local Adaptation Modulates Kelp's Responses to Global Climate Change: A Phenotypic and Genetic Approach

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Ocean warming (OW), ocean acidification (OA) and associated changes in the seawater carbonate system are expected to have direct physiological and ecological impacts on marine calcifying and non-calcifying organisms. However, organisms' responses to global climate changes can be influenced by local environmental conditions. For example, along the Chilean coast, large fluctuations in pH/CO_2, temperature and nutrient have been well documented as a consequence of e.g. upwelling events. This has led to suggestions that organisms living in highly variable environments might be more tolerant to future global and local changes than those from less fluctuating environments. In order to test this, we investigated and compared the physiological and molecular responses of juvenile *Macrocystis* sporophytes to OW and OA from populations exposed to different environmental variability (upwelling: Las Docas: 32°08´S, 71°42´W; v/s non-upwelling: El Tabo 33°27´S, 71°66´W). Juveniles from both populations (previously acclimated for three months in common-garden conditions) were incubated under the combination of three temperatures (12, 16, 20 °C) and two CO_2 treatments (ambient: 400µatm/pH 7.9, OA: 1200µatm/pH 7.5) for three weeks with ambient nutrients. We found that growth, NO_3^- assimilation (NR activity), and carbonic anhydrase (CA) and NR gene expressions were higher in individuals from Las Docas compared to individuals from El Tabo, across most of the experimental treatments. However, photosynthetic rates from both populations were unaffected by temperature or CO_2. Our results showed that individuals from populations naturally exposed to greater local variation in seawater temperature, pH/CO_2 and nutrient have greater physiological and molecular plasticity than those from less fluctuating environments, making them more tolerant to global and local changes than other ecotypes. This might be of great importance for the species conservation purpose as some populations are declining severely across the globe (i.e. 95% declines of *Macrocystis* forests in Tasmania, Australia).

Key words: climate change, local adaptation, macroalgae, ocean acidification, ocean warming.

Responses of a British Columbia bivalve foundation species to acidification experiments incorporating environmental and population complexity: Investigating transgenerational exposures, responses to dynamic PCO_2 treatments, and synergistic effects of thermal and acidification stress

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Bivalves have been globally identified as vulnerable taxa to ocean acidification (OA), with periods of enhanced sensitivity within and across life-stages, and sublethal exposures can result in carry-over effects. In British Columbia (BC), Canada, several mytillids act as foundation species, yet their physiological responses to current and future OA scenarios are poorly understood despite the potential cascading effects on BC coastal ecosystems.

Recent monitoring work suggests that carbonate chemistry conditions in BC coastal waters are highly dynamic across multiple temporal and spatial scales. Yet, most organismal OA experiments to date rely on fixed levels of PCO_2/pH, do not include additional environmental stressors likely to co-vary in the future, and focus on single life-stages. These studies are crucial to investigate mechanisms of sensitivity and identify physiological thresholds. However, experiments that include variable carbonate chemistry, incorporate additional stressors such as temperature, and explore effects of transgenerational and trans-life-stage exposure, can better reflect the natural environment and ultimately provide more accurate forecasts of the fate of organisms under future climate scenarios.

We present preliminary results of organismal physiological and transgenerational responses to OA of adult broodstock of the native Pacific blue mussel (*Mytilus trossulus*) and the early life stages of their larval offspring. We exposed reproductively active adult mussels for one month to three different PCO_2 treatments: static ambient, static high, and a dynamic treatment consisting on an sinusoid signal fluctuating between ambient and high treatments within a 24-hour period . In a fully factorial and cross-over design, we then separately spawned the three sets of broodstock and exposed the resulting embryo groups to the static ambient and high PCO_2 treatments and two different temperatures: optimal (18°C) and elevated (22°C). We will discuss observed responses in adult and larval stages to treatments, as well as the potential carry-over effects from adults to larvae.

Key words: mussels, trans-generational response, dynamic exposure, multi-stressor experiment

Physiological assessment in response to two near-future OA escenarios during abalone (*Haliotis rufescens*) larval development

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Ocean acidification has shown an impact on the restructuring of marine habitats, changes in the marine food web, and the reduction of marine resources of aquaculture interest. The AO eventually decreases the saturation state of the mineral calcium carbonate, which is necessary for shell formation by various mollusc larvae. Red Abalone (*Haliotis rufescens*) is represented within the most relevant classes of capture and culture in mollusc aquaculture and is a biological model to investigate the effect of acidification because it is a calcifying species of pelagic-benthic transition. For this reason, the present research aims to evaluate the physiological performance and transcriptomic profiles during the red abalone larval development and its response to chronic acidification stress. A CO2-injection system was designed to simulate the near-future OA (pH 7.8 and 7.6), and a control was incorporated (pH 8). We adjusted and measured the pH daily, and the variability of DIC and TA was discreetly measured to evaluate the aragonite saturation state. Physiological performance was assessed through oxygen consumption, hatching, survival, shell size, and settlement. During settlement, a short-term stress experiment was incorporated into the design to evaluate the effect of acute and chronic stressors. Preliminary results indicate differences in pH variability between the experimental and control systems during the 24 days of bioassay. Significant differences between hatching, survival and shell size rates were found, indicating a notable negative effect on the larval population of the simulated near-future OA scenarios. Settlement showed no significant differences between the experimental and control pH of the chronic stress bioassay. However, an opposite effect was observed in larvae of the different pHs during acute stress bioassay. In a scenario where acidification plays an important role in the larval development of various species, this study will elucidate the susceptibility of red abalone, a mollusc of high aquaculture interest.

Key words: Ocean Acidification, oxygen consumption, abalone, calcification, larval development.

Challenges of Scaling Ocean Acidification Impacts from Lab to Field

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Accurately predicting the effect of ocean and coastal acidification on marine ecosystems requires understanding how responses scale from laboratory experiments to the natural world. This work grew out of a National Science Foundation ocean acidification workshop held in 2018 in an effort to bring scientists together to build synthesis papers based on OA research. We focused on benthic calcifying macroalgae as a model system due to their ecological importance, how much research in the lab and field had been done to date and because of the expertise in our author team. We performed a semi-quantitative analysis to compare directional responses between lab experiments and field studies. Some responses, including community-level measurements, were consistent across lab and field. There were also notable mismatches in directionality of responses with more negative impacts reported in lab experiments. Recommendations for improving our ability to scale up will also be presented.

Nutritional Content of *Emiliania huxleyi* Under Ocean Warming and Acidification

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In phytoplankton, lipids serve as structural membrane molecules and as energy storage. These compounds provide a source of energy to consumers and changes in the availability of these lipids can have a significant impact on consumer productivity. Coccolithophores are vulnerable to ocean acidification, therefore it is critical to establish the effects of climate change on these significant marine primary producers and the consequences that these changes can have on the food web. Here, we determined the impact of ocean warming (OW) and ocean acidification (OA) on nutritional condition (lipids), growth rate, relative calcification (PIC:POC), and morphology of the most abundant living coccolithophore species, *Emiliania huxleyi*. We used a regression type approach using 9 pH levels (ranging from 7.66 – 8.44) and two temperatures (15°C and 20°C). Lipids (ng) per cell were greater under OA and there was a significant interaction between pH and temperature. Growth rates were distinctly lower at 15°C than at 20°C. The PIC:POC ratio was at an optimum within at mid-pH experimental conditions for both temperatures. Coccosphere diameter was smaller at 20°C and at low pH, highlighting an interaction between OW and OA. On the whole our results suggest that OW and OA may positively influence both the nutritional content of coccolithophores and consumer productivity. Considering solely the ecophysiology of coccolithophores, however, OW and OA may have a negative impact.

Key words: ocean acidification, ocean warming, coccolithophore, lipids, calcification

Effects of $p\mathrm{CO_2}$ on Aerobic Respiration and Critical Oxygen Pressure (P_{crit}) of Two Squat lobster Species (*Pleuroncodes monodon* and *Cervimunida johni*)

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Organisms living in oxygen minimum zones (OMZ) have different physiological mechanisms allowing them to cope with environmental hypoxia conditions. However, respiration also causes the production and accumulation of CO_2, therefore OMZ waters are also rich in CO_2. Then the combination of low pO_2 and high $p\mathrm{CO_2}$ may represent a physiological challenge for the organisms that populate these areas. In this research we explore aerobic respiration responses in two squat lobster species that inhabit within the OMZ, *Pleuroncodes monodon* and *Cervimunida johni*, exposed to different $p\mathrm{CO_2}$ environments. We hypothesize that both species will perform better in hypoxic environments having high $p\mathrm{CO_2}$, than with low $p\mathrm{CO_2}$. To evaluate this hypothesis we estimated metabolic rate (MR: µmol g^{-1} h^{-1}) and critical pressure of oxygen (P_{crit}: kPa) on adults and juveniles of *P. monodon* and adults of *C. johni,* when exposed to low (400 µatm) and high (1400 µatm) $p\mathrm{CO_2}$ conditions. Our results show that MR was significantly higher in high $p\mathrm{CO_2}$ conditions for adult *P. monodon*, while the opposite was found in juveniles of the same species where significantly higher values were found in low $p\mathrm{CO_2}$ conditions. For *C. johni* instead, there were no differences in the MR among treatments. Low P_{crit} were found for both squat lobster species suggesting a high hypoxia tolerance. P_{crit} was lower in high $p\mathrm{CO_2}$ in juveniles of *P. monodon* and adults of *C. johni*. In adult *P. monodon* there were no differences among $p\mathrm{CO_2}$ conditions having low P_{crit} values in both conditions. Results indicate that high $p\mathrm{CO_2}$ is relevant for hypoxia tolerance in both species.

Key words: Metabolic Rate, Hypoxia, Crustacean

Laboratory Experiments Reveal Reef Invertebrates in the Northern Gulf of Mexico are Sensitive to Warming yet, can Acclimate to Acidification

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Despite potentially synergistic, antagonistic, or additive consequences of ocean acidification and warming, little is known about species' sensitivity to global change in the northern Gulf of Mexico. The Gulf has temperate and tropically distributed species as well as large spatial variability in carbonate chemistry. Therefore, we will address this knowledge gap by examining how acidification and warming will impact reef invertebrates. In controlled laboratory experiments, we tested how 30 days of constant, lowered pH_T (7.8_T, 7.5_T compared to present-day average of 8.1_T) or elevated temperature (+2°C, +4°C from present-day average of 29.4°C) affected survivorship, feeding, metabolism, and calcification, in the adult stage of three common reef invertebrates: Arrow Crab (*Stenorhynchus seticornis*), Titan Acorn Barnacle (*Megabalanus coccopoma*), and Leafy Jewel Box Clam (*Chama macerophylla*). These species vary in mobility and calcification yet, all three species showed the ability to adjust to acidified conditions over the duration of the experiment, i.e., respiration became more like their response at the initial time point. Additionally, calcification in barnacles and bivalves was affected by lowered pH conditions. In barnacles, calcification decreased with decreasing pH conditions. However, contrary to predictions, bivalves exhibited the highest mean calcification at the lowest pH condition after 30 days of treatment. The responses to lowered pH conditions show there may be some ability to acclimate to acidification for certain species. In warming manipulations, the survivorship of crabs and barnacles was greatly affected. Only 25 percent of crabs survived the 0.5°C/day ramp to the highest temperature, while 100 percent of individuals at present-day condition survived the full experimental duration. For barnacles, the 30-day exposure to the highest temperature resulted in a 66 percent reduction in survivorship. Experiments testing the combined effects of warming and acidification on organisms' physiologies and predator-prey interactions are ongoing and preliminary results will be shared.

Key words: acidification, warming, invertebrate responses

Internal Chemistry dictates Responses of Coralline Algae to Ocean Acidification

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Coralline algae are important ecosystem engineers and foundation organisms. Their skeletons consist of magnesian calcite leading to the view that they are particularly vulnerable to ocean acidification (OA). While most coralline algal taxa are indeed sensitive to OA, some are tolerant. How differential susceptibilities will shape future coralline algal communities, however, cannot be predicted with confidence unless the physiological drivers that underlie species-specific tolerances are identified. To this end, we assessed the physiological and geochemical responses of seven species of coralline algae to the effects of ecologically relevant seawater pH (8.03, 7.93, 7.83 and 7.63) in a manipulative lab experiment. Calcification of four species declined with pH. Conversely, calcification of three species was unimpacted by pH, implying OA tolerance. Tolerance to OA was coupled to the species' ability to maintain stable carbonate chemistry at the site of calcification to support calcification, likely *via* ion pumps. Conversely, in sensitive taxa, we observed pronounced changes in internal calcium carbonate saturation state (Ω_{CF}) and skeletal magnesium content. However, the results imply that these are only indirectly related to OA, since Ω_{CF} does generally not decline but increases. Likely reason for this are changes in calcification rate and ion-pumping, to limit the increasing energy expenditure of these processes. In addition, OA appears to induce photodamage in sensitive taxa that could explain the inability to continuously support ion-pumping and growth under OA, but would almost certainly exacerbate problems associated with supplying sufficient energy to these processes. Collectively, our results indicate that the organism's ability to maintain favourable carbonate chemistry at the site of calcification under declining pH is a crucial driver of differential responses in coralline algae to OA. Identification of this driver will aid with forecasting OA-induced changes in the coralline algal community and related flow-on impacts on ecosystem functioning.

Key words: coralline algae, resistance, ocean acidification, physiology, biomineralization

The combined effects of ocean acidification and temperature levels on the thermal niche of two invertebrate species

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To make robust projections regarding the impacts of climate change, it is critical to understand how abiotic factors may interact to constrain the distribution and productivity of marine organisms. Here we reported results of laboratory experiments that examined the effect of near-future changes in temperature (cooling [OC] or warming [OW]) an elevated pCO_2 levels (acidification, OA) on small juveniles of two species characteristic of the southeastern coast of the Pacific Ocean. Experiments were conducted in small juveniles of *Concholepas concholepas* and *Loxechinus albus*. In Chile, the gastropod *C. concholepas* is the main target of local fishers and a keystone rocky shore predator. Meanwhile, the sea urchin *L. albus* is benthic shallow water coastal herbivore. After exposing the individuals for a 1-month to contrasting pCO_2 (~500 and 1400 μatm) and temperature (15°C and 20°C for *L. albus*) and (10°C, 15°C, 20°C and 25°C for *C. concholepas*) levels. Critical thermal maximum (CTmax) and minimum (CTmin) as well as thermal tolerance polygons were assessed based on self-righting success as an end point. Survival and *HSP70* transcription were also investigated. In both species survival was not affected. In *C. concholepas* extreme cooling and warming under OA conditions reduced the partial thermal tolerance polygons and growth whilst increased *HSP70* transcription in comparison to present-day conditions. In *L. albus* there was a synergistic effect of OA × OW on *HSP70* transcription levels which were higher than in control conditions. The results highlight the importance of incorporate organismal and cellular level traits and more than one stressor when comparing the effects of climate change-related stressors on marine organisms. We conclude that near-future levels of pCO_2 and temperature will likely result in a physiological-based reduction in overall thermal performance with important consequences on the spatial distribution of theses species.

Key words: *Concholepas concholepas*, *Loxechinus albus*, Thermal tolerance, Ocean warming, Ocean acidification,

Dungeness crab in an acidifying ocean

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Dungeness crab, the most valuable fishery on the U.S. West Coast, show mixed response to ocean acidification and other climate change stressors. Through species response experiments in controlled aquaria, we explore CO_2 sensitivity by looking at a variety of metrics, including those that drive demographic processes (e.g. survival and growth rate) and those that provide insight into the physiological mechanisms underlying the response (e.g. metabolic pathways and calcification). We observe negative effects of high CO_2 on the larval stage, but, surprisingly, higher survival of juvenile crabs raised high CO_2 compare to those reared in ambient conditions. We hypothesis that the higher survival may be the result of a cryptic CO_2-senstive pathogen. The experimental data were input to models that explore population level processes related to management issues, such as environmental thresholds. The differing sensitivities of different life stages and uncertainties about the factors driving population dynamics complicate predictions of climate change effects on Dungeness crab.

Key words: Dungeness crab, Puget Sound, life-stage models, thresholds

Physiological response of oyster larvae to interactive effects of climate change variables

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For calcifying organisms, such as bivalves, short term exposure to increased ocean acidification (OA; elevated ρCO_2) reduces growth rate, increases mortality, and disrupts shell formation in larvae. Climate change predictions suggest rising temperatures and increased rainfall events causing prolonged low salinity exposure, both of which can intensify the negative effects inflicted by OA alone. Understanding how climate change will affect essential aquaculture species is critical to long term ecological and economic stability. We used the eastern oyster (*Crassostrea virginica*) as a model species in a full factorial design to test the interactive effects of temperature (23 and 27°C), salinity (17 and 27), and OA (700 and 1,800 µatm pCO_2) during larval development. The combined effects of salinity and OA significantly reduced growth, resulting in the lowest growth in treatments with both high OA and low salinity. Salinity alone also had a significant negative effect on larval survival that was intensified when coupled with high OA. Differential gene expression data will also be used to identify response to climate change variables at a molecular level to help inform breeding programs by highlighting vulnerabilities and possible avenues for selective breeding. These data will be incorporated into predictive models and used to help inform breeding programs. Understanding the interaction of these three environmental variables, OA, temperature, and salinity, is critical to projecting the long term effect of climate change on aquaculture species.

Key words: Aragonite saturation state, ocean acidification, shellfish, salinity, aquaculture

How Will Biota Respond to A Changing Ocean? A Best Practice Guide for Multiple-Driver Research

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An increasing number of researchers are incorporating additional drivers, such as warming and hypoxia, into their ocean acidification experiments. However, designing *intercomparable* multiple-driver experiments is challenging, given the large number of relevant drivers and experimental permutations. To help researchers align their experimental approaches to multiple driver experiments, a web-based Best Practice Guide (https://meddle-scor149.org/) has been developed by the Scientific Committee on Oceanic Research (SCOR) infrastructural project "Changing Ocean Biological Systems: how will biota respond to a changing ocean?". This freely available, five-part resource includes:

1. *Best practice guide*: an evolving electronic book that demonstrates how to break down complex questions into a series of tractable, multiple-driver experiments.
2. *Video tutorials*: eight video tutorials provide background information and explore specific aspects of multiple-driver research, including Developing a Driver Inventory, Multiple Driver Experimental Design, and Experimental Evolution.
3. *Decision support tool*: a three-step questionnaire guides researchers through the selection of an appropriate experimental design, development of a data analysis plan, and identification of necessary resources.
4. *Simulation software*: MEDDLE simulation software generates multiple-driver experimental data, allowing researchers to explore experimental design and analysis options before time and resources are invested into the experiment.
5. *Teaching resources*: lecture slides, activities, and recommended schedules facilitate incorporation of these resources into classes, laboratories, seminars, and workshops.

Adoption of the recommendations within this Best Practice Guide will allow the ocean acidification community to better align its research efforts, leading to improved prediction of responses to ocean change.

Key words: multiple driver, multiple stressor, experimental design, best practice guide, MEDDLE

Ocean Acidification Negatively Impacts Marine Primary Productivity by Interfering with Iron Acquisition in Phytoplankton

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In high-nutrient, low chlorophyll (HNLC) regions, the scarcity of iron drives biogeochemical cycles, controls ocean carbon flux and constrains the growth of phytoplankton. In this context, the ocean acidification-induced changes in seawater carbonate ion are not considered to impact primary productivity. However, we recently showed that diatoms access dilute concentrations of labile ferric iron using a transferrin-like mechanism. These ‘phytotransferrins’ have a second-order dependency on the concentration of seawater carbonate ion, raising the intriguing possibility that the concentration of carbonate controls the bioavailability of iron. To determine whether changes in carbonate ion impacts the uptake of iron, we measured iron uptake rates in 14 different Southern Ocean phytoplankton, revealing that decreases in carbonate ion negatively impact iron uptake across major groups of environmentally relevant phytoplankton taxa, including diatoms, coccolithophores, chlorophytes, cryptophytes and phaeocystis. These laboratory findings were subsequently confirmed in mesocosm experiments during the 2019 Southern oCean seAsonal Experiment (SCALE) cruise to the South East Atlantic. Because phytotransferrin-mediated iron uptake represents a direct biomolecular link between atmospheric CO_2, iron bioavailability and ocean productivity, we will conclude with a brief discussion of the implications in the context of short- and long-term ocean acidification events.

Key words: primary productivity, biogeochemistry, feedbacks, trace metals, ecosystems

Energetic response of Atlantic surflcam *Spisula solidissima* to Ocean acidification: an experimental and dynamic energy budget model

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The Atlantic surfclam (*Spisula solidissima*) is an economically important fishery (> $29.2 million US dollars) in the northwest Atlantic. Increased global carbon dioxide (CO_2) in the atmosphere has resulted in ocean acidification (OA) in Atlantic surfclam habitat. A vulnerability assessment categorized the Atlantic surfclam as being highly susceptible to OA, however to date little is known about specific physiological the effects. In this study, we combined laboratory experiments with dynamic energy budget (DEB) modeling to explore how the Atlantic surfclam will respond to projected RCP scenarios.

A 12-week experiment was conducted in which 648 surfclams, fed *ad libitum*, were exposed to varied CO_2 levels (566, 1380, 2164 ppm). At weeks 4,6,8, 10 and 12 feeding rates, respiration, and excretion were measured on 7 individuals per condition. Scope for growth (SFG) rates were reduced at high CO_2 levels as a result of increased excretion rates and decreased clearance rates. Furthermore, oxygen:nitrogen (O:N) ratios dropped, suggesting that a switch in metabolic strategy may have occurred at higher CO_2 levels. The laboratory data indicated surfclams have some compensatory responses to OA.

The data was then integrated into a Dynamic energy budget (DEB) model. The laboratory data was used to calibrate the data, while 25 years of field data was used to validate the DEB model for a population located on Georges Bank and another in the Mid-Atlantic Bight. Temperature and CO_2 concentrations were projected under RCP scenarios (2.6, 6.0, and 8.5) for growth and reproduction. Under RCP 8.5 changes in growth would be observed by the year 2090, however, changes in reproduction estimators could occur as early as 2045. This study highlights the importance of linking physiological laboratory experiments with dynamic energy budget models to understand the effects of OA on bivalve growth and reproduction.

Key words: Ocean acidification, scope for growth, dynamic energy budget modeling, bioenergetics

Ocean Warming and Acidification Degrade Shoaling Performance and Lateralisation of Novel Tropical–Temperate Fish Shoals

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Gregarious behaviours are common in animals and provide various benefits such as food acquisition and protection against predators. Many gregarious tropical species are shifting poleward under current ocean warming, creating novel species and social interactions with local temperate taxa. However, how the dynamics of these novel shoals might be altered by future ocean warming and acidification remains untested. Here we evaluate how novel species interactions, ocean acidification, and warming affect shoaling dynamics, motor lateralisation, and boldness of range-extending tropical and co-shoaling temperate fishes under controlled laboratory conditions. Fishes were exposed to one of twelve treatments (combinations of three temperature levels, two $_{p}CO_2$ levels, and two shoal type levels: mixed-species or temperate-only) for 38 days. Lateralisation (a measure of asymmetric expression of cognitive function in group coordination and predator escape) of tropical and temperate species was right-side biased under present-day conditions, but side bias significantly diminished in tropical and temperate fish under ocean acidification. Ocean acidification also decreased shoal cohesion irrespective of shoaling type, with mixed-species shoals showing significantly lower cohesion than temperate-only shoals irrespective of climate stressors. Tropical fish became bolder under ocean acidification (after four weeks), and temperate fish became bolder with increasing temperature, while ocean acidification dampened temperate fish boldness. Our findings highlight the direct effect of climate stressors on fish behaviour and the interplay with the indirect effects of novel species interactions. Because strong shoal cohesion and lateralisation are key determinants of species fitness, their degradation under ocean warming and acidification could adversely affect species performance in novel assemblages in a future ocean, and might slow down tropical species range extensions.

Key words: ocean acidification, ocean warming, shoaling, species interactions, tropicalisation

Ocean Acidification and the Behaviour of Marine Fishes

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It is a little over a decade since research commenced into the effects of anthropogenic ocean acidification on marine fishes. In that time, we have learned that projected end-of-century CO_2 levels can affect the physiology, growth and survival of some species, but not others. There are also wide-ranging effects on behaviour that could alter performance and survivorship of some species. In this talk I discuss the overwhelming evidence from a decade of research showing that elevated CO_2 can affect the behaviour of a wide variety of fishes. More than 90 research papers, by many different researchers, report significant effects of elevated CO_2 on behaviour of fish from coral reefs and other habitats. Yet a similar number of studies report no effects. Some species appear to be tolerant to elevated CO_2 and different studies do not always yield the same results. Furthermore, other environmental variables, such as elevated temperature and natural CO2 fluctuations, can diminish the effects of elevated CO_2 on fish behaviour. It is important to understand this variation, and why it occurs, to better predict where and when ocean acidification will affect fish populations.

Key words: fish behaviour, evidence, scientific method

Effects of Different Oxygen and pH Regimes on Energy Metabolism and Biological Functions of the Ragworm *Hediste diversicolor*.

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Oxygen deficiency (hypoxia) and low pH (hypercapnia) are common stressors in coastal habitats that can negatively affect metabolic performance of benthic organisms due to the perturbations of energy metabolism and acid-base status. These changes can have implications for behavior and ecological functions of marine organisms. However, the physiological mechanisms and ecological consequences of the effects of hypoxia and hypercapnia on bioturbators such as the ragworms *Hediste diversicolor* are not understood. We exposed *H. diversicolor* for 21 days to four different combinations of two oxygen (100% and 20% air saturation) and two pH (normocapnia pH 7.9; hypercapnia pH 7.4) levels and measured their bioturbation and bioirrigation capacity, respiration, ammonia excretion and cellular bioenergetics. Oxygen consumption was not affected by hypoxia and/or hypercapnia, while ammonia excretion decreased in all conditions compared to the control (normoxia-normocapnia) group. Worms acclimated to normoxia-hypercapnia showed a decrease in glycogen reflecting increased energy need for acid-base regulation during hypercapnia. Protein content also decreased in worms co-exposed to hypercapnia under normoxic or hypoxic conditions, but O:N ratio did not change indicating that the decrease in proteins was likely due to a decreased protein deposition rather than enhanced protein breakdown. Bioturbation was not affected, while bioirrigation capacity increased in worms acclimated to normoxia-hypercapnia and hypoxia-normocapnia. Our results indicate that despite increased energy demand for acid-base regulation in hypercapnia, ecological activities (bioturbation and bioirrigation) were not negatively affected by environmentally relevant hypoxia and hypercapnia levels in the ragworms.

Key words: hypoxia, hypercapnia, energy metabolism, bioturbation, bioirrigation

Does the effect of ocean acidification and salinity variation on crab *Callinectes danae* gene expression and physiology increase over long periods of exposure?

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Ocean acidification can affect marine organisms in several ways. Therefore, studies are needed to assess the physiological and molecular impacts on different species. *Callinectes danae* crab is an important ecological and economic resource. The present study evaluated the effects of ocean acidification on Na^+/K^+-ATPase gene expression and on a set of physiological parameters (oxygen consumption, ammonia excretion, energy substrate, hepatosomatic index and osmotic and ionic regulatory capacity) in crab *C.danae.* The animals were kept in the salinities (20, 25 , 30, 35 and 40) and at pH 8.0 (control) or 7.3 (acidified) in the short (3 days) and long term period (30 days). A reduction in Na+/K+ ATPase gene expression was observed for short periods in animals maintained at salinities 35 and 40 (pH7.3), and a subsequent increase in the period of 30 days. An increase in oxygen consumption was observed in both periods, but at different salinities 25 (3 days), 20 and 40 (30 days), probably due to a greater need of energy requirement to maintain homeostasis. However metabolic depression was observed at salinity 30 in animals kept for long periods in acidified medium. The ammonia excretion presented reductions in salinity 30 (3 days), in a long period the effect was intensified with reductions in salinities 25, 30 and 35, possibly due to competition between the transporters Na^+/H^+ and $Na^+/NH^+{}_4$. The hepatosomatic index increased in salinities 30 (3 days) and 40 (30 days), suggesting accumulation of energy reserves or reduction in the use of digestive enzymes. The energetic substrate and osmoregulatory pattern remained unchanged although the concentrations of Cl^- and Na^+ ions were reduced by 25 and 35S (30 days). In general, animals maintained for a longer period of time at reduced pH were worse affected. Although some effects of water acidification appear after short-term exposure, they generally intensify after long-term exposure. The alterations observed may indicate that despite *C. danae* is an animal euryhalin and inhabits different environments, ocean acidification can alter its physiological and molecular patterns, with consequences for the growth, development and distribution of the species.

Key words: metabolism, crustaceans, climate change, osmoregulation, aquaculture

Genetic variation and phenotypic plasticity in the response of a coral reef fish to ocean acidification

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The impacts of ocean acidification will depend on the ability of marine organisms to tolerate, acclimate and eventually adapt to changes in ocean chemistry. We performed a unique transgenerational experiment with a common damselfish from the Great Barrier Reef to determine the molecular response of a coral reef fish to short-term, developmental and transgenerational exposure to near future elevated CO_2. This aids in teasing apart plastic responses due to developmental plasticity and reveals within-generation specific reactions to be driven by epigenetic regulators. Importantly, we find that altered gene expression for the majority of within-generation responses returns to baseline levels following parental exposure to elevated CO_2 conditions. However, gene expression involved in glucose homeostasis remains uncompensated across generations. Furthermore, we included different parental phenotypes measured by their level of behavioral tolerance to elevated CO_2 and found that responses of offspring varied largely with parental phenotype. We show that the transgenerational signal of tolerance is connected to the circadian rhythm and suggests adaptive potential of impaired behaviors from high CO_2 to be due to existing natural variation. Our aim is to further understand this tolerance to elevated levels of CO_2 which will aid in future predictions of resilience and population persistence in the light of rapidly increasing acidification of the oceans.

Key words: Ocean Acidification, Behavioral impairment, Coral Reef Fish, Plasticity, Gene Expression.

Comparing Physiological Effects, from Cellular to Whole-Organism, of Co-exposure to Ocean Acidification and Warming in Two Groups of Larval Eastern Oysters, *Crassostrea virginica*

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The Chesapeake Bay is influenced by natural and anthropogenic drivers that create spatially and temporally variable environmental conditions that regularly reach levels projected for the open ocean by year 2100. In this dynamic environment, Eastern oysters, *Crassostrea virginica*, currently experience multiple stressors that likely challenge their biology. While increasing sea surface temperature and ocean acidification, two crucial climate change-related stressors, are known to independently affect oysters, especially already-vulnerable larvae, the simultaneous experience of both can challenge energy requirements for maintaining metabolic performance. This challenge causes larvae to shift their energy towards basal processes that are necessary for survival (i.e. ion regulation) and away from other aspects of their biology (i.e. growth) that contribute to the fitness of the species. Few studies have linked changes in cellular mechanisms to those at the whole-organismal scale for a holistic understanding of the physiological effects of multiple stressors. Studies also have not compared physiological responses of wild and selectively-bred groups of *C. virginica*, considering their two important roles: a reef-building, ecosystem engineer and selectively-bred broodstock for aquaculture. We cultured larvae from selectively-bred and wild broodstock under a factorial combination of two temperature and carbonate chemistry scenarios, referred to in terms of pH: control temperature and pH, low pH at control temperature, high temperature at control pH, and a multi-stressor treatment. To detect changes in physiological mechanisms from cellular to whole-organism levels, we measured antioxidant defence, total protein, total lipid, respiration, and growth. Results currently indicate that larvae from selectively-bred oysters raised under acidic conditions, with or without warming, experience low growth and more oxidative stress, signalling a shift in their energy budget towards basal processes. Linking mechanisms from cellular to whole-organism scales between different groups of *C. virginica* will provide an understanding of potential bottlenecks between individual- and population-level success in the future.

Key words: Ocean acidification, warming, *Crassostrea virginica*, larvae, physiology

Ecophysiological Responses of Four Soft Coral Genera to Ocean Acidification

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Climate change and in particular ocean acidification have differing effects on marine organisms. Interestingly, selected Alcyonacean soft corals have shown to be more resistant to ocean acidification when compared to reef-building corals in terms of survival, growth, and calcification rates. However, our current knowledge on the effects of ocean acidification on soft corals is still limited. Existing studies on this group suggest high species-specificity in their ecophysiological response to ocean acidification, but more comprehensive work covering several taxa is needed. In this study, corals belonging to the octocoral genera *Antillogorgia*, *Plexaurella, Sinularia* and *Xenia*, selected to cover a broad phylogenetic range, were exposed for three months to ocean acidification conditions expected under the RCP8.5 scenario for the year 2100 (pH 7.78, pCO_2 > 1000 ppm. In contrast to previous studies, our preliminary analyses of the ecophysiological parameters assessed colony growth, polyp pumping frequencies, respiration, net and gross photosynthesis, maximum photochemical efficiency (F_v/F_m) and effective photochemical efficiency ($\Delta F/F_m'$), showed no significant differences in response to the acidification treatment. No mortality or bleaching was observed, indicating a remarkable tolerance to ocean acidification conditions in all genera. This general tolerance to ocean acidification may give soft corals an additional advantage over the more susceptible stony corals under climate change. Based on these results, soft corals may become an increasingly dominant ecological functional group in global reef ecosystems of the future.

Key words: Photosithesis, Coral physiology, Octocorals, Ocean acidification tolerance.

Effects of Acute Exposure to Reduced pH on the Physiology of American Lobster Embryos (*Homarus americanus*)

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In marine invertebrates, early life stages can be especially vulnerable to reduced pH conditions. In the face of ocean and coastal acidification, both lethal and sub-lethal impacts of low pH conditions in early life could have negative consequences for recruitment and fitness. However, the tolerance of the American lobster to low pH conditions during embryogenesis is largely unknown. In this study, the effects of acute exposure to reduced pH conditions on the physiology and survival of lobster embryos were investigated. A range of pH treatments were selected to capture a full scope of physiological stress responses. Embryos were obtained from ovigerous females (n = 6 females; n = 180 embryos per female) and distributed across six pH treatments (8.0, 7.7, 7.5, 7.0, 6.5, 6.0). Following an exposure period of 24 hours, embryos were evaluated for survival, oxidative stress, oxygen consumption, embryonic heart rate, and Na^+/K^+ATPase activity. In accordance with moderate and extreme stress, both metabolic rate and Na^+/K^+ATPase activity generally increase under moderately reduced pH conditions, but are depressed at very low pH levels. Indications of oxidative stress subsequently increase with declining pH. We integrate these results with evidence from other key stressors and life-stages to describe how effects of low pH on early-life physiology might scale up to shape life cycle and population-level processes.

Key Words: physiology, embryogenesis, American lobster

Effects of upwelling in calcification, growth and mortality of Chilean scallops (Argopecten purpuratus) cultured in Tongoy bay (30° 12'S, 71° 34'W)

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Coastal systems influenced by upwelling events are dynamic and are exposed to high environmental variability. The rise of cold, hypoxic, acidic and rich in nutrients waters generated by upwelling events can affect the physiological performance of the species that inhabit these systems. The northern scallop (*Argopecten purpuratus)* is a commercially important bivalve grown mainly in Tongoy Bay. This locality is seasonally influenced by Pt. Lengua de Vaca upwelling center. *A. purpuratus* has been described as tolerant to environmental stress, however it has not been determined how the upwelling can affect the physiological performance of the scallop, being particularly significant to understand how the set of oceanographic variables associated with upwelling events impacts features that are commercially important. In this study, we assess the monitoring of a scallop production line grown in Tongoy Bay among the years 2016 and 2018 for the estimation of growth, calcification and mortality rates in relation to environmental variability in terms of upwelling intensity. Our results show that there is a difference both the environmental parameters as in the physiological responses evaluated between the different upwelling seasons. During the intense upwelling, lower growth rates were recorded, and higher calcification and mortality rates compared to no-upwelling seasons. In addition, important differences were found between the two years of study, product of El Niño phenomenon during 2016. We conclude that upwelling in Tongoy has negative effects on the physiology of the scallop. In productive terms and against a scenario of upwelling intensification, scallops would take a longer time to reach commercial size, generating in turn thicker shells.

Key words: Scallop, upwelling, physiology, calcification, growth

The Effects of Projected Future CO_2 Concentrations on the Behaviour of Two Species of Tropical Cephalopod

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There is increasing evidence that projected future carbon dioxide (CO_2) levels can alter behaviour in marine invertebrates, including in highly active invertebrates such as cephalopods. We tested the effects of upper end-of-century projected CO_2 levels (~1,000µatm) on the behaviours of two species of tropical squid (*Idiosepius pygmaeus* and *Sepioteuthis lessoniana*), including anti-predator behaviours, predatory behaviours, activity levels, and learning abilities. The responses to elevated CO_2 among behavioural traits was similar between the two species. Both species had a greater than two-fold increase in activity levels at elevated CO_2. Furthermore, squid were less likely to attack prey in predatory trials, and took longer to initiate an attack while displaying altered body pattern choice when they did attack at elevated CO_2. *Idiosepius pygmaeus* also had an increased striking distance as well as a reduced preference for attacking the posterior end of prey at elevated CO_2. Effects of elevated CO_2 on anti-predator behaviours of *I. pygmaeus* was also tested; squid were more likely to jet escape and ink in response to a visual startle stimulus at elevated CO_2. Lastly, *S. lessoniana* was tested in a repeated measures learning experiment to determine the effects of elevated CO_2 on learning and the capacity for conditional discrimination. *S. lessoniana* is the first squid species to demonstrate a capacity for conditional discrimination and elevated CO_2 had no demonstratable effect on the learning capacity of the species. These experiments show for the first time the behavioural sensitivities and tolerances of a cephalopod species to elevated CO_2 across a wide range of behavioural traits. Notably, the two species are from separate taxonomic orders, indicating a potential for several taxa of cephalopod to respond to elevated CO_2 similarly. Given the life-history strategy of cephalopods, it is important that future studies investigate the potential for adaptation to future ocean conditions.

Key words: Activity, Behaviour, Cephalopod, Learning, Predator-prey

Multiple climate change stressors impact fundamental subcellular stress response in marine calcifiers: Novel approaches for stress detection and quantification

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Coastal habitats are already rapidly changing due to climate change, especially in combination with anthropogenic pressures. Multiple stressors, including ocean acidification (OA), warming (W), marine heat waves (MHW), and eutrophication are interacting over spatial and temporal scales. The impacts on ecologically and economically relevant marine calcifiers such as molluscs and crustaceans are poorly understood. Climate change stressors can trigger subcellular oxidative damage, with evident responses such as changes in the mitochondrial integrity and cytoskeleton activity and accumulation of oxidative products, with direct energetic constraints and subsequent physiological impairments. Research approaches related to the measurements on the subcellular level provide an early detection and quantification of stress, species intra- and inter-specific sensitivity and insights into potential energetic implications. We set up lab-based experiments with projected combination of multiple stressors, including W, OA, and food availability, with particular emphasis on the MHW conditions based on the physical and biogeochemical observations over the last 30 years. Based on the rates of the MHW onset and decline, we also conducted the experiments to establish the time and species recovery scope. We developed novel subcellular methods to detect and quantify stress by using microscopic, flow cytometry and immunohistochemical techniques focusing specific on the measurements of the mitochondrial integrity and oxidative stress accumulation. Through controlled exposure to stressors, we observed the occurring subcellular changes and quantified stress relationship for economically important Mediterranean mussel (*Mytilus galloprovincialis*) and the invasive green shore crab (*Carcinus aestuarii*). We determined the principal drivers and their interaction causing the stress response and recovery at the cell-tissue interface. Novel cutting-edge method using subcellular stress biomarkers potentially offers offer quick visualization and assessment for the cellular response with the scope of determining *in situ* early-warning stress and its progression. This is critical in the already stressed coastal and aquaculture habitats, where biological monitoring is essential for the successful management and informed conservation efforts related to the climate change.

Key words: multiple stressors, ocean acidification, marine heat waves, biomarkers, stress response

Effects of ocean acidification on *Caulerpa* spp.

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It is unclear how ocean acidification will impact non-calcareous seaweeds, with considerable variability existing in their responses measured to date. Some of this variability could be explained by differences in dissolved inorganic carbon (DIC) uptake. *Caulerpa* are one of the few rare genera that have species both with and without CO_2 concentrating mechanisms (CCMs). CCMs allow active uptake of HCO_3^-. It has been suggested that species without CCMs are more likely to benefit from ocean acidification, due to currently being DIC limited. The bulk of non-CCM species are small rhodophytes with low community biomass and cover. The two most common *Caulerpa* species in New Zealand, *C. brownii* and *C. geminata* could have vastly different responses to ocean acidification as they have different DIC acquisition strategies. *C. brownii* does not have a CCM, while *C. geminata* possesses a CCM. We investigated the effects of ocean acidification on growth, photo-physiology and DIC utilization by *C. brownii* and *C. geminata* in a manipulative laboratory experiment. The two species were exposed to four mean seawater pH treatments (8.03, 7.93, 7.83 and 7.63). In all cases, mean and variability in growth rates of *C. brownii* increased under ocean acidification scenarios, while growth rates for *C. geminata* declined under ocean acidification treatments. This is concordant with predictions that non-CCM species will be capable of utilising additional CO_2, while species with a CCM cannot utilize addition CO_2, while at the same time demonstrating that DIC use alone does not predict responses to ocean acidification. We show divergent responses of two *Caulerpa* species that could have implications for their future abundance and roles in Australasia. However, further research is required to ascertain whether these trends will persist under concurrent ocean warming.

Key words: chlorophytes, CO_2 concentrating mechanisms, ocean acidification, DIC, physiology

Neurobiological Mechanisms Underpinning Behavioural Responses to Elevated CO_2 in a Cephalopod

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The nervous system is central to coordinating behavioural responses to environmental change, likely including rising seawater carbon dioxide (CO_2) levels. We exposed two-toned pygmy squid *Idiosepius pygmaeus* to current-day (~450 μatm) or elevated (~1,000 μatm) CO_2 levels for seven days. Squid were treated with sham, gabazine ($GABA_A$ receptor antagonist) or picrotoxin (antagonist of molluscan GABA-, glutamate-, acetylcholine- and dopamine-gated Cl^- channels) immediately before behavioural measurements, followed by dissection of, and RNA extraction from, the central nervous system (CNS) and eyes. Elevated CO_2 treatment increased conspecific-directed behaviours and activity levels. Both antagonists had different behavioural effects at elevated compared to current-day CO_2 conditions. This supports previous research that disrupted $GABA_A$ receptor function underpins altered behaviour in elevated CO_2 conditions, and provides the first pharmacological evidence, for any marine organism, that other ligand-gated Cl^- channels are also involved in CO_2-induced behavioural changes. RNA-sequencing data from the CNS and eyes was mapped against a *de novo* transcriptome assembly created from PacBio long-read ISO-seq data. We found molecular signatures for disrupted GABAergic, monoaminergic, glutamatergic, and cholinergic neurotransmission, including neurotransmission mediated by ligand-gated Cl^- and cation channels, and G-protein coupled receptors, at elevated CO_2. Furthermore, expression of genes involved in GABAergic and cholinergic neurotransmission was correlated with CO_2-induced behavioural changes in the same individual squid. Our results show that elevated CO_2 disturbs various types of neurotransmission, thereby altering vital ecological behaviours.

Key words: ocean acidification, cephalopod, behaviour, neurotransmission, gene expression

Calcification and Photosynthetic Responses of Reef-Building Corals to Ocean Acidification

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Reef-building corals are threatened by ocean acidification (OA), which typically has a negative effect on coral calcification. However, OA can elicit both linear and tipping point (i.e., non-linear) responses, yet it remains poorly understood which of these responses dominate. In contrast to calcification, it has been hypothesized that photosynthesis rates may increase under OA; however, whether such a fertilization effect exists is currently also unknown. To address these two knowledge gaps, we conducted (1) a response type analysis for both calcification and photosynthetic responses, and (2) a meta-analysis to assess how OA impacts photosynthetic response (photosynthesis rates and photochemical efficiency of Fv/Fm). Using published raw calcification and photosynthetic response data, linear and parabolic models were fitted to OA treatments which revealed that linear responses dominated in 71% (calcification) and 67% (photobiology) of cases. This demonstrates that tipping-point responses for calcification and photobiology under OA are likely rare. The meta-analysis assessing effect-sizes, revealed that decreases in pH corresponding to the emission-intensive IPCC scenario SSP 8.5 for 2100 (pH 7.7) had no effect on photosynthetic response. This was independent of whether photosynthesis rate and Fv/Fm were analyzed together or independently. When all published treatment responses were used for the meta-analysis, including those with pH <7.7, coral photosynthetic response was reduced by 9.4% for every 0.1 unit reduction in pH, Fv/Fm alone was unaffected by OA. These results demonstrate that a fertilization effect for photosynthetic responses does not exist, suggesting that any benefits from increased CO_2 levels are outweighed by the physiological cost of operating in a low pH environment. The prevalence of linear responses for both calcification and photobiology, as well as the lack of a fertilization effect, will significantly improve our ability to predict future coral responses to OA. However, challenges remain, including the consolidation of both response types and magnitudes, as well as incorporating more aspects of coral life history when modeling physiological responses.

Key words: ocean acidification | coral | calcification | photosynthesis | effect size meta-analysis | response types

Response of the Physiological Condition of *Mytilus edulis* and *Donax variabilis* to Temporal and Spatial Variation in Water Quality

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Climate change and its impact on calcifying organisms is presently a vigorous area of study. To assert that climate change is causing significant changes in study organisms, a baseline of organism condition is needed. Furthermore, organism condition needs to be monitored through time, to detect any changes in physiological condition. It is well documented that the Eastern Shore of Virginia, U.S.A. has been and will continue to experience significant changes in water temperature and carbonate chemistry in the coming years. This study operates under the assumption that water quality changes have a significant effect on bivalve species' condition. The goal of this study is to affirm whether there have been significant changes in the physiological condition of two bivalve species through time and between barrier islands on the Virginia Eastern Shore. The research questions being answered are as follows: Have there been directional changes in the physiology of *Mytilus edulis* and *Donax variabilis*, specifically in shell length and condition index, within the last 13 years? Do these trends vary among islands?

To answer these questions, a historical archive containing blue mussels and coquina clam recruits, sampled on Virginia barrier islands from the years 2005-2018 is being used. Condition index and shell height are calculated for bivalve species collected from three islands: Metompkin, Myrtle, and Smith (blue mussels) and Hog, Metompkin, and Wreck (coquina clams). Significant differences in the condition index and shell length of mussels and clams, in response to variation in water quality among years and islands, were observed. There is a possibility that the data produced from this study provides evidence of a range contraction in blue mussels and range expansion in coquina clams. Physiological condition and shell morphology of these bivalve species may serve as a useful bioindication of climate change within the Virginian barrier island ecosystem.

Key words: physiology, bivalves, water quality, Virginia

Unifying biological field observations to detect and compare ocean acidification impacts across marine species and ecosystems

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Recent years have seen a globally coordinated effort to observe the changes in seawater chemistry caused by the oceanic uptake of anthropogenic CO_2. The Global Ocean Acidification Observing Network (GOA-ON) has driven international efforts to define the physical and chemical parameters that are needed to monitor ocean acidification (OA) and describe the most appropriate methods by which those parameters should be measured. While the physico-chemical observation progresses, quantifying the biological consequences of OA remains challenging. Biological observations on parallel global, regional and local scales will be essential, but the challenge is to identify a strategy and set of fundamental biological and ecological indicators that are firstly relevant across marine ecosystems, secondly have a strongly demonstrated link to OA, and thirdly have implications for ocean health and the provision of ecosystem services. With the goal of establishing a planet-wide perspective on the ecosystem level impacts of OA, we identify optimal monitoring strategies (frequency and duration) to observe biological rates of change, allowing combining these data at regional and global scales. We will delineate five fundamental ecosystem traits and their observable indicator factors: calcified organisms and calcification, autotrophs and primary production, heterotrophs and secondary production, biodiversity and community structure, as well as genetic adaptation.

Key words: Monitoring, Biological Indicators, Global, Observations

Experimental assessment of Ocean Acidification combined with Deoxygenation using a copepod *Tigriopus japonicus*

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Acidification and deoxygenation are major threats to ocean environments. Despite the possibilities of their co-occurrence, little is known about their interactive effects on marine organisms. In this study, we investigated effects of low pH and low dissolved oxygen (DO) on nauplii of a copepod *Tigriopus japonicus*, which inhabits in tidepools along coasts. To test the effects of interaction between acidification and deoxygenation, we set 25 experimental treatments in both five levels of pH between 7.6–8.1 (corresponds to 450–1500 μatm pCO_2) and of DO between 50–230 μmol/kg, and the experimental seawater was produced by bubbling CO_2 and N_2 gases to natural seawater. These conditions cover width of present (8.1) to this century end levels of pH (7.6) in coastal environment and 20% (50 μmol/kg) to 100% (230 μmol/kg) saturation degree of DO. We then investigated survivorship of the nauplii (mostly in stages 1–4) after 48h at 25°C. We found that low DO affected the nauplii more than pH. Survivorships were more than 90% in ≥150 μmol/kg DO, and the values decreased in lower DO, but they did not reach 0%. For each pH condition, we calculated the 50% lethal concentration (LC_{50}) of DO. The 48-h LC_{50} of DO did not show straight increase depending on pH decrease: the highest value was detected at pH 7.6, and the lowest was detected at pH 7.8, not at pH 8.1 (control). *T. japonicus*, at least in its early life stages, possibly be affected when ocean acidification and deoxygenation co-occur severely in the natural environment. However, at around pH 7.8 level of acidification, this copepod species may have tolerance to deoxygenation.

Key words: hypoxia, dissolved oxygen, hypercapnia, nauplii

Theme C: Ecological effects of ocean acidification and stressors in a changing ocean

Coral Reef Ecosystem Responses across a Strong Ocean Acidification Gradient in the U.S. Pacific Islands

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The U.S. Pacific Islands span a dramatic natural gradient in climate and oceanographic conditions, and benthic community states vary significantly across the region's coral reefs. Here we leverage a decade of integrated ecosystem monitoring data from American Samoa, the Mariana Archipelago, the main and Northwestern Hawaiian Islands, and the U.S. Pacific Remote Island Areas to evaluate coral reef community structure and reef processes across a strong natural gradient in aragonite saturation state (Ω_{ar} = 2.5-4.2). We assess spatial patterns and temporal trends in carbonate chemistry measured in situ at 37 islands and atolls between 2010 and 2019, and evaluate the relationship between long-term mean Ω_{ar} and benthic community cover and composition (benthic cover, coral genera, coral morphology) and reef process (net calcium carbonate accretion rates). Our findings show that net carbonate accretion rates demonstrate significant sensitivity to declining Ω_{ar}, while most benthic ecological metrics show fewer responses to lower-Ω_{ar} conditions. These results indicate that metrics of coral reef net carbonate accretion provide a critical tool for monitoring the long-term impacts of ocean acidification that may not be visible by assessing benthic cover alone. The perspectives gained from our long-term, in situ, and co-located coral reef environmental and ecological data sets provide unique insights into effective monitoring practices to identify potential for reef resilience to future ocean acidification and inform effective ecosystem-based management strategies under 21st century global change.

Key words: coral reefs, ocean acidification, carbonate accretion, U.S. Pacific Islands

VULNERABILITY OF DUNGENESS CRABS UNDER MULTI STRESSORS INDICATES DETRIMENTAL NEGATIVE BIOLOGICAL EFFECTS

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Ocean Acidification and Hypoxia (OAH) is of increasing concern for the nearshore ecosystems that are providing important habitats for ecologically and economically significant calcifying species. This is particularly relevant for Dungeness crab (*Metacarcinus magister*), which is perennially one of the most valuable commercial fisheries along the California Current Ecosystem (CCE). Recent scientific findings have demonstrated Dungeness crab vulnerability to low pH, resulting in dissolved exoskeleton and neurophysiological receptors important for behavioral and sensory functioning. However, the effects of OAH (low pH/low oxygen) stressors on this species are unknown despite the fact that such exposure in the CCE often co-occurs during the vulnerable early stage periods. Hindcast model outputs from the biogeochemical ROMS-BEC model at 1 km resolution demonstrates a positive linear relationship between pH and DO, indicating that at lower pH (below 7.7), the organisms will frequently be exposed to lower oxygen (DO) levels especially during April-October period. As such, it is essential to understand the biological ramifications from the interactive OAH stressors potentially leading to synergistic outcomes, the information that critical to inform efforts to predict climate change impacts on fisheries and ecosystems and develop management responses. Using multistressor experimental platform, we exposed juvenile Dungeness crabs to various OAH exposure combinations for a 2-week duration. Subsequently, we measured various biological responses, ranging from cellular (gene expression) to physiological (biomineralization), and organismal responses (survival). We did not found more exoskeleton dissolution at combined OAH conditions compared to lower pH, confirmed also by the results of mitochondrial activity. While the pH is not a major driver of mortality, we found significantly more mortality at OAH compared to a low DO only, with more than 50% of all juveniles affected by mortality after just 7-day OAH exposure. Using model outputs with selected OAH thresholds, we investigated spatial projections in the CCE areas in which dissolution and mortality processes are most prevalent, indicating the greatest level impacts due to the current OAH exposure.

Key words: Dungeness crab, multiple stressors, ocean acidification, biological impacts, vulnerability assessment.

Simulating the Impact of Ocean Acidification and Associated Stressors on the Eastern Oyster, *Crassostrea virginica*, in Chesapeake Bay

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The Eastern oyster, *Crassostrea virginica*, is an ecologically, economically, and culturally important species in estuaries along the U.S. East and Gulf coasts, including the Chesapeake Bay. The species is currently estimated to be at less than 1% of its historic abundance in the Chesapeake, and concerted efforts are underway to restore the species throughout the bay. Growth of oysters via aquaculture has also increased rapidly in the bay in recent years, and Virginia now ranks in the top three U.S. states in annual oyster production. However, restored and cultured oysters in the Chesapeake are subject to the negative impacts of ocean acidification (OA), along with a myriad of co-stressors associated with climate change, including warming temperatures, variable salinity, increased total suspended sediment (TSS) loads, and diel cycling hypoxia. Co-restoration of seagrasses has been proposed as a way to mitigate the negative impacts of OA on oysters, since seagrasses take up CO_2 to fuel photosynthesis, thereby increasing pH. We have expanded an existing oyster bioenergetics model, *EcoOyster*, which already included the effects of temperature, salinity, and TSS on oysters, to include the impacts of OA (see companion abstract by Blachman et al.) and diel cycling hypoxia. We ran *EcoOyster* with observed water quality time series at a number of sites around the lower Chesapeake Bay and Virginia Eastern Shore, with and without superimposed long-term declines in pH due to OA, to quantify the impacts of pH and associated co-stressors on oyster growth and condition. A comparison of modeled growth at sites with and without seagrass beds demonstrated the potential of seagrasses to mitigate the negative impacts of OA. Results have quantified OA thresholds beyond which oysters are increasingly vulnerable, the interactive effects of multiple stressors on these thresholds, and the potential for seagrass to mitigate the thresholds.

Key words: Eastern oyster, bioenergetics model, ocean acidification, Chesapeake Bay

Dissecting ocean acidification potential impacts during the early life cycle of the Tropical Pacific shrimp *Penaeus vannamei* in Ecuador

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In crustaceans, the impact of ocean acidification (OA) is variable amongst species, life stages, and ecosystems. The tropical Pacific shrimp, *Penaus vannamei*, is an appropriate experimental model species, not only because it's relevant in aquaculture and fisheries worldwide, but due to its ecophysiological treats. This species naturally inhabit different environments along its life cycle, through oceanic and different marine coastal waters, and can be acclimated for farming in a wide range of pH and salinity. We are carrying-out experiments to assess the responses to ocean acidification conditions in lab during early larval stages, post-larvae and juveniles to determine the impact on growth, survival and development. We used an automated pH-control system with direct CO_2 injection, with four replicates by treatment. Total Alkalinity and pH were analysed in discrete samples of each replicate, validated and adjusted with adequate reference material, and used the CO2calc software for the calculations of pCO_2 and DIC. Temperature and salinity were maintained constant at 25 ±0.5°C and 33 UPS, respectively. So far, our results on juveniles (5.8±0.6 g) exposed during three weeks to low pH (pH 7,2) showed no-significant differences on growth and survival compared to current coastal water conditions (pH7.9). However, on early stages (from nauplii to zoea) the effect was drastic, at pH 6.8 there was 41% reduction of growth (length) compared to controls (pH 8.0) at 24h of exposure and total mortality at 48h; while at pH 7.4 a total mortality occurred at 72h; it was also found a significant delay on development on both low pH levels compared to controls. Overall, this work shows under experimental conditions that the developmental stage is pivotal on the tropical Pacific shrimp response to ocean acidification.

Key words: tropical Pacific, shrimp, aquaculture, equatorial biome, development

Global Declines in Coral Reef Calcium Carbonate Production under Ocean Acidification and Warming

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Ocean warming and acidification threaten the future growth of coral reefs. This is because the calcifying coral reef taxa that construct the calcium carbonate frameworks and cement the reef structure together are highly sensitive to ocean warming and acidification. However, the global-scale effects of ocean warming and acidification on rates of coral reef net carbonate production remain poorly constrained, despite a wealth of studies assessing their effects on the calcification of individual calcifying organisms. Here we present global estimates of projected future changes in coral reef net carbonate production under ocean warming and acidification. We apply a meta-analysis of responses of coral reef taxa calcification and bioerosion rates to predicted changes in coral cover driven by climate change to estimate the net carbonate production rates of 183 reefs worldwide by 2050 and 2100. We forecast mean global reef net carbonate production under representative concentration pathways (RCP) 2.6, 4.5 and 8.5 will decline by 70, 148 and 156% respectively by 2100. While 65% of reefs are projected to continue to accrete by 2100 under RCP2.6, 94% will be eroding by 2050 under RCP8.5, no reefs will continue to accrete at rates matching projected sea level rise under RCP4.5 or 8.5 by 2100. The projected reduced coral cover due to bleaching events predominately drives these declines, rather than the direct physiological impacts of ocean warming and acidification on calcification or bioerosion. More degraded reefs will also be much more sensitive to the impending environmental change. These findings highlight the low likelihood that the world's coral reefs will maintain their functional roles without near-term stabilization of atmospheric CO_2 emissions.

Key words: Corals, coralline algae, accretion, reef growth, carbonate production

Modeling the Multiple Action Pathways (MAPs) of ocean acidification effects on Pacific cod in the eastern Bering Sea

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Ocean acidification (OA) has the potential to significantly affect the production of valuable fishery resources, including gadids and other groundfishes through multiple ecological pathways. These include the direct physiological effects on larvae growth and survival as well as potential disruption of sensory systems and foraging behaviors. Indirect effects include alteration of species composition, productivity, and nutritional value of lower trophic levels. Best predictions, based on food-web theory and phytoplankton physiology, indicate a loss of essential nutrients (e.g. essential fatty acids) available to higher levels of the food web. Accurate predictions of the effects of OA on the productivity of critical marine resource species is dependent upon an improved understanding of OA's multiple ecological pathways, the interactions between them, and their relationship to other environmental and ecological stressors. In this study, we develop a model describing the multiple action pathways of OA for Pacific cod in the eastern Bering Sea. This Individual Based Model of the early life history is parameterized from empirical observations of responses to variation in CO2, temperature, and prey quality and quantity for Pacific cod and its congeners. By integrating with the recently validated carbonate system components in the Regional Oceanographic Model System (ROMS) Bering10K model, this study provides spatially-explicit estimates of climate change effects on Pacific cod recruitment potential in the Bering Sea. Moreover, our analyses quantify the relative importance of the multiple action pathways by which OA and temperature changes will impact Pacific cod. Finally, we discuss about how these changes could impact the entire stock and its fishery.

Key words: eastern Bering Sea, Pacific cod, ocean acidification, fish larvae

Impacts of future climate change on Chesapeake Bay carbonate chemistry and oyster growth

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Increasing oceanic uptake of atmospheric carbon dioxide (CO_2) and high riverine nutrient loads cause a decrease in seawater pH and calcium carbonate saturation states in coastal waters, a phenomenon known as coastal acidification. Such changes in water chemistry have implications for calcifying organisms in the Chesapeake Bay, particularly the eastern oyster *Crassostrea virginica,* a vital species to the regional ecosystem and economy. Low calcite (Ω_{Ca}) saturation states inhibit formation of adult oyster shells and thus lead to slower growth rates and higher mortality of oysters. A three-dimensional physical-biogeochemical model forced with downscaled Earth system model output was used to estimate mid-century carbonate chemistry in the Chesapeake Bay. Two future runs, one with projected 2050 IPCC atmospheric CO_2 alone and one with 2050 IPCC atmospheric CO_2 along with 2050 air temperature, were compared to a baseline run with 1990s CO_2 and temperature. Model results suggest that future temperature change caused uniform reductions of pH in surface water, while future CO_2 change led to greater seasonal variation in pH values, with values spiking in the spring and dropping in late summer. Ω_{Ca} values in 2050 regularly dipped below an acidification threshold for eastern oyster calcification of 1.26 in the York and Rappahannock rivers, both regions where wild oyster harvest, aquaculture, and restoration commonly occur. Model outputs were further used to force an oyster bioenergetics model to predict mid-century oyster growth. Oysters further up the York and Rappahannock river are projected to experience net dissolution by the mid-2050s due to Ω_{Ca} values falling below the calcification threshold for the majority of the year. This work aims to inform stakeholders of regions in the bay where oyster growth and aquaculture production will be reduced due to acidification.

Key words: Coastal Acidification, *Crassostrea virginica,* 3-D Model, Chesapeake Bay

To Settle, or not to Settle: Marine Biofilms, Larval settlement and Ocean Acidification

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Larval settlement and metamorphosis are key processes in the life cycle of benthic marine invertebrates. Ocean acidification (OA) could alter these processes directly (i.e. by altering the physiology or settlement capacity of the larvae), as well as indirectly (i.e. altering settlement substrates or settlement cues).

Settlement substrates and settlement cues play a very important role in the larval recognition and attachment process, and marine biofilms are key settlement inducers for a variety of taxa. Changes in bacterial assemblages or community composition could alter the settlement cues in such a way that larval settlement and metamorphosis success could be compromised.

We investigated whether marine biofilms grown under different seawater pH levels could influence differential settlement outcomes in the serpulid polychaete *Galeolaria hystrix*. For this experiment, marine biofilms were grown in a range of pH treatments (7.0 to ambient) for a total incubation time of 60 weeks. Biofilms of different ages (7, 10 and 14 months) were used in a settlement assay with competent *G. hystrix* larvae in order to quantify settlement success on the different biofilms. In addition, the microbial community composition of the marine biofilms was investigated using amplicon sequencing of the small subunit ribosomal rRNA gene (16S and 18S), in order to investigate whether changes in settlement outcome could be related with a shift in microbial community composition.

The results of our investigations show that pH incubation treatment strongly influenced biofilm community - at both eukaryote and prokaryote levels - as well as settlement success, although the mechanisms behind it could not be discerned. In contrast, biofilm age played no role in either biofilm community composition or settlement success.

The results of this research will enable us to study the potential mechanisms through which OA might affect settlement substrates, and therefore influence settlement processes in marine invertebrates.

Key words: Ocean acidification, larval settlement, marine biofilms, microbial community, settlement substrates

Assessing the Potential Impacts of Ocean Acidification on Phytoplankton Communities in River influenced Coastal Ecosystems

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Coastal environments are greatly influenced by terrestrial inputs, particularly the outflow from rivers which often supports high levels of respiration. In general, coastal environments are not as well-buffered as marine waters which have naturally higher pH and higher bicarbonate and carbonate ion concentrations. Furthermore, many coastal environments are more exposed to anthropogenic influences and to coastal upwelling making them particularly susceptible to ocean acidification. Although there is growing evidence that ocean acidification will alter the community structure and function of marine primary producers, such impacts on coastal-estuarine phytoplankton, which are typically exposed to a wider range of *p*H than their truly oceanic counterpart are still far from certain. Recent results from ecological and metatranscriptomic surveys in two significantly river impacted coastal ecosystems along the east coasts of Brazil and the USA in the North Atlantic, suggest that phytoplankton functional types may in fact be regulated by dissolved inorganic carbon (DIC) concentrations, carbon concentrating mechanisms (CCMs), and to a lesser degree by dissolved inorganic nitrogen or phosphorous availability. Shipboard and laboratory CO_2 manipulation experiments lead us to posit that coastal-estuarine phytoplankton are highly sensitive to changes in carbonate chemistry. Thus ocean acidification could fundamentally alter the structure of plume phytoplankton communities and the overall role of the plume's phytoplankton communities in the biogeochemistry of the western North Atlantic Ocean.

Key words: Land-Ocean Continuum, Phytoplankton Functional Types

Coral-Algae Interactions under Ocean Acidification

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Increasing carbon emissions caused by anthropogenic activities have led to a global decrease of oceanic pH; a phenomenon termed as 'ocean acidification' (OA). Hermatypic corals show decreased net calcification rates under OA. However, this increase in oceanic pCO_2 can enhance turf algal growth that tend to trap large amounts of sediment, leading to anoxia and decreased local pH. Therefore, competition between corals and turf algae could turn in favor of the turf under increased pCO_2. Furthermore, the increase in turf algae could contribute to shift corals reefs towards net dissolution. In this study, we aimed to examine coral-algae competition under OA and the mechanisms that influence their interactions under both ecologically realistic (CO_2 seeps) and laboratory conditions. Microcolonies of *Acropora solitaryensis* (non-resistant to OA) and *Porites heronensis* (resistant to OA) were prepared by stripping the coral tissue of half of the coral colony, leaving behind bare skeleton prime for turf algal settlement. The pH conditions were control (8.1 pH) and acidified (7.8 pH) treatments for the incubation experiment, and control (400 ppm pCO_2) and acidified sites (900 ppm pCO_2) at the Shikine Island CO_2 seep (Japan) for the transplantation experiment. The transplantation experiment is still ongoing, but corals in the incubation experiment showed net calcification decreased under OA conditions, leading to net dissolution of *A. solitaryensis*. Furthermore, pH within the turf algal mat showed large diurnal fluctuation with reduced pH (7.67 ± 0.37 pH) under dark condition and elevated pH (8.4 ± 0.3 pH) under light, regardless of treatment and coral species. These preliminary results show that as OA favors turf algae over corals, coral reefs will shift towards an algal state, and from net accretion to net dissolution.

Key words: ocean acidification, hermatypic corals, coral-algae interactions, CO_2 seeps, dissolution

Evaluation of growth, primary productivity, nutritional composition, redox state, and antimicrobial activity of red seaweeds *Gracilaria debilis* and *G. foliifera* under pCO_2 induced seawater acidification

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The genus *Gracilaria* is an economically important group of seaweeds as several species are utilized for various products such as agar, used in medicines, human diets, and poultry feed. Hence, it is imperative to understand their response to predicted ocean acidification condition. In the present study, we have evaluated the response of *Gracilaria foliifera* and *G. debilis* to carbon dioxide (pCO_2) induced seawater acidification (pH 7.7) for two weeks in controlled conditions. As a response variable, we have measured growth, productivity, redox state, primary and secondary metabolites, and mineral compositions. We found a general increase in the daily growth rate, primary productivity, pigments, soluble and insoluble sugars, amino acids, and fatty acids, and a decrease in the mineral contents under the acidified condition. Under acidification, the level of malondialdehyde (MDA, membrane damage) decreased, however, no significant changes were found in the total antioxidant capacity and a majority of enzymatic and non-enzymatic antioxidants except an increase in tocopherols, ascorbate, and glutathione-s-transferase in *G. foliifera*. These results indicate that elevated pCO2 will benefit the growth of the studied species. No sign of oxidative stress markers indicating the acclamatory response of these seaweeds towards lowered pH conditions. Besides, we also found increased antimicrobial activities of acidified samples against several of the tested food pathogens. Based on these observations, we suggest that *Gracilaria* spp. will be benefitted from the predicted future acidified ocean.

Key words: ocean acidification, ocean warming, oxidative stress, polyphenols, red algae

ATLANTIC HETEROPODS AS INDICATORS OF ENVIRONMENTAL CHANGE IN THE SOUTHERN CALIFORNIA CURRENT.

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Atlantids are holoplanktonic gastropods that bear an aragonitc shell and in the long term, they might be affected by ocean acidification. However, little is known about how their distribution and abundance vary regarding changes in the environmental conditions. The strongest seasonal changes in plankton species composition and environmental conditions in the California Current System, occur between winter and spring, mainly related to upwelling and water masses distribution. Other important changes in the environment happen in the interannual scale related to ENSO (La Niña 2010-2012, El Niño 2015-2016) and marine heat waves (2013-2015). The aim was to determine the species composition and the environmental factors that affect the seasonal and interannual variation of the distribution and abundance of Atlantidae species in the Pacific coast off Baja California between 2012-2016, based in four oceanographic cruises carried out in winter and three in spring, with 284 zooplankton samples analysed. We found 14 species, where winters were more diverse than springs, with the most species recorded during the warm anomalies observed on the winters of 2014 and 2016. Through canonical correspondence analyses, we determined that atlantids distribution in winters was correlated to physical factors (temperature, salinity, and water masses in the area) while in spring, their distribution was correlated with chemical factors (hypoxic conditions and the aragonite saturation horizon depth).

Key words: holoplanktonic mollusks, interannual variation, aragonite saturation depth.

Response of keystone coccolithophore species to natural and anthropogenically-induced variations of CO_2 in the Southern Ocean

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The Southern Ocean plays a major role in global overturning circulation and represents the largest sink for anthropogenic CO_2 in the world oceans. This vital service, however, comes at a high cost, since the increase in the oceanic CO_2 leads to a reduction in pH and decrease in the concentration of carbonate ions, a process known as ocean acidification. Projections of the pCO_2 in the surface waters of the Southern Ocean, suggest a rapid decrease of pH in the coming decades with accompanying decreases in the saturation of calcium carbonate minerals. This pronounced change in the ocean carbonate chemistry poses a serious risk for marine ecosystems in general and for marine calcifying organisms in particular. Coccolithophores are unicellular eukaryotic algae that secrete calcite plates (coccoliths). Satellite imagery reveals extensive blooms of *Emiliania huxleyi* in the Southern Ocean, where high concentrations of coccolithophore particulate inorganic carbon (PIC) extend along the circumpolar Subtropical, Subantarctic and Polar Fronts during austral summer. Changes in coccolithophore abundance, composition and degree of calcification may potentially impact the entire marine ecosystem and ocean chemistry, ultimately affecting the climate. Long-term field observations in the natural habitats of the coccolithophores are critical to evaluate possible responses of coccolithophores to environmental change. Here, we compare morphometric parameters in the coccoliths of the keystone species *E. huxleyi* and *Calcidiscus leptoporus* registered during an annual cycle in the Pacific Sector of the Subantarctic Zone, with those from a set of surface sediment samples and those found in a sediment core covering the last 40,000 years. Our results allow us to reconstruct the response of these two species to environmental variations in the Southern Ocean and reveals that some coccolith morphometric parameters covary in relation to changes in ocean carbonate chemistry driven by changes in atmospheric CO_2 concentrations.

Key words: Southern Ocean, coccolithophores, calcification, sediment traps,

Modeling species interactions to evaluate whether seagrass can alter the physiological condition of Eastern oysters under ocean acidification

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Ocean acidification (OA), a global anthropogenic stressor, may irrevocably damage estuarine ecosystems and their services. Oysters, including the Eastern oyster *Crassostrea virginica*, respond negatively to conditions of OA, reaching physiological thresholds – conditions of seawater chemistry beyond which their performance declines. On short time scales (hrs to days), seagrass metabolism has the potential to alter seawater chemistry sufficiently to mitigate OA impacts on oysters and possibly induce beneficial changes in carbonate chemistry conditions. Synergistically, oyster filtration and metabolism have the potential to clarify estuarine waters and increase pCO_2 required by seagrasses, respectively, thereby increasing light penetration and seagrass photosynthesis that further buffer the impacts of OA on oyster metabolism. We used laboratory experiments to quantify ecologically-relevant thresholds for OA impacts on *C. virginica* (growth, calcification, respiration, filtration, excretion and condition index). Thresholds for declining performance occurred at a lower pH for younger oysters than for older oysters. Results were combined with a literature synthesis to parameterize formulations for the effect of pH on oyster vital rates in the coupled oyster-ecosystem model *EcoOyster*. *EcoOyster* was then coupled with the seagrass bio-optical model *GrassLight* to explore the potential for seagrass metabolism to mitigate the impacts of OA on oyster restoration and aquaculture. We present results from simulations of future OA with and without the presence of seagrass and evaluate which seagrass ecosystem characteristics (e.g. bed density, flushing time) are required to prevent oysters from reaching OA thresholds. Estimates of these species interactions support assessments of potential for co-restoration of seagrass to mitigate OA thresholds for oysters.

Key words: oyster, seagrass, physiology, modeling, metabolism

LONG TERM TRENDS OF pH AND SEA SURFACE TEMPERATURE OVER COLOMBIAN MARITIME AREAS AND THE THREATS TO REGIONAL CORALS

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Ocean acidification and warming is currently occurring and they will be enhanced in the future, affecting marine ecosystems and impacting the social and economic systems of the world. Data on pH and sea surface temperature (SST) recorded in the Colombian Caribbean and Pacific Ocean were analysed, and the long term trends, which locally represent the global ocean acidification and warming phenomena, were identified. Based on these changes we deduced the sensitivity of several species and genera of corals. A reduction of approximately 0.086 units/decade in the pH for the Caribbean Sea, and of 0.090 units/decade for the Pacific Ocean was evidenced. We also found a rise of about 0.19ºC/decade in the sea surface temperature for the Caribbean Sea and of 0.15ºC/decade for the Pacific Ocean in the study. Due to ocean acidification and warming interact with regional processes, it was established the differences of long term trends of pH and SST between coastal and oceanic sectors of Colombian maritime areas. In the Caribbean Sea, the decrease in pH is higher in the coastal sector (0.12 units /decade) than in the oceanic sector (0.036 units/decade); while in the Pacific Ocean, the decrease in pH is higher in the oceanic sector (0.23 units/decade) than in the coastal sector (0.044 units/decade). On the other hand, the increase in SST in the Caribbean Sea is greater in the oceanic sector (0.17°C/decade) than in the coastal sector (0.062°C/decade); while the SST rise in the Pacific Ocean is greater in the coastal sector (0.29°C/decade) than in the oceanic sector (0.081°C/decade). Based on the review of evidences and specific studies published by other authors about the corals sensitivity to pH reduction and sea temperature increase, we established the sensitivity of several species and genera of corals in Colombian Caribbean Sea and Pacific Ocean.

Key words: Ocean acidification, ocean warming, pH, sea surface temperature, corals impact.

Altering planktonic trophic interactions of the Arctic through the different temperature- and CO_2-sensitivities between small and large phytoplankton

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Rapid temperature rise and high CO_2 conditions are among the serious stressors in the marine ecosystem. Impacts of those stressors on plankton ecosystem ultimately propagate to higher trophic levels. However, understanding the trophic interactions between phytoplankton and their predator under multiple environmental stressors are the challenging unexplored issues to better predicting changing marine ecosystem. Here we measured the temperature and CO_2 sensitivities of marine phytoplankton and microzooplankton in the western Arctic Ocean, where is experiencing rapid climate change. Increasing temperature enhanced the growth of phytoplankton at a pace of 0.1 day^{-1} °C^{-1} under in situ CO_2 levels. Elevated CO_2 levels significantly depressed or enhanced the temperature sensitivity of larger or smaller phytoplankton traits, respectively. Fertilization effect of high CO_2 levels on CO_2-limited large cell-sized phytoplankton assemblages diminished under the increased temperature. Microzooplankton grazing was closely coupled with the growth rate of their prey, suggesting that microzooplankton is highly resilient to the direct effects of multiple environmental stressors. These results suggest that the smaller is highly competitive among planktonic assemblages in the Arctic Ocean under climate change. Increasing the number of trophic levels through the decrease in the size of phytoplankton could dramatically decreases in the energy transfer efficiency, and therefore the production of higher trophic levels. Furthermore, a smaller plankton-dominated ecosystem has potentially positive feedback on atmospheric CO_2 because they are inefficient constituents of carbon sequestration to the deeper ocean.

Key words: Ocean acidification, phytoplankton, microzooplankton, temperature sensitivity, Arctic Ocean

Ocean acidification alters invertebrate behaviour across multiple trophic levels

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Ocean acidification poses a range of threats to marine invertebrates; however, the emerging and likely widespread effects of rising carbon dioxide (CO_2) levels on marine invertebrate behaviour are still little understood.Here, we show that ocean acidification alters and impairs key ecological behaviours in a range of marine invertebrates, including several mollusc species, across multiple trophic levels. We show that projected future elevated CO_2 conditions (~650-975 µatm pCO_2) impair prey escape behaviours during predator-prey interactions, including reducing the number of prey that choose to escape, increasing the time taken to initiate escape and altering prey escape trajectory. We find meso-predators catch six-times less prey, despite being three-times more active, with implications for the energy budget. Furthermore, activity, defensive behaviour and predatory strategies in higher-order predators are altered. The mechanisms for behavioural alteration appear to be interference with nervous system receptors that are found widely across the animal kingdom, in both invertebrates and vertebrates.The alteration of key ecological behaviours in marine invertebrates and fishes by near-future ocean acidification could have potentially far-reaching implications for predator–prey interactions and trophic dynamics in marine ecosystems. Evidence that the behaviours of multiple species across multiple trophic levels are altered by elevated CO_2 suggests food web interactions and ecosystem structure will become increasingly difficult to predict as ocean acidification advances over coming decades.

Key words: behaviour, invertebrate, mollusc, predator-prey, food web

Projections of Reef Habitat Persistence under Ocean Acidification and Warming: Implications of Restoration and Coral Adaptation on the Persistence of the Inshore Patch Reef Cheeca Rocks.

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For reef framework to persist, calcium carbonate production by corals and other calcifiers needs to outpace loss through physical and biological erosion. This balance is both delicate and dynamic and is currently threatened by the effects of ocean warming and acidification. Although the protection and recovery of ecosystem function, such as carbonate deposition, are at the center of most restoration and conservation programs, decision makers are limited by the lack of predictive tools to forecast habitat persistence under global change scenarios. To address this, we developed a modeling approach, based on carbonate budgets, that ties species-specific responses to site-specific global change using the latest generation of climate models projections (CMIP6). Additionally, we examine the potential effects of coral thermal adaptation by increasing the bleaching threshold in quarter degree increments up to 2°C above the maximum monthly mean. We applied this model to Cheeca Rocks, an outlier in the Florida Keys in terms of high coral cover and explored the outcomes of restoration targets scheduled in the coming 12 years at this site by the Mission Iconic Reefs restoration project. Regardless of coral adaptative capacity or restoration, net carbonate production at Cheeca Rocks declines heavily once the threshold for the onset of annual severe bleaching (ASB) is reached. The only scenarios where ASB is pushed after 2100 are when a decreased emissions scenario is coupled with coral adaption to >1.25˚C. Even in these cases, however, the Cheeca Rocks reef will not be able to retain accretion potential rates that keep pace with future SLR projections. Reef persistence remains ultimately dependent on the rate and extent of CO_2 emissions. Nevertheless, restoration interventions combined with increases in thermal tolerance of corals, may delay the onset of mass mortalities in time for a low-carbon economy to be implemented and management interventions to become effective.

Key words: Climate Change, Coral Reef, Framework building, Adaption, Restoration

Theme D: Insights from natural ocean acidification analogues

What we learn from the Shikine CO_2 seep on the effects of high CO_2 on hermatypic corals

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Anthropogenic emission of CO_2 is driving ocean warming and acidification. Numerous studies have shown the detrimental effects of OA on hermatypic corals. Natural analogues for ocean acidification such as CO_2 seeps and semi-enclosed bays, represent a unique tool to study the direct and indirect effects of OA on hermatypic corals, and the potential for acclimation and adaptation to these future conditions. The elevated CO_2 selects for coral species and individuals resistant to OA, allowing the study of the eco-physiological traits that provide this resistance and the ecological mechanisms that will drive the shift in biological communities. Ocean warming and acidification are reorganizing marine communities and so, novel biological interactions will certainly play an important role in shaping future ecosystems. Here we present our research finding that we obtained at the Shikine CO_2 seep and their implication for the future of coral communities. We show that the few coral species can survive in the high CO_2 areas have specific physiological traits, a high potential for energy (ATP) production, and that these are not acquirable by sensitive species. We also show that the combined effects of warming and acidification could stop the poleward shift of coral observed in warm temperate areas of Japan, and that with the loss of kelp driven by increased fish herbivory, will result in simplified ecosystems.
Although natural analogues represent a unique opportunity, studies using individual sites do not allow always provide the generalized view required to expand our knowledge to other biogeographic areas. To foster research using multiple natural analogues and an exchange of information, we created the ICONA (International CO2 Natural Analogues) Network with French and Italian counterparts. The results obtained will be directly provided to the scientific and policymaker communities through the collaboration with IOC-UNESCO.

Antagonistic interplay between pH and food resources affects copepod traits and performance in a year-round upwelling system

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Linking pH/pCO_2 natural variation to phenotypic traits and performance of foundational species provides essential information for assessing and predicting the impact of ocean acidification (OA) on marine ecosystems. Yet, evidence of such linkage for copepods, the most abundant metazoans in the oceans, remains scarce, particularly for naturally corrosive Eastern Boundary Upwelling systems (EBUs). This study assessed the relationship between pH levels and traits (body and egg size) and performance (ingestion rate (IR) and egg reproduction rate (EPR)) of the numerically dominant neritic copepod *Acartia tonsa*, in a year-round upwelling system of the northern (23°S) Humboldt EBUs. The study revealed decreases in chlorophyll (Chl) ingestion rate, egg production rate and egg size with decreasing pH as well as egg production efficiency, but the opposite for copepod body size. Further, ingestion rate increased hyperbolically with Chl, and saturated at ~1 μg Chl L^{-1}. Food resources categorized as high (H, >1 μg L^{-1}) and low (L, <1 μg L^{-1}) levels, and pH-values categorized as equivalent to present day (≤400 μatm pCO_2, pH >7.89) and future (>400 μatm pCO_2, pH <7.89) were used to compare our observations to values globally employed to experimentally test copepod sensitivity to OA. A comparison (PERMANOVA) test with Chl/pH (2*2) design showed that partially overlapping OA levels expected for the year 2100 in other ocean regions, low-pH conditions in this system negatively impacted traits and performance associated with copepod fitness. However, interacting antagonistically with pH, food resource (Chl) maintained copepod production in spite of low pH levels. Thus, the deleterious effects of ocean acidification are modulated by resource availability in this system.

Key words: Eastern Boundary Upwelling systems, pH variations, organismal response to ocean acidification, interactive effects of resource and ocean acidification, copepod traits and performance.

Carbon assimilation in the community inhabiting the secondary chlorophyll maximum of the low pH anoxic marine zones of the Eastern tropical North and South Pacific

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The anoxic marine zones (AMZs) are places in the ocean distinguished from the oxygen minimum zones (OMZs) by the complete absence of detectable oxygen. These places are recognized as a source of CO_2 to the atmosphere, have low pH values (~7.5), the nutrients are abundant and the light is almost absent (<1% of incident light). When the anoxic layer overlaps with these low, but present light levels, a secondary chlorophyll maximum (SCM) is developed, composed mainly by two not yet cultivated ecotypes of *Prochlorococcus* cyanobacteria. This great abundance has been explained by the presence of divinyl chlorophyll *a* (Chl a_2) as main photosynthetic pigment, very efficient in capturing solar energy. However, some studies suggest a possible complementary heterotrophy, which would be very important for AMZ *Prochlorococcus* owing it experience periods with absence of light and, therefore, lack of energy to perform photosynthesis. In this study we compared measurements of $\delta^{13}C$ for particulate organic carbon (POC) from the primary and secondary chlorophyll maximum (PCM and SCM respectively) with an anoxic layer without a SCM. We complemented these measurements with C uptake rates experiments in the Eastern Tropical North and South Pacific. Results shows that there are no significant differences between $\delta^{13}C$-POC SCM from the North and South Pacific. However, significant differences were found between $\delta^{13}C$-POC with and without a SCM, highlighting the importance of picophytoplankton modifying the C cycle at the top of AMZ. In addition, bicarbonate uptake rate in the SCM exceeded uptake of glucose by 28-fold during light incubations and 2-fold during dark incubations. This last highlights the impact of light (even if it is low) in C assimilation rates in the SCM, important considering the predicted future vertical expansion of the AMZ and their unknown associated biochemical changes.

Key words: Carbon, SCM, AMZ, *Prochlorococcus*

Past, present, and future upwelling season ocean acidification and hypoxia conditions on the Olympic Coast (Washington, USA)

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The northern coast of Washington state has been used for millennia by four U.S. coastal treaty tribes, who rely extensively on marine resources. Since 2006, the Olympic Coast National Marine Sanctuary has deployed bottom-mounted moorings throughout the sanctuary to monitor hypoxic events during the April–October upwelling season. Hypoxia forms on the shelf when phytoplankton blooms spurred by upwelling senesce, and decomposition depletes bottom-water oxygen. We used time-series data from seven mooring sites at 15–42 m depth with oxygen, temperature, and salinity data spanning 2006–2019 to reconstruct the complete marine carbonate system using empirical relationships developed based on high-quality shipboard measurements and using oxygen and temperature as proxies for carbonate system parameters. Using estimates of anthropogenic carbon accumulation in coastal waters, we compared pre-industrial, 2030, and 2040 carbonate chemistry to projections for the year 2100 from the regional ROMS model, J-SCOPE. Climatologies of past, present, and future oxygen and carbonate system conditions along the Olympic Coast indicate that 1) major along-shelf gradients exist, with intra-seasonal worsening of acidification and hypoxia conditions in the south but not the north; 2) in the present, the thermodynamic aragonite saturation threshold ($\Omega_{arag} < 1.0$) is crossed earlier in the season and for longer duration than the hypoxia threshold ($O_2 < 62$ µmol/kg); and 3) relative to the pre-industrial, thresholds for aragonite saturation and other carbonate system parameters are crossed earlier in the season and with longer duration in the present. Further, because of non-linearities in the carbonate system, near-future and end-of-century projections of ocean conditions vary by space and depth depending on the parameter examined (fCO_2 vs. pH vs. Ω). This study is part of a regional vulnerability analysis of northern California Current Ecosystem organisms and the tribal communities who are on the front lines of climate and ocean change impacts.

Key words: ocean acidification, hypoxia, upwelling, carbonate chemistry, California Current Ecosystem

Heterogeneity of CO_2 dynamics in the Brazilian Northeast Equatorial coast

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The land-ocean continuum consists of distinct but closely connected ecosystems. The carbon processing in these areas is known to be a major component of the global carbon cycle. However, this thematic is still overlooked in low latitude areas. The equatorial section of the northeast coast of Brazil is a diverse region that comprises different ecosystem typologies, such as coral reefs, estuaries, and mangroves. This coast also exhibits different climate domains with some areas enduring long periods of dry season and others with tropical humid climate. Here we present the database of the first measurements of pCO_2 in this coastal region obtained by the Coastal Biogeochemistry Laboratory (UFC), funded by FUNCAP/CNPq. Continuous measurements of pCO_2 (n=6783), salinity, temperature, and wind speed were taken by an autonomous equipment nationally developed. Also, discrete surface seawater samples were analysed for hydrochemical parameters. pCO_2 values ranged from 339.5 to 7895.7 µatm with significant differences between the ecosystems, reflecting the high heterogeneity of coastal areas. The estuarine delta typology presented the highest variability, probably reflecting the influence of mangrove tidal creeks, while the seawater measured at the continental shelf had the lowest variation. Salinities ranged from 0 to 40.8 and presented inverse and significative correlation with the pCO_2 (r=-0.62). Although there was a significant correlation of pCO_2 with temperature (r=0.51), the CO_2 variability was predominantly driven by non-thermal effects. The inverse and significant correlation between dissolved oxygen and pCO_2 (r=-0.49) corroborate the influence of biologic processes in these systems. This database represents the first national efforts in studying these coastal systems concerning pCO_2 direct measurements, estimations of air-sea CO_2 fluxes and carbonate system dynamics, with a purpose to include our data as representative of equatorial regions in global networks and to contribute to a better understanding of the carbon cycle in coastal systems.

Key words: pCO_2; coastal systems; Equatorial Atlantic

Coccolithophore community in the Peruvian Acidic Coastal Upwelling System: Temporal and spatial variability

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The coastal upwelling system off Peru is characterized by natural low pH waters but with spatial and temporal significant variability. In particular, under El Niño (EN) conditions the oceanography and biogeochemistry experiment significant changes consequence of warm water masses distribution close to the coast bringing high pH conditions. The present study provides a first comprehensive analysis of the coccolithophore community, distribution patterns, abundance and biodiversity in the Peruvian coastal upwelling ecosystem and under non-EN and EN conditions. Between 2014 and 2015, twenty-one species were identified of which *Emiliania huxleyi* (87%) was clearly the most dominant, followed by *Ophiaster spp.* (8%), *Gephyrocapsa oceanica*, and *Florisphaera profunda* (3%). Coccolithophore abundance and diversity increased from coastal to oceanic zone under different oxygen and pH conditions. The highest abundance was recorded (average by station, 215.56 $x10^3$ cells L^{-1}) with the presence of warm waters with high pH values near the coast possibly influenced by EN event 2014. However, a coccolithophore community less abundant but is still present appears under the influence of an active coastal upwelling zone and very low pH condition (7,8). Our results show the high sensitivity of spatial-vertical distribution, abundance and diversity of coccolithophore species related to the intensity of the coastal upwelling. They provide a baseline to monitor coccolithophore responses to pH changes in the environmental conditions and understand future scenarios.

Key words: coccolithophore community, distribution patterns, coastal upwelling system, El Niño.

Spatial and diurnal variability of net water-air CO_2 fluxes in an amazon macrotidal estuary

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Tropical estuaries generally act as a source of CO_2 to the atmosphere, due to the high content of detritic organic matter. However, the variability of net water-air CO_2 flux (FCO_2) over a diurnal cycle is poorly understood, although its importance, because it is strongly influenced by short-term processes (24h) such as photosynthesis, respiration and tidal cycle. In this study, we evaluated the diurnal variability of FCO_2 in a macrotidal channel in an amazon estuary. We determined the hydrographic (temperature and salinity) and biogeochemical parameters (pH, total alkalinity - AT, total dissolved inorganic carbon - CT and CO_2 partial pressure) in surface water sampled in summer 2019, over two tidal cycles (25 hours) at three sites. The average AT was 1011.11 ± 149.90 µmol kg^{-1} and the average CT was 982.23 ± 181.76 µmol kg^{-1}. The average FCO_2 was 20.04 ± 24.38 mmol m^{-2} d^{-1} (0.84 ± 1.02 mmol m^{-2} h^{-1}) in the upstream, 28.80 ± 37.50 mmol m^{-2} d^{-1} (1.20 ± 1.56 mmol m^{-2} h^{-1}) in the middle and 3.58 ± 7.41 mmol m^{-2} d^{-1} (0.11 ± 0.23 mmol m^{-2} h^{-1}) at the mouth of the macrotidal channel. Statistically, there were no significant differences between the sampled sites. However, there were significant differences during the tidal cycle at all sampled sites. Salinity and pH showed significant variability ($p < 0.05$), mainly correlated with the tidal cycle, while temperature showed significant variability between day and night ($p < 0.05$). The main driver of changes in the carbonate system in the macrotidal channel was the semidiurnal tidal cycle. These findings demonstrate the importance of considering short-term variability in FCO_2 biogeochemical studies in estuaries, especially those that are dominated by macrotidal.

Key words: CO_2 fluxes; Diurnal variability; Macrotidal; Amazon estuary.

New Sea Surface CO_2 Fugacities measurements in the Argentine Sea

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Ocean acidification (OA), as a consequence of the excess of anthropogenic CO_2 captured by the ocean, represents a threat to marine biota and has strong impacts on fisheries. The Argentine continental shelf and its shelf-break constitute one of the highly productive areas of the world oceans, sustaining commercially important populations of fish and invertebrates. This region makes an important contribution to the global ocean CO_2 uptake (Bianchi et al., 2009) and merits a continuous spatio-temporal monitoring. This work presents a quality-controlled dataset of sea surface CO_2 fugacities ($fCO_{2\ sea}$) obtained in the Argentine Sea during 2018 and 2019. $fCO_{2\ sea}$ data were collected with a General Oceanics 8050 underway system, installed on the R/V "Victor Angelescu". In the COSTAL section (from Mar del Plata coast to the continental slope, VA-01/19 cruise, January 2019) sea surface-air fCO_2 differences ($\Delta fCO_{2(sea\text{-}air)}$), pH, total alkalinity and dissolved oxygen (DO) in the water column were analyzed in relation to the phytoplankton and bacterioplancton (Bac) communities. During the study, the coastal region was a source of CO_2 ($\Delta fCO_{2(sea\text{-}air)} = 30.7 \pm 4$ µatm). By contrast, the mid shelf was a strong CO_2 sink area ($\Delta fCO_{2(sea\text{-}air)} = -126.08 \pm 19$ µatm) that presented a seasonal stratification between 25-30 m, with a noticeable maximum pH (8.128 ± 0.02) and DO (317.7 ± 12.4 µmol.kg^{-1}), associated with the highest Bac biomasses (> 22 mgC.m^{-3}) and a chlorophyll-a maximum (up to 17 mg.m^{-3}), dominated by nano- and ultra-phytoplankton. The information obtained is a contribution of the DiPlaMCC-INIDEP, CONICET-IAI-CRN3094 and Pier-2-Peer/GOA-ON projects, and is a relevant tool to assess the spatio-temporal variability of CO_2 in the Argentine Sea, including areas associated with main fisheries. The continuation of such a monitoring will allow determining patterns in carbon chemistry, identifying areas of heightened vulnerability and assessing trends in response to OA.

Key words: sea-air fCO_2, Argentine Sea.

Volcanic $C0_2$ vents at the Galapagos: a natural laboratory for long term multidisciplinary ocean acidification research

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Galapagos is possibly the most pristine archipelagos in the world and, due to its location and marine current system around it, is a compendious of the Eastern Pacific ecoregion. Ocean acidification (OA), a process of increasing seawater acidity caused by the uptake on anthropogenic carbon dioxide (CO_2) by the ocean; is expected to change surface ocean pH to levels unprecedented for millions of years, affecting marine organisms at different levels, from shell formation up to food web structures, trophic interactions and community structure.

The Galapagos, honouring its title of "Living Laboratory of Natural History" has the only natural CO_2 seeps identified so far on the Eastern Tropical Pacific. Roca Redonda, located north of Isabela Island, is a shallow submarine volcano where the conditions of OA are naturally simulated when CO_2 originated from its activity is released through cold vents, acidifying the water column. In a series of research trips conducted during 2018-2019, carbon chemistry parameters and benthic community structure were analysed. It was determined a that the site is effectively acidified, with a pH of ~7.556 (total scale) and that this value is driven by CO_2, as the dissolved inorganic carbon concentration was ~2234 µmol/kg. The benthic community showed interesting characteristics like the presence of several calcifying organisms that were not expected on the site as is has been pointed out by previous studies on similar sites. The conservation of the Galapagos' unique environment relies upon research and sensible fact-based management in order to develop adaptation and mitigation strategies for the marine ecosystems, and these preliminary results shows that the Roca Redonda seep at the Galapagos can be used as a window future OA scenarios at the archipelago.

Key words: CO_2 seep, submarine volcano, ocean acidification, Galapagos, pH

Implications of ENSO on the coast-ocean gradient of siliceous and calcareous phytoplankton communities off the central coast of Peru

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Callao, one of the main upwelling centers off the Peruvian coast, presents high oceanographic variability that modulates the composition of phytoplankton community, primary producers of the marine ecosystem. One of the siliceous groups (diatoms) and the calcareous group (coccolithophores) play a crucial role in the biological pump, fixing CO_2 and being responsible for half of the $CaCO_3$ precipitation in the world ocean, respectively. The objective of this work was to evaluate the implications of ENSO on the coast-ocean gradient on phytoplankton, with emphasis on the composition, structure and biodiversity of diatoms and coccolithophorids, off the central coast of Peru (12 °SL). Samples were collected with a Niskin bottle at a 10 m depth from a line from the coast to 50 nautical miles off Callao, from 2017 to 2021 and with a bimonthly frequency. Quantitative analysis was performed by Utermöhl method, obtaining cell densities (cel.L^{-1}). Biomasses (µg C. L^{-1}) were calculated in terms of organic carbon according to Davidson and Menden-Deuer & Lessard, and diversity by Shannon index (H'). During the Coastal El Niño 2017, a great diversity of nanoflagellates and diatoms of intermediate stages of succession occurred, mainly at 8 NM; at 30 NM, the nanoflagellates were the most abundant phytoplankton group; at 50 NM a bloom of the coccolithophore *Gephyrocapsa oceanica* occurred. During the Coastal El Niño 2018-19, the greatest diversity and percentage contribution of diatoms occurred from 30 and 50 MN, while the coccolithophore *Emiliania huxleyi* registered the highest biomass at 50 NM. The increase in productivity during La Niña 2020-21 was evident, with the highest percentage contributions of diatoms and abundance of total phytoplankton at 30 NM. Different intensities of ENSO events mainly modulated the composition and community structure of diatoms, nanoflagellates and coccolithophores, impacting the CO_2 balance in the Peruvian upwelling ecosystem.

Key words: coastal upwelling ecosystem, ENSO, diatoms, coccolithophores community, Peru.

Variability of carbonate chemistry in the coastal upwelling area in front of Pimentel, Lambayeque – Perú

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The Peruvian sea is characterized by presenting several areas of coastal upwelling, which during their active phase bring cold, nutrient-rich and CO_2-rich waters to the surface of coastal areas, lowering the pH of the water, making them corrosive. One of these areas is located in front of Pimentel, in which during el 2019, along a 5-mn transect with five oceanographic stations, we determined the pH and the aragonite saturation state (Ω_{arag}) as well as the other parameters of the marine carbonate system such as the total dissolved inorganic carbon (DIC) and the total alkalinity (TA), which were calculated based on the measured pH and the pCO2. Also, the sea surface temperature, dissolved oxygen concentration and salinity were determined. During the summer, pH values <7.967 were observed in all stations, while in the rest of the seasons all values were greater than 8. High pH values (> 8) were associated with low DIC values (< 905.038 $\mu mol.kg^{-1}$), especially in spring; high DIC values occurred in summer. Total alkalinity was low in spring, and high in summer and autumn, while pCO_2 was high in summer and low in fall and spring. In summer the Ω_{arag} <2.24 $\mu mol.kg^{-1}$and in spring it was between 2.34 - 4.58 $\mu mol.kg^{-1}$. Salinity was less than 34.855 ups in summer and 34,197 ups in spring, values greater than 35 ups were recorded in the rest of the year. Dissolved oxygen values between 2 - 4 $ml.L^{-1}$ were only observed in summer and autumn; values of up to 7 $ml.L^{-1}$ were observed in spring; while the SST between 14° and 17° C was found in autumn and spring. In conclusion, our results indicate that only in summer did an upwelling and was characterized by high DIC and TA and a low Ω_{arag}.

Key words: *p*CO2, pH, aragonite saturation state, upwelling, Pimentel, Perú

Early life stages of Mediterranean corals are more sensitive to ocean acidification than adults

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Volcanic CO_2 vents are ideal sites to study the long-term effects of ocean acidification on long-lived calcified species, such as corals. At the Island of Ischia (Italy), we investigated, both *in situ* and *ex situ*, whether past exposure to low pH confers physiological tolerance to ocean acidification in different life stages and affects sexual reproduction. Adult colonies of *Astroides calycularis* (azooxanthellate) and *Cladocora caespitosa* (zooxanthellate), and larvae of *A. calycularis* were sampled at CO_2 vent and ambient pH sites. They were then maintained under controlled conditions in the laboratory, during two distinct 6-month experiments, under ambient (pH_T 8.0), low (pH_T 7.7) and extreme low pH (pH_T 7.5, only for larvae from CO_2 vents). Adult net calcification and respiration of both species, and net and gross photosynthesis of *C. caespitosa* were unaffected by the pH treatments regardless of their environmental history. Larvae of *A. calycularis* from the CO_2 vents were smaller and had a lower survivorship and settlement success than larvae from the ambient pH site regardless of experimental pH treatment. Colonies of *C. caespitosa* were smaller and less abundant near CO_2 vents. Histological sections of *C. caespitosa* from the vents demonstrated an asynchrony of spawning between male and female, which could have major effects on fertilization. Our results suggest that adult colonies of *A. calycularis* and *C. caespitosa* exhibit tolerance to acidification. However, long exposition to low pH appears to decrease sexual reproduction and early life stages development, which are both of particular relevance for the persistence of healthy populations.

Key words: ocean acidification, CO_2 vents, Mediterranean Sea, coral

Highlights from 8-years of monitoring Ocean Acidification in Norwegian waters

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In 2011, a multi-institutional monitoring program for ocean acidification in Norwegian waters, from the Skagerrak and North Sea in the south, to the northern Barents Sea in the north was funded by the Norwegian Environment Agency. The observational program encompass measurements of carbonate chemistry and ancillary variables such as salinity, temperature, and inorganic nutrient concentrations to provide baseline observations and information on the spatial and temporal variability. We use a combination of sampling platforms such as water column measurements along repeated transects from the coast to open ocean and underway measurements of surface-water carbonate system measurements for seasonal studies. One of the aims of the repeated surveys in the Norwegian Sea is to investigate the trends in pH, which has been observed to decrease at a faster rate than the global mean pH decrease rate, most likely due to the influence of anthropogenic CO_2. The observations in the Barents Sea show lowest pH and aragonite saturation in the polar surface water and in the bottom water, but no clear trends are discerned between 2011 and 2018. The aragonite dissolution horizon is located at about 2000 m in the Norwegian Sea. The observed variability in the Norwegian waters are attributed to oceanographic and anthropogenic processes, such as the influence of mixing of water masses, freshwater/meltwater inputs, oceanic CO_2 uptake, and biological production and respiration. The data provide information that are used in projections of future CO_2 emission scenarios and estimates in changes in the depth of the calcium carbonate ($CaCO_3$) saturation horizon. However, to determine the individual drivers of ocean acidification and their regional, seasonal and interannual variability, integrated monitoring including measurements or proxies for biological productivity, ocean physics, and land-ocean exchanges, in both surface water and in the water column is essential. main drivers of the carbonate system and ocean acidification in the Norwegian waters.

Key words: total alkalinity, pH trends, excess CO_2, Atlantic water, Arctic water

NICHE PLASTICITY allows species to BENEFIT from ocean acidification

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Global change is forecast to affect the ecological niches of species and their interaction with other organisms. A species might adjust to a fast-changing environment by altering their ecological niches. The trophic niche is the most commonly studied niche axis, but species are likely to adapt to climate change by modifying their other niches as well and consequently modifying their interactions within a community. Here we used natural CO_2 vents at a temperate rocky reef as an analogue for future ocean acidification to determine how the multidimensional niche space of four fish species adjusts to elevated CO_2 and how it affects interspecific interactions. Stomach content, stable isotopes, behaviour and habitat use were used as proxies to measure the ecological niche space. The trophic niche based on stable carbon and nitrogen isotopes was broader at vents than controls for all four species, including one based on stomach content of prey numbers and biomass. One species had larger populations at vents and these populations correspondingly showed a broader behavioural and habitat-use niche. This increase in habitat niche was associated with an alteration in habitat use. A subordinate species showed the same adjustments in habitat niche, yet it was only the species whose populations were greater under ocean acidification that showed an increase across all niches considered. As overall result, the investigation of the interspecific interactions based on species density and unified niche space overlap, based on the four proxies, indicates that species that can adjust their niche space and have high density at vents are likely the most successful species. We conclude that plastic behaviour and habitat use could have an adaptive potential in response to elevated CO_2, which may be beneficial for their persistence in a high-CO_2 world.

Key words: ocean acidification, CO_2 vents, adaptation, multidimensional niche

Calcifying Phytoplankton in the Eastern South Pacific for Understanding Ocean Acidification

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Coccolithophores are unicellular phytoplankton characterized by a covering of calcite plates. These calcifiers play an important role in the inorganic carbon cycle and possibly as ballast that sinks organic carbon to the deep-sea. Most efforts to understanding coccolithophore response to ocean acidification have involved lab experiments focused on the cosmopolitan species *Emiliania huxleyi*. However, it is unclear how the physiological effects under controlled conditions translate to community-level responses in the field. Molecular evidence suggests *E. huxleyi* is a single species with alternative genetically-determined morphotypes which may be selected in different environments. We studied the distribution, composition and realized niches of coccolithophore assemblages and *E. huxleyi* morphotypes in contrasting $pCO_2/pH/\Omega_{calcite}$ environments of the Eastern South Pacific (oceanic waters, mesotrophic waters, upwelling systems, and Patagonian channels). Out of 40 coccolithophore species, *E. huxleyi* was the most prevalent (30-100 % relative abundance). The moderately-calcified A morphotype dominated most *E. huxleyi* populations, but an extreme R hyper-calcified morphotype (R/HC) dominated in upwelling systems with high pCO_2/low pH. Realized niche analysis suggests that different carbonate parameters, as well as temperature and salinity, might have contrasting effects. All *E. huxleyi* morphotypes had wider tolerances than closely related species. Within *E. huxleyi*, the A morphotype had the widest niche, but the R/HC morphotype had narrow tolerance to $\Omega_{calcite}$ despite wide tolerance to pH and pCO_2, raising alternative interpretations of previous lab results. This suggests that distinct carbonate chemistry parameters may be separate stressors and there may be variation in their relative importance even within a single species.

Key words: coccolithophores, *Emiliania huxleyi*, ocean acidification, coastal upwelling

Storms and sea-ice processes in the high Arctic Ocean enhance wintertime ocean CO_2 uptake

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The ice cover in the Arctic Ocean has decreased during the last decades, manifested particularly as an extensive transition from thicker multiyear ice to thinner first-year ice. As the summer sea-ice cover is decreasing, larger areas with open water will be exposed to the atmosphere. In winter, the sea ice partly prevents direct CO_2 exchange between ocean and atmosphere. However, frequently occurring storms in winter and spring cause open leads and breakup of the ice sheet, increasing the potential for direct air-sea CO_2 exchange. During storm events, vertical mixing takes place and brings enriched CO_2 from sub-surface water to the surface. In addition, sea-ice processes impact the underlying water. This will have implications for the ocean CO_2 system and ocean acidification. Data from January to June 2015 obtained during the Norwegian young sea ICE (N-ICE2015) expedition are presented, where the ship drifted with four different ice floes and covered the deep Nansen Basin, the slopes north of Svalbard, and the Yermak Plateau. Unique winter-to-spring data of Arctic under-ice water CO_2 fugacity (fCO_2) and estimates of the impact of sea-ice biogeochemical processes on the surface water CO_2 system are presented and discussed. Depending strongly on the open-water fractions and storm events, the ocean CO_2 sink varied between 0.3 and 86 mmol C m^{-2} d^{-1}. The observed under-ice fCO_2 ranged between 315 µatm (in February) and 153 µatm (in June), indicating that the surface water fCO_2 was undersaturated relative to the atmospheric fCO_2. In winter, the main drivers of the change in under-ice water fCO_2 were dissolution of $CaCO_3$ (ikaite) and vertical mixing. In June, in addition to these processes, primary production and sea-air CO_2 fluxes were important.

Key words: Arctic Ocean, sea ice biogeochemistry, CO_2 fluxes, storm events, ocean acidification

Coastal Carbonate System Variability along an Active Lava-Seawater Interface

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The most recent volcanic eruption in the Canary Archipielago (La Palma) started on September 19th 2021. The affected coastal area was a shoreline below an 80-100m cliff and a sandy beach in the southern part. We followed the carbon dioxide system in the coastal waters before, during and after the lava reached the ocean in three lava flows. An increase in temperature and salinity was observed due to seawater heating and water vapour formation, followed by a decrease in pH_T, related to the release of magmatic volatiles and water-rock reactions. A portion of the magmatic acidic volatiles (CO_2, SO_2, HCl, HF, HBr) that remained within the lava as it flowed to the ocean was released when it entered the seawater. They mixed with the water vapour, but also affected the seawater pH. We measured decreases in the alkalinity (A_T) and total dissolved inorganic carbon (C_T). On September 30th, the NC_T decreased by 90 µmol kg^{-1} while the NA_T decreased by 224 µmol kg^{-1}, reaching 2180 µmol kg^{-1}. These results indicate that the effect is not only due to strong acid addition but to the loss of carbonate species, affecting both variables, together with silicate and phosphate precipitation with metals from the lava, changing the AT.

The anomalies found in the carbon dioxide and hydrography properties were localized in the water in contact with the lava. A decrease in density caused an upwelling of hydrothermally influenced seawater which was displaced towards the open ocean as a shallow 4-6m deep plume with anomalous values observed as far as 1.5km in the first meter. When the lava was not arriving at the sea or was falling on previously formed rocks, the affected area was limited to the first few tens of centimetres of the water column and at distances of 10-15m.

Key words: Carbonate system, lava-seawater interface, acidification

Using natural analogues to study the combined effects of hurricanes and ocean acidification on tropical reefs.

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Volcanic CO_2 seeps are well established analogues for the study of future ocean acidification (OA) on tropical reefs. In addition to OA, increased seasonal differences between air and sea-surface temperature are predicted to lead to a greater frequency of stronger hurricanes also effecting these sensitive ecosystems. However, how hurricane recovery may be modulated by OA in natural systems remains unknown.

Consequently, photo-quadrats were used to survey how species distribution and biodiversity associated with shallow CO_2 seeps (Anse Bateaux reef, Dominica) were affected by category 5 hurricane "Maria" (17/9/2017), and the role of pCO_2/pH in modulating the community before the hurricane and over 2 years of reef recovery. pH at the site ranges from 6.9 at the seeps to 8.2 at >30m distance. Salinity, temperature, and total alkalinity is constant across the site and study periods (summers 2015-2019).

The reef community which is dominated by a number of corals, calcifying alga, and urchins at a pH of 8.2 changes at a pH of about 7.7 to become dominated by tube sponges (*Aplysina*) with fewer urchins and calcifying corals/alga. On the seeps (pH 6.9) the community is dominated by brown non-calcifying alga and anemones, small calcifying alga and brain corals are found but in much lower numbers. Following the hurricane encrusting coral species with a low hydrodynamic profile (e.g *Porites astreoides* and *Millepora*) had the greatest survival, interestingly these species are also more tolerant to OA surviving pH as low as 7. Erect corals with larger surface area, (e.g *Porites divaricate*) were more sensitive to low pH and hurricane disturbance. During the first 2 years of recovery corals were slow to re-establish, with sponges recovering more quickly. This suggests in the future encrusting corals, and fast recovering pH tolerant sponges (e.g. *Aplysina)* may have an advantage.

Key words: Coral reef, natural analogues, ocean acidification, hurricanes

Fate of cold-water coral reefs – using natural gradients to identify dominant drivers of ecosystem change resulting from ocean acidification and warming

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Current knowledge of the response of cold-water coral (CWC) reefs to ocean acidification and warming is limited and based mainly on observations from short-term perturbation experiments on a few coral species. It is difficult to correctly up-scale from these and predict effects of climate change on CWC reefs because laboratory experiments are run on a temporal scale of months to a year, which is unlikely to correctly elucidate how organisms that become several hundreds, if not thousands, of years old will respond to long-term changes in ocean chemistry and temperature.

Here, we present two studies were small-scale vertical and horizontal gradients in carbonate chemistry, temperature and food availability around 5 Norwegian CWC reefs were used to assess how the interaction of multiple drivers affects the structure and functioning of CWC reefs. The first study compares species occurrences and the metabolic cost of survival of key species at the CWC reef at the LoVe Node 7 methane seep, with two near-by reefs. At Node 7 methane has been seeping since the establishment of the reefs 7000-10000 years ago. The second study surveyed the macro-fauna species composition along steep vertical fjord walls with well documented vertical gradients in carbonate chemistry and temperature.

Multivariate statistics demonstrated a dominant role of temperature in structuring the wall reef communities, while carbonate chemistry and food availability only played sub-ordinate roles in this. At lower temperatures scleractinian corals, large sized gorgonians and sponges dominate and were replaced by small gorgonian corals and fan shaped sponges at higher temperatures. Further work in the summer of 2022 will document the influence of the methane seepage and associated elevated CO_2 levels on community structure of CWC reefs and elucidate the critical physiological traits enabling the existence of reefs in environments naturally enriched in CO_2.

Key words: cold-water coral reefs, natural gradients, community structure, physiology

Studying changing carbonate chemistry in the Arctic Ocean using satellite Earth observation

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Recognised as being at the forefront of global change, the Arctic Ocean will be a vital for predicting how ocean acidification (OA) will affect lower latitudes in the future. The nature of the Arctic Ocean means collecting in situ data on a high spatial and temporal scale is impractical. Here we discuss a novel method of synoptic scale monitoring OA in the Arctic Ocean using satellites Earth observations and the potential applications of the data provided by this method.

OA can be monitored by measuring the carbonate chemistry parameters, total alkalinity (TA), dissolved inorganic carbon (DIC), pH and pCO_2. TA and DIC can be calculated using empirical relationships with measurable oceanographic variables for example salinity and temperature. Satellites Earth observation now routinely monitor these variables, so these relationships can now be applied to use satellite data. Here we have first evaluate published relationships for their use with satellite data in the Arctic Ocean and then second developed regional specific relationships for TA and DIC. Finally we calculate the full carbonate system to characterise contemporary variability of aragonite saturation state and pH. The data provided from this method will enable identification of vulnerable regions experiencing greatest change in carbonate chemistry. Future work will concentrate on comparing the dataset developed from this study with published studies on the impact of OA to species to further our understanding of the potential risk of OA to fisheries.

Key words: monitoring, satellite Earth observation, Arctic Ocean

Feedback mechanisms stabilise degraded turf algal systems at a CO_2 seep site

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Human activities are rapidly changing the structure and function of coastal marine ecosystems. Large-scale replacement of kelp forests and coral reefs with turf algal mats is resulting in homogenous habitats that have less ecological and human value. Ocean acidification has strong potential to substantially favour turf algae growth, which led us to examine the mechanisms that stabilise turf algal states. Here we show that ocean acidification promotes turf algae over corals and macroalgae, mediating new habitat conditions that create stabilising feedback loops (altered physicochemical environment and microbial community, and an inhibition of recruitment) capable of locking turf systems in place. Such feedbacks help explain why degraded coastal habitats persist after being initially pushed past the tipping point by global and local anthropogenic stressors. An understanding of the mechanisms that stabilise degraded coastal habitats can be incorporated into adaptive management to better protect the contribution of coastal systems to human wellbeing.

Key words: CO_2 seeps, community dynamics, competition, inhibition, turf algae

Diel carbonate chemistry variability in eutrophied reefs of Bolinao, Northwestern Philippines

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Eutrophication brought about by intensive mariculture activities can locally enhance seawater acidification. This is happening in Bolinao, Pangasinan located in Northwestern Philippines where unregulated fish farming has resulted to buildup of organic material from uneaten feeds and wastes. When this material is decomposed, CO2 is released with consequent decrease in pH. Here we investigate diel trends in carbonate chemistry of three reef sites in the Bolinao reef flat following a eutrophication gradient from nearest to farthest from the mariculture area. pH and total alkalinity (TA) were measured from discrete water sampling; while dissolved inorganic carbon (DIC), partial pressure of CO2 (pCO2), and aragonite saturation state (Ω_{ar}) were derived. The reef nearest the mariculture area had low pH (7.94), high TA (2194 µmol kg^{-1}), and high DIC (1919 µmol kg^{-1}). From the high resolution temporal patterns in pH, diel fluctuations of >0.3pH unit were seen with pH (total scale) dropping to 7.8 in the reef nearest the mariculture area. Using TA-DIC vector analysis, the reef close to the mariculture area exhibited the lowest slope value (m = -0.01) compared to the other two reefs. This implies that the calcification/net photosynthesis ratio favors photosynthesis in this reef. Acidified and eutrophied conditions allow turf algae to dominate the benthic cover of the reef thus influencing carbonate chemistry dynamics. Further sampling under seasonal scale were done to examine the influence of water movement on the reefs. Together, this study explores the usefulness of carbonate chemistry as a tool to monitor the metabolic state of reefs in response to acidification.

Key words: Coastal acidification, eutrophication, coral reef, carbonate chemistry, pH sensor

Ocean Acidification State in the Arctic: Contemporary Dynamics Around the *Svalbard* Archipelago

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The Arctic Ocean is particularly vulnerable to acidification with reduced sea ice cover enhancing the uptake of anthropogenic CO_2 and freshwater inputs lowering carbonate ion concentrations ($[CO_3^{2-}]$) and the saturation state of the calcium carbonate (Ω). Around the Svalbard archipelago, warm Atlantic Water encounters the seasonally-ice covered Arctic waters to create a dynamic transition zone where the sea ice extent, meltwater inputs, deep mixing, nutrient supply and biological production influence the ocean acidification state. The contemporary state of ocean acidification is described by evaluating inter-annual variability in pH, $[CO_3^{2-}]$ and Ω in the surface layer during 4 consecutive summer seasons of contrasting years (2014-2017). Biologically induced increases in Ω compensated reductions in Ω due to dilution effects in meltwater influenced surface waters. Sea ice meltwater and terrestrial water inputs provided a minor source of alkalinity that enhanced the buffering capacity and increased Ω. In the high ice years of 2014 and 2017, the cooler, fresher and deeply mixed water column yielded net respiration and decreased Ω relative to the 4-year average. Greater incursions of Atlantic Water on the Svalbard shelf in 2015 were coupled to reduced sea ice cover, earlier ice melt and a warmer surface layer. Nutrient enrichment from mixing with Atlantic Water fuelled biological production to increase Ω, which was slightly compensated by decreases in Ω from entrainment of CO_2-rich subsurface waters. Atlantic Water acted as a source of alkalinity and increased the buffering capacity and Ω in the presence of biological carbon uptake to compensate inorganic carbon enrichment. The process of *Atlantification* from increased Atlantic Water inflow could elevate Ω through advection of nutrients to support primary production and carbon uptake and inputs of alkalinity, increasing the CO_2 buffer capacity against acidification.

Key words: ocean acidification, marine carbonate system, Atlantic Water, marginal ice zone, Arctic Ocean

Fish assemblages cope with ocean acidification: a study case from two Mediterranean shallow CO_2 vents

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Naturally acidified systems (*e.g.* shallow CO_2 vents) are used worldwide to test ecological hypotheses about the effects of ocean acidification (OA) on marine ecosystems. Here, we used two temperate CO_2 vents to assess the effects of OA on the necto-benthic fish assemblages associated with seagrasses meadows (*Posidonia oceanica* and *Cymodocea nodosa*) at two locations: Ischia and Vulcano Islands (Italy). We hypothesized a reduction of fish species richness and abundance of juveniles (the most vulnerable life stage), and a homogenization of assemblages under OA conditions. We tested this hypothesis comparing, at both locations, fish assemblage structure at low pH sites (close to the CO_2 vents) and reference sites with ambient pH using underwater visual census technique.

In both vent systems, the assemblages structure and the abundance of juveniles did not differ between low pH and reference sites. In contrast, results revealed that the two systems responded differently to OA in terms of species richness (S) and total abundance (N), probably due to a different answer of the two seagrass systems (*P. oceanica* and *C. nodosa*). In Ischia, higher S and N were associated with low pH conditions, while no differences were evident in Vulcano among the different pH conditions. Overall, the species contributing the most to dissimilarity among low pH and reference sites were invertivorous (*e.g. Coris julis*) and the herbivore *Sarpa salpa*, showing higher abundances under OA conditions in both vents. This pattern may represent a response to enhanced food resources (invertebrates' abundance) and seagrasses palatability in the acidified sites, which may help invertivorous and herbivorous fish to withstand the higher energetic cost to live under high pCO_2 / low pH conditions. Finally, this result indicates a species-specific response to OA and opens interesting questions about the ecological consequences on the functioning of different seagrasses systems and associated communities.

Key words: fish biodiversity, size structure, juveniles, seagrass meadows, natural CO_2 vents.

Watershed Controls of Acidification Dynamics in Estuaries of the United States: from Case Study to National Assessment

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The human modification of carbon and nutrient transport from land to sea is recognized as an important driver of acidification in coastal and estuarine systems. However, there are few studies quantifying these land-based impacts on space and time scales relevant for informing: 1) likely impacts to endemic organisms, and, 2) the potential efficacy of management actions operating at local versus global scales. To address these questions, we present a case study of Tillamook Estuary, OR (USA), a small open-coast estuary in the northern California Current Large Marine Ecosystem subject to coastal upwelling and river discharge from an agriculturally-developed watershed. From July 2017 through July 2018, we conducted a series of sampling cruises to characterize the CO_2 biogeochemistry of the estuary, coastal ocean, and riverine end-members. We quantified the roles of allochthonous input of oceanic and riverine dissolved inorganic carbon (DIC), as well as autochthonous estuary carbon cycling, in controlling the seasonal pH, $CaCO_3$ saturation state, and $p$$CO_2$ dynamics of the estuary. Variability in the ocean and riverine end-members was the primary control on estuarine CO_2 chemistry, while autochthonous cycling acted as a seasonally variable sink and source of DIC. Riverine DIC levels were highest in areas of increased agricultural activity and hypothesized to be driven by human land use change. Observed riverine DIC enrichments were combined with published estimates of oceanic anthropogenic carbon burdens to estimate the magnitude and timing of human changes to present-day CO_2 chemistry in the estuary. Most of the perturbation in estuarine chemistry was due to ocean acidification-driven changes in the ocean waters advected into the estuary. We also present an overview of a new project aimed at assessing the relative vulnerability of United States estuaries to these anthropogenic changes in coastal watershed carbon and nutrient delivery.

Key words: estuary, acidification, watershed, nutrients, management

Long-term spatio-temporal variability of DIC, carbon dioxide flow and ocean acidification rate on the Arctic shelf

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The Arctic Ocean is affected most of all in the World Ocean by global climate changes, one of the important consequences of which is the change in the balance of carbon dioxide in the Russian Arctic seas and the impact of its variability on the carbonate system (CS) of its waters. The data on temperature, salinity and CS parameters (pH, total alkalinity, pCO_2) was collected in expeditions held by Shirshov Institute to the Arctic seas (July-September 2015–2021б Kara and Laptev seas). CTD data and sampling were obtained with SBE system. pH was measured with potentiometric method (Hanna Instruments and Methrom with Orion electrodes), total alkalinity was measured by direct titration (Easy Titrino and Methrom) with visual end-point. Other CS parameters were calculated with CO2sys program. CO_2 in the atmosphere was measured with Picarro G 2132-I equipment. CO_2 flux was calculated according to R. Wanninkhof (2014) method. The results obtained revealed a strong spatial and temporal variability of DIC, aragonite saturation as well as the carbon dioxide flux in the Kara Sea, depending on the continental runoff, sea ice melting time, and production-destruction processes. Changes in the carbonate system of the Arctic shelf invariably lead to acidification of its waters. It is necessary to continue the study to assess the dynamics of these processes on the continental slope and in the deep Arctic. The data analysis was supported by President grant MK-3506.2022.1.5.

Key words: Arctic, carbon dioxide, acidification, variability

Natural Analogues of an Arctic in Rapid Transition (AnalogueART working group)

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Northern oceans are in a state of rapid transition, however, our knowledge of the likely effects of climate change and ocean acidification on key species in the food web, functionally important habitats and the structure of Arctic and sub-Arctic ecosystems is limited and based mainly on short-term laboratory studies on single species. In tropical and temperate systems natural analogues (Gradients and Mosaics) of carbonate chemistry drivers have been used to further our knowledge of the sensitivity of biological systems to predicted climate change, and thus assess the capacity of different species to show long-term acclimation and adaptation to changes in carbonate chemistry. Natural analogues have also provided the means to scale-up from single-species responses to community and ecosystem level responses. However, to date the application of such approaches is limited in high latitude systems. Here we present an overview of work within the Analogues of an Arctic in Rapid Transition Working Group (AnalogueART) (ESSAS hokudai.ac.jp/working groups/). Presenting a range of Arctic and sub-Arctic case studies where environmental gradients and mosaics in Carbonate Chemistry (including, CO2 and methane cold seeps, fjords, up-welling areas, and mixing of Arctic and Atlantic water) are being used to elucidate how future climate change may effect vulnerable systems (including, cold water coral reefs, intertidal invertebrates, and shellfish important to aquaculture). We will also discuss the need for the standardisation of methods across natural analogue research and the method development necessary to move from single-stressor gradient studies to more complex multi-stressor Mosaic studies.

Key words: Natural Analogues, Arctic, carbonate chemistry, cold water coral, aquaculture,

Fe Biogeochemistry in a High CO_2 Ocean

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Iron is a trace element, essential for the development of organisms and has a great impact on the carbon cycle through the planktonic communities and their productivity. Soluble iron in its reduced form Fe(II) is the species mainly available by phytoplankton, unlike oxidized iron, Fe(III), of low solubility and strongly complexed with the organic compounds of the medium. Due to the pH, T and oxygen conditions of the marine environment, Fe(II) is thermodynamically unstable and tends to oxidize rapidly. The acidification of the medium favors the presence of Fe(II). In addition, organic matter plays an essential role in the cycle of Fe in the ocean. The presence of organic compounds can reduce Fe(III) to Fe(II) and also stabilize Fe(II) through complexation, being a pH-dependent process. The main objective of the ATOPFe project is to investigate which mechanisms determine the presence of dissolved Fe(II) in the marine environment, and how they are affected by the ocean acidification, warming and the presence of organic matter. To get this objective, studies carried out in different oceanic regions are combined with laboratory studies, in order to respond, from the theoretical point of view of marine chemistry-physics, to those mechanisms that control the behavior of Fe(II) and that can explain the effect of ocean acidification on the biogeochemical cycle of iron and its interaction with phytoplankton.

Key words: iron, trace metals, ATOPFe, acidification, oxidation kinetics

Functional biodiversity loss in newly discovered natural CO2 vent systems

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We assess the loss of functional diversity in benthic marine communities exposed to ocean acidification (OA) by using newly discovered natural CO_2 vent systems along the coast of Ischia (Italy) across depths of 3 - 48 meters. These new CO_2 vent systems locally acidify the seawater with gas comprising 92-95% CO_2 (no sulphur, and no temperature anomalies). These sites span a variety of different habitats such as rocky reefs, semi-dark cave habitats, and deep reefs, the latter dominated by calcifying organisms that are particularly vulnerable to OA. We characterized i) the physical and chemical parameters by using *in situ* SeaFET^{TM} Ocean pH sensors coupled with discrete water samples and ii) changes in community at the CO_2 vents (n=4) compared with two reference areas with ambient pH, hosting similar habitat types but outside the influence of CO_2 venting (n=8). In addition to conducting classic analyses of change in species composition and community structure, we assess the loss of functional diversity, *i.e.* the range of species biological traits. For this purpose, we quantified the percent cover of 155 benthic species algae and invertebrates) and characterized the ecology of each species using 7 functional traits describing (among others): growth form and rates, feeding characteristic, presence or absence of calcareous skeleton. Results suggest that functional diversity decreases with increasing acidification across different habitat types. We further explore how this loss is linked to some key processes related to ecosystem functioning. This study contributes to broadening the scope of the ecological effects of OA on marine ecosystems as well as addressing functional change in whole and across community types.

Key words: natural CO_2 vents, functional diversity, ecosystem functioning, life-history traits

Seasonal variability of the air-sea CO_2 flow in a sub-Antarctic glacier fjord (Chile, 53°S): Patagonia southernmost fjords as a CO_2 sink region?

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Climatic stressors are major drivers of changes in the structure and functioning of aquatic food webs and the “biological carbon pump”. A major stressor is the fluctuation in freshwater inputs from glacial melting, which affects ocean pH as well as total alkalinity and pCO_2. However, the role of air-sea CO_2 fluxes on the biogeochemical conditions of coastal subantarctic regions under a changing ocean has been scarcely studied. Since high latitude fjord systems could play an important role in the regional carbon cycle, our study focused on further understanding the main factors that modulate the pCO_2 seasonal variability. High-resolution pCO_2-pH-CTD-O sensors were deployed along with three synoptic hydrographic cruises during austral fall-winter-spring 2018 at Santa Inés glacier – fjord Seno Ballena system (53°S). Our main results showed moderate seasonal variability of main variables: pCO_2 (364±48 - 398±10 µatm), Ω_{Ar} (1.7±0.3 - 1.9±0.5), and pH (8.0±0.0 - 8.1±0.0). We suggest that the observed mesoscale variability was modulated mainly by biological processes such as photosynthesis and respiration, as well as cryospheric processes such as freezing/thawing of glacial ice at the head of the fjord. Air-sea CO_2 flows varied throughout the period, with negative values ranging seasonally with -2.4 $mmol \cdot m^{-2} \cdot hr^{-1}$ in Fall, -0.1 $mmol \cdot m^{-2} \cdot hr^{-1}$ in Winter, and -0.9 $mmol \cdot m^{-2} \cdot hr^{-1}$ in Spring. These results pointed out that the fjord was acting as a CO_2 sink area and was saturated with respect to the atmosphere most of the time. Monitoring biogeochemical variables will provide the scientific knowledge needed to protect marine refugee areas and to develop a tool for managing environmental issues in sub-Antarctic regions.

Key words: CO_2 flow, glacier-fjord, photosynthesis.

Theme E: Ocean acidification and society

pH Magnitude, Variability and Predictability across Pacific Coast Estuaries determines the level of shell dissolution in Economically important Calcifiers under Ocean Acidification scenarios

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Coastal regions of the California Current Large Marine Ecosystem System (CCLME) are among the most rapidly changing systems with respect to anthropogenic ocean acidification (OA). Over the last few decades of biogeochemical OA observations, significant shoaling of the saturation depth have been observed, resulting in lower pH and decreased saturation state, prolonged OA exposure, and greater diel pH variability. These conditions have already been detected in some estuarine and coastal regions of the Northeast Pacific and CCLME and have negative biological implications, particularly with respect to ecologically important indicator species (e.g., pteropods) and economically important marine calcifiers, including various stages of Dungeness crabs, larval stages of red sea urchins, and Pacific and Olympia oysters. Despite concerns for economically important calcifiers under future carbonate chemistry conditions, shell dissolution remains a largely understudied process despite its multiple adverse effects on essential processes. Severity of dissolution is related to the mean and amplitude of exposure, increasing under lower pH and aragonite saturation state, higher amplitude of variability, the combination of these factors, as well as under less predictable habitat conditions. Despite some physiological tolerance, results synthesized across studies show that shell and exoskeleton dissolution can cause serious problems among economically important calcifiers, with multiple consequences inextricably linked to the ecology and energetics of calcifying species. Field conditions across Northeast Pacific coastal estuaries indicate that increased shell dissolution is likely to be especially acute at the landward edge of many estuaries that are especially important sites for the aquaculture industry and crab fisheries. Despite negative future projections, we found that lower diel variability combined with increased habitat predictability could have potentially beneficial effects on these habitats. In addition, co-culturing aquaculture species with kelp can create higher habitat predictability. We discuss these implications in the context of coastal habitats for aquaculture and its adaptation.

Key words: aquaculture, carbonate chemistry variability, oysters, Dungeness crabs, shell dissolution

Evaluation of carbonate chemistry in two stations with contrasting conservation characteristics: First 3 years of measurements

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The lack of knowledge about the chemistry of carbonates in coastal areas of Colombia has not allowed taking preventive and protective measures to conserve coral formations, ecosystems of great ecological and economic importance for the country. In order to contribute to increase this knowledge, pilot monitoring has been implemented since 2019 at two stations with contrasting conservation characteristics in the Colombian Caribbean. Bahía Chengue, a protected area with low anthropic activities located within the Tayrona National Natural Park, and Bahía de Santa Marta, an area exposed to various anthropic activities such as ports, maritime traffic, tourism, and discharge of wastewater from the city, a situation that is intensified in the rainy season. At each station, were measured monthly salinity, temperature, dissolved oxygen, and oxidation-reduction potential, and discrete samples were collected at three depths (shallow, medium, and deep) to measure nutrients, chlorophyll a, Total organic carbon, dissolved inorganic carbon (DIC), and total alkalinity (TA). The DIC was determined with the AIRICA analyzer from MARIANDA and the TA by the open cell titration, both methods at a weather level. The CO2sys program was used to determine the chemistry of the carbonates. The Ωarag in the two stations is above 2.50. This results are the baseline of the current state of carbonate chemistry in the study area, and it allows to understand the spatio-temporal changes of the coastal area of Colombian Caribbean and the variations in carbonate chemistry caused by local factors like the increase of nutrients and organic matter induced by continental discharges and upwelling. The spatial and temporal variation found, demonstrates the need to employ continuous measurement systems at a weather level and the importance to measure additional parameters that help to interpret the variability.

Key words: Acidification, Santa Marta, Carbonate chemistry.

Exposure of commercial shellfish to changing pH levels: how do we scale-up experimental evidence to regional impacts?

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Ocean acidification has become one of the most studied topics in the last 15 years. Most of the research published to date suggests that acidification will have direct and indirect effects for species and ecosystems. One key challenge is to integrate different sets of information together to support analysis and assessments. Wider modelling tools to 'scale-up' some of these observed changes are needed to apply experimental results over spatio-temporal scales. Of particular importance are the observed effects on commercial species and predicting the impacts on economic resources and ecosystems; fundamental questions that will need to be tackled to support fisheries and aquaculture. This paper highlights the challenges of combining different sources of information on acidification effects to determine how commercial species would be likely affected under future pH levels, and that modelling, and experiments need to be better aligned. We conclude that the current experimental evidence does not offer sufficient insights into impacts at projected pH levels, and that future experiments must be designed to consider the pH levels experienced by organisms already, as well as modelled pH ranges in the future, and organism plasticity. These types of studies are key to inform decision making and planning for an effective ocean acidification monitoring and management programme to safeguard commercial shellfish stocks.

Key words: commercial species, ocean acidification, modelling, integration.

Carbon Dioxide Removal Research at NOAA

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The recent IPCC's 6th Assessment Report acknowledged that society must act aggressively to hold warming to ~1.5 - 2 ℃ above pre-industrial levels by the end of the century. In discussion of Mitigation (WG3), nearly every scenario that achieved these goals included *"deep emissions reductions"* in addition to substantial carbon dioxide removal (CDR). As an internationally recognized leader in science, environmental stewardship, and community resilience, the U. S. National Oceanic and Atmospheric Administration (NOAA) is well-positioned to lead in the analysis of impact, effectiveness, feasibility, risk and co-benefits of many CDR techniques, including ocean acidification mitigation. NOAA is recognized around the world for its leadership in Earth system science and environmental stewardship. NOAA leadership and transparency in observing and studying the atmosphere and ocean make it a trusted agent for assessing the effectiveness of CDR approaches. Additionally, NOAA's deep connections to regional and local stakeholders across the nation connects decision makers with the data they need to pursue evidence-based, actionable solutions for climate adaptation and mitigation. NOAA's emphasis on big-picture, long-term monitoring and its research capabilities are ideally suited to understand, evaluate, and verify these efforts and their potential for success. NOAA has a suite of capabilities that can be applied to understand and assess CDR and understand its impacts on ecosystems and society. In this talk, we discuss how CDR techniques intersect with NOAA's existing research mandates in science, stewardship, and service, with an emphasis on ocean acidification mitigation.

Key words: NOAA, Carbon Dioxide Removal, mitigation, adaptation, negative emissions

Physical and mental health consequences of ocean-acidification driven changes to marine biodiversity

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The ocean, and biota within, provides a range of goods and services critical to human health and wellbeing. The biological systems are, and will increasingly be, affected by global changes including ocean acidification. Consequently, we propose that ocean acidification should be understood as an emerging issue not just in terms of ecosystem impacts but also in the context of human health and wellbeing. We use a qualitative literature review approach to consider how the effects of ocean acidification on biota can influence aspects of human life. Specifically, focus is placed on the effects of ocean acidification on seafood quantity and quality (nutritional composition, chemical contamination, toxin accumulation), and how this could contribute to malnutrition in human populations. We also consider how ocean acidification-driven modifications of species and biodiversity could result in the loss of culture, livelihoods, recreational activities, and social connections to have mental health consequences. Given that these physical and mental health consequences will be experienced in combination, we then explore the complex interconnections that exist between these impacts. Finally, we propose management approaches that may enhance the acidifying ocean's capacity to continue supporting human health and wellbeing. The benefits and costs of such approaches will, however, be dependent upon the local socio-economic contexts in which they are implemented, potentially exacerbating current inequalities in the distribution of global health challenges. Given the potential for ocean acidification to impact both marine biota and human health outcomes, this aspect needs to be further considered in research exploring the effects of global change on society.

Key words: ocean acidification, human health, nutrition, mental health

The Vulnerability of the Fisheries Sector to Climate Change in the Mediterranean Region

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In this paper, we study the impacts of the ecological and socio-economic risks on the fisheries in the Mediterranean region from a solely economic point of view. Our objective is to study the vulnerability of the fisheries sector in the Med Sea to the different risks. In the first section, we analyze the FAO Fishstat data in different countries. We separate the area into three subdivisions due to their different characteristics: Northern Mediterranean countries of Spain, France, Monaco, Italy, Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, Albania, Greece and Malta, Southern Mediterranean countries of Morocco, Algeria, Tunisia, Libya, Egypt and Eastern Mediterranean countries of Turkey, Syria, Lebanon, Israel, Palestinian territories and Cyprus. We then discuss the main environmental risks of warming, ocean acidification, hypoxia, deoxygenation, pollution and habitats loss and socio-economic risks of demography, coastal urban cities, small/industrial fleets, artisanal/recreational fisheries, overfishing, countries' degree of development, poverty level, jobs related to fisheries to the fisheries in the Mediterranean. In the third section, we study the impacts of those risks on the fishery sector and on the economies of the Mediterranean countries thanks to a vulnerability index and sensitivity analysis. Finally, we suggest some policy recommendations following our analysis of the observed and projected situation of the fisheries in the Mediterranean region.

High-latitude Seagrass Pools Experience Carbonate Chemistry Decoupling During Times of High Photosynthetic Activity

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The global phenomenon of ocean acidification has resulted in local efforts by nearshore communities to explore phytoremediation as a way to mitigate the negative effects of acidification on the aquaculture shellfish industry and local biodiversity. Seagrass is one such organism that has been touted as a mechanism to potentially mitigate acidification by taking up CO_2 and driving higher pH and saturation state values during times of high photosynthetic activity. This study investigated the effects of seagrass on the carbonate system in an enclosed high-latitude bay situated within Kachemak Bay, Alaska, USA. Three, shallow, intertidal pools were identified in Jakolof Bay, Alaska, and characterized by seagrass density as being high, patchy, and absent. Each pool was monitored for a 2-week period before and after flood tide to identify the hourly changes in carbonate chemistry with increasing lengths of residence time and biological activity. During the neap tidal phase, a high-resolution sampling regiment was carried out when pools were emerged for 24 h. Discrete measurements of pH, alkalinity, and DIC were taken along with O_2, temperature, salinity and nutrients as ancillary data used to correlate with carbonate chemistry changes. Results show that within hours after tidal emergence there was a steady rate drop in alkalinity and DIC while pH increased. These results indicate that intertidal seagrass beds may experience a rapid drop in alkalinity and DIC that is not captured by measuring only pH. This study reports a decoupling of the carbonate system and raises the concern of standard practices assuming alkalinity constant and measuring pH in seagrass beds to characterize carbonate chemistry variability. This work is placed in the context of seagrass as phytoremediation and how its physiology shapes carbonate chemistry variability.

Key words: Seagrass, ocean acidification, carbonate chemistry, phytoremediation

Preliminary assessment of pH variation in small scale aquaculture of whiteleg shrimp larvae in Ecuador

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Vulnerability of marine organisms to pH variations may differ among developmental stages. Several crustaceans' species are reported to be affected by pH decreases, especially during early stages. Previous studies in our group found that whiteleg shrimp (*Penaeus vannamei*) could be highly vulnerable to low pH conditions during their early developmental stages, rising concerns on its ecological and aquaculture consequences. Whiteleg shrimp farming is an expanding activity in tropical countries, representing more than 50% of crustacean production around the world. In Ecuador it is the first non-oil export product, generating close to US$5K million per year in exports. One key point in this industry is the larviculture that is usually carried out in small and medium production laboratories with limited technology, and rarely monitoring of seawater chemical conditions. To know the pH variability in this system we have started a collaborative work to measure parameters that are expected to be directly relevant for the culture such as pH (total scale), salinity, temperature, and dissolved oxygen in a larvae production farm in Ecuador. Here we present the preliminary data from a daily basis monitoring, and also discuss the actions taken by the industry to minimize conditions that may affect aquaculture production. These results will be put in context the management in small and medium scale aquaculture systems, from the perspective of seawater conditions and production, highlighting its potential implications for the future of shrimp aquaculture.

Key words: Aquaculture, shrimp, early stages, pH monitoring

Assess, Anticipate, Adapt: Vulnerability and Responses to Ocean Acidification in the US

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The NOAA Ocean Acidification Program (OAP) has funded collaborative projects that synthesize ocean acidification (OA) information at a regional-scale to assess where societal vulnerabilities exist or are emerging, in order to provide actionable information for marine resource decision makers. This information is intended to provide national to local marine resource decision makers (including U.S. Congress, Federal, state, tribal, and local agencies) with an improved understanding of the complex ways in which OA may impact ocean and coastal ecosystems, ecosystem services, and human communities to facilitate adaptation to OA. Equipping decision makers with actionable information, used to develop adaptation strategies, requires the synthesis of disparate types of data (chemical, biological, ecological and social), as well as translation of multi-disciplinary OA science tailored to support decision-making needs. Here we will present some of the results of the funded projects and highlight some lessons learned with this approach.

Key words: ocean acidification, vulnerability assessment

Modeling ocean acidification in the Bering Sea to support long-term planning and management of the largest U.S. fishery

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Ocean acidification (OA) poses a significant threat to several commercially and culturally important species in the highly productive Bering Sea marine ecosystem. Seasonal manifestations of OA are already occurring in the Bering Sea, in the form of late summer bottom water conditions that are undersaturated with respect to aragonite, a soluble form of carbonate used by marine shell-building organisms. Although these more acidic conditions are generated by natural processes, OA is projected to increase their duration, magnitude, and spatial extent. It is critical to develop skillful predictions and projections of these more acidic water conditions, in order to support sustainable fisheries management over long- and short-term time scales. This work describes ongoing efforts to provide current and future water carbonate chemistry conditions to fisheries stakeholders using a regional biogeochemical ocean model. Multi-decadal projections provide spatio-temporal information for how OA conditions may evolve throughout the Bering Sea shelf and highlight key differences between climate emissions scenarios, providing a regional perspective for the impact of climate mitigation strategies. Meanwhile, near-term products provide fisheries stakeholders with updated environmental information for stock assessment and the fisheries management process. This effort recently culminated with the development of an indicator for the Eastern Bering Sea Ecosystem Status Report (ESR) and input into the Ecosystem and Socioeconomic Profiles (ESPs) for two crab stocks. Our vision is to continue developing and refining this approach and to expand available products in order to support evidence-based decisions in sustainable marine resource management for the largest U.S. fishery.

Key words: High-latitude, downscaling, fisheries, regional modeling

Resource, Biodiversity and Water Quality Baseline Mapping of the *Cakau ni sasi* and *Yarawa* Reef Ecosystem within the Great Sea Reef of Fiji

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The Great Sea Reef (GSR) in Fiji is the third longest continuous barrier reef in the world with a complex array of flora and fauna covering an area of around 202,700 km^2. Resource exploitation in from the GSR forms a critical source of livelihood for 12 districts with more than 70,000 inhabitants. Historical and baseline information for GSR is absent. This work was focused on the development of baseline habitat resource maps, creating inventory of flora and fauna and physiochemical baseline of the intertidal zone cover of the *Cakau ni sasi* reef and *Yarawa* reef which form part of GSR. These reefs are managed by Votua village community in Ba, Fiji.
Images generated using WorldView2 and onsite data logging was used as a base for mapping out the resources. There were six classes of benthic cover identified for the two reefs. These were 'algae', 'coral', 'loose sediment', 'part buried reef', 'rubble', 'sea grass'. pH, temperature, salinity and phosphorous contents were recorded. The World Wildlife Fund (WWF) in Fiji carried out survey of the biodiversity.

The ecosystem maps generated her show the benthic cover, water quality parameters including pH measurements, coastal land use activities, fishery activities and socioeconomic information for *Cakau ni sasi* and *Yarawa* reefs. Biodiversity survey revealed a large biodiversity with threatened, endangered, endemic species as well as new species. pH values range between 7.725 to 8.165 which was much lower than anticipated. Detection of Phosphorous levels indicates pollution from anthropogenic activities.

The information presented can form a basis for the formulation of ecosystem and community based management approaches. A sustained monitoring program with regular map generation and biodiversity survey is needed to better formulate and monitor management approaches, inform policy decisions and develop community resilience against projected changes toward the abundance and distribution of resources.

Key words: Great Sea Reef, benthic cover, habitat map, satellite imagery, Ocean Acidification

Long-term effects of high CO_2 on growth and survival of juveniles of the striped venus clam *Chamelea gallina:* implications of seawater carbonate chemistry

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Ocean acidification (OA) will decrease shellfish growth and survival, with ecological and economic consequences for fisheries and aquaculture. However, the high variability of results among experiments, and the lack of long-term studies, make it difficult to predict the effect that OA will have on bivalve species. We tested the long-term effect of high CO_2 on growth, calcification rates, and survival of juveniles of the commercial bivalve species *Chamelea gallina* from Southern Portugal. The local high alkalinity of seawater probably buffered the negative effect of the pH drop, and after 75 days juveniles increased their growth and calcification rates with CO_2. However, after 217 days, the situation reversed, bivalves under control conditions had the highest growth and calcification rates, while individuals under high CO_2 presented negative calcification rates. The biometric variable that responded first was the width of the individuals, followed by the height and length of the shells. Survival was unaffected except for a mortality peak of juveniles under control and intermediate conditions as a consequence of a temperature drop. In the short term, *C. gallina* will increase their calcification rates to compensate for OA. However, in the long term, the additional energy expended will be translated into growth losses with negative repercussions for the fisheries and aquaculture. The cultivation of shellfish on high alkaline seawater should be further explored as a bioremediation measure to mitigate the negative effect of OA on shellfish aquaculture.

Key words: Ocean acidification (OA); shellfish; juveniles; striped venus clam; seawater carbonate chemistry

Theme F: Global to regional policy, actions, communication and capacity building for ocean acidification, e.g. research networks, communication, and outreach

An overview of the Ocean Acidification International Coordination Centre's (OA-ICC) efforts to advance OA science

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As research activities on ocean acidification and related stressors continue to develop, there is a growing need to coordinate and promote collaboration within the community. To address this, the OA-ICC was established by the International Atomic Energy Agency (IAEA) in 2013. Since its inception, the OA-ICC has facilitated numerous activities within three main domains: 1) increasing capacity in developing countries through training courses and the provision of equipment, 2) disseminating information on ocean acidification through providing open-access resources to scientists, including a news stream, a bibliographic database, and a portal for experimental data, and 3) promoting collaboration by supporting the Global Ocean Acidification Observing Network (GOA-ON) and regional OA networks. The OA-ICC organizes expert workshops on topics relevant to the scientific community, such as the management and access to global ocean acidification data, the development of best practices and the standardization of methodology to increase inter-comparability of results. The OA-ICC is working closely with several international partners such as IOC-UNESCO, The Ocean Foundation, NOAA OAP, and SOLAS-IMBER. The Centre co-chairs the UN Community of Ocean Action on Ocean Acidification, which brings together stakeholders across the globe to enhance progress on the various Commitments made towards the Sustainable Development Goal (SDG) 14.3 on OA. The OA-ICC also participated in the development of the SDG 14.3.1 Methodology, led by IOC-UNESCO, which provides guidance on how to contribute and report OA data through the SDG process. In addition, the OA-ICC is implementing an ongoing Coordinated Research Project to advance understanding on the effects of ocean acidification on seafood around the world and to explore adaptation strategies for aquaculture and seafood industries. The OA-ICC plays an important role in facilitating advances in OA research and in increasing capacity of scientists around the world.

Key words: capacity building, SDG14.3, coordination, communication, databases

Co-produced ocean acidification scenarios for coastal Norway

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In a rapidly acidifying ocean, the safeguarding and strengthening of the blue economy requires that scientific knowledge is delivered that is focussed and relevant. It is paramount that optimum and appropriate studies are undertaken to develop relevant management of coastal and marine systems of high climatic and socioecological importance: understanding global change through local knowledge. The challenge of ocean acidification (OA) is recognized by the United Nations and a specific indicator under Sustainable Development Goal #14 has been developed under the custodial of agency of the Intergovernmental Oceanographic Commission: *14.3.1. Average marine acidity (pH) measured at agreed suite of representative sampling stations.* Through the Global Ocean Acidification Network, an implementation strategy is in place to maximize the utilization of OA observations to improve our understanding of ecosystem response and optimize models. The challenge, however, remains to deliver knowledge for coastal services not represented by national or institutional monitoring programs. This knowledge should be co-produced and interpreted to fit stakeholder needs and to be optimally relevant for service-sensitivity studies. We report here an investigation of two Norwegian fjords with little or no background information on the carbonate system and an uncertain role of management entities. Stakeholder engagement produced a monitoring strategy that was tailored to the unique conditions and existing coastal services; and one which would not have been designed by the scientists, alone. These observations were used to inform downscaling of regional models and the current carbonate system state and projections were evaluated with local to national industrial and management institutions. The identification that some ecosystems were already beyond, or approaching, OA thresholds for key ecosystem players and, that within years-to-decades, societally important coastal services would be challenged, has led to a rethinking of coastal management.

Key words: Ocean acidification, coastal, ecosystem services, co-production, stakeholders

South Asia Regional Hub on Ocean Acidification (SAROA)- ocean acidification research for sustainable oceans

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South Asia has some of the largest and biologically rich marine ecosystems including mangroves, estuaries, intertidal mudflats, coastal lagoons and coral reefs. More than 200 million people in South Asia are directly dependent on coastal and open ocean bioresources. As the second fastest economically growing region in the world, the regional seas and oceans of South Asia are facing multi-faceted pressures including from relative rise in sea-level, salinity intrusion, nitrogen and plastic pollution, in addition to emerging threats of ocean acidification. Ocean acidification (OA) in South Asia can have huge consequences for unique coastal biotopes, blue economy and linked GDP. The South Asia Regional Hub on Ocean Acidification (SAROA), a GOA-ON endorsed Hub has been established and intends to bring together early-career as well as experienced scientists with a common interest towards documenting geographically distributed data on OA across seas and oceans of South Asia; monitor OA and effects on coastal bioresources and beyond such as involving citizen scientists. SAROA Hub has also spearheaded the momentum towards establishment of national OA monitoring programs in South Asia including in Sri Lanka, Bangladesh and Myanmar. The Hub is developing innovative approaches for targeted capacity building of early-career researchers with an interest to undertake OA measurements in the region while integrating successful platforms established by GOA-ON such as Pier2Pier partnerships and ultimately contribute towards long-term goal of data sharing under SDG 14.3.1.SAROA intends to play a key role by engaging with policy makers, social scientists and citizens of South Asia through existing programs such as the South Asia Co-operative Environment Programme (SACEP) so as to highlight and mainstream OA research outcomes towards long-term sustainability and achieving healthy regional seas and oceans across the region and beyond.

Key words: South Asia; Ocean Acidification; monitoring; capacity building; policy

Supporting State Action on Ocean Acidification: Mobilizing Solutions-focused Science, Policy and Management in California

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Waters off the coast of California are acidifying at twice the rate of the global average, driven by uptake of carbon dioxide released by the burning of fossil fuels, exacerbated by wind-driven upwelling and changing land uses. Given the risks posed to the region's marine ecosystems, species, and lucrative fisheries, California policy and management leaders have taken proactive steps during the last decade to increase our understanding of impacts, invest in decision-relevant science, and develop one of the first state ocean acidification (OA) action plans. Momentum and success in the region have been supported by the development of decision support tools with a firm scientific foundation that address priority management needs and that incite and maintain policy interest in a complex emerging issue. Here, we will draw on case studies from our work as a non-profit boundary organization created by legislation to bridge the gap between cutting-edge research and sound ocean management. We will share learning and insights from our experiences (1.) working with state government to convene science advisory panels, including the bi-national West Coast OA and Hypoxia Science Panel and the California OA and Hypoxia Task Force; (2.) bringing scientists and natural resource managers together to inform research along the California Current Ecosystem focused on understanding vulnerability of key species of management interest to OA; and (3.) advancing "blue carbon" science as a local ocean acidification reduction tool. These are examples of the knowledge-to-action translational effectiveness of boundary organizations in strengthening science-informed decision-making, thus building institutional capacity for improved ocean governance. Insights from these processes may help other regions seeking to engage decision-makers in the global effort to advance scientific research and reduce the drivers and impacts of OA.

Key words: capacity building, management, policy, US West Coast, decision-making

New science program to study ocean acidification along the coast of Africa and the Indian Ocean as part of the EAF Nansen Program

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In 2017, the 30-year old measurement program onboard R/V Dr. Fridtjof Nansen within the EAF Nansen program was extended to include observations and studies on ocean acidification (OA) in addition to nutrients and dissolved. The same year a new Science Theme 10 was developed titled Climate Change and Biogeochemical processes. The main aim is to investigate the chemical change of the ocean by investigating core environmental variables along transects in key areas vital for biological production. One major objective is to assess variability and change in ocean acidification state such as the pH, total alkalinity, in addition to the ocean CO_2 uptake and the depth of the calcium carbonate saturation horizon. Other science objectives are to use paleo proxy data from sediment cores to study the past variability in dissolved oxygen in relation to physical forcing and primary production. Specific study sites involve upwelling systems, oxygen minimum zones/low pH/high CO_2, vulnerable benthic habitats as well as freshwater influenced coastal systems. The Science Theme 10 is also involved in knowledge and capacity building for marine chemistry focusing on training workshops for measurements of spectrophotometric pH and total alkalinity to the partner countries. The EAF Nansen program is supported by FAO and the Norwegian Ministry of Foreign affairs (NORAD) and R/V Dr. Fridtjof Nansen which is governed by the Institute of Marine Research, Norway.

Key Words: marine CO_2 system, calcification, biological and physical processes, air-sea CO_2 exchange, upwelling

U.S. Interagency Working Group on Ocean Acidification: Federal Policy and Coordination through National Strategic Plan and Vulnerability Report

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The United States Interagency Working Group on Ocean Acidification (IWG-OA) coordinates research and monitoring activities across the various federal agencies. Recently, the IWG-OA completed a revised strategic plan on federal research and monitoring of ocean acidification in the United States. The plan is organized around seven themes: research, monitoring, modelling, technology development and method standardization, assessment of socioeconomic impacts, education and outreach, and data management and synthesis. Thirteen different agencies contributed to the report, which will guide research and monitoring investments to improve our understanding of ocean acidification, its potential impacts on marine species and ecosystems, and adaptation and mitigation strategies. Additionally, the IWG-OA is working on a new legislatively-mandated report that examines vulnerability to ocean acidification in the United States through the lens of gaps in monitoring and research, as well as impacts to coastal communities. The report is organized by regional chapters that highlight the unique vulnerabilities of each region of the country, and will guide future research and collaboration needed to better understand vulnerability and identify adaptation measures. Many external stakeholders, including regional coastal acidification networks, were engaged during the development of the report and contributed important ideas about what is needed to engage communities around vulnerability to ocean acidification. This nationwide report is the first of its kind and will be followed by updated regional vulnerability reports every six years. Together, both of these reports are important examples of national policy on ocean acidification.

Key words: Federal Policy; Vulnerability Assessment; Strategic Plan

The development of accessible best practices for monitoring ocean acidification globally through the "GOA-ON in a Box" initiative

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One of the main goals of the Global Ocean Acidification Observing Network (GOA-ON) is to increase ocean acidification data coverage around the world; this is critical for understanding ocean chemistry at the local scale while contributing to global efforts including the Sustainable Development Goal target 14.3 to "minimize and address the impacts of ocean acidification". The lack of instrumentation has hampered the establishment of sustained measurements for many countries and research organizations. In response, simplified methods and kits to measure pH and total alkalinity, known as 'GOA-ON in a Box' have been developed with collaboration from experts in the field and GOA-ON partners including The Ocean Foundation, the NOAA Ocean Acidification Program, the IAEA Ocean Acidification International Coordination Centre, the Intergovernmental Oceanographic Commission of UNESCO, and others. Since the development of GOA-ON in a Box, such kits have been provided to sixteen countries in Africa, the Pacific Small Island Developing States, Latin America, and the Caribbean. Recipients of the GOA-ON in a Box kits have received basic and advanced trainings to ensure their ability to properly sample, measure, and analyse carbonate chemistry data from discrete seawater samples and autonomous sensors using the kits. A key component of this effort is the development of Practical Standard Operating Procedures (SOPs) and including best practices manuals outlining recommendations for

producing secondary standards, checklists for conducting fieldwork and maintaining lab equipment, as well as spreadsheets for calculating carbonate chemistry parameters. The development and distribution of the GOA-ON in a Box kits and its associated best practices documents play an important role in conducting carbonate chemistry measurements and obtaining data in otherwise data-sparse regions, ultimately helping to establish ocean acidification monitoring programs and inspire policy action.

Key words: capacity building, GOA-ON, SOPs, methodologies, ocean acidification

OBSERVATORY FOR THE STUDY OF OA IN CUBA. FIRST RESULTS AND CHALLENGES FOR ITS SUSTAINABILITY

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Cuban Observatory for the Study of Ocean Acidification was created in 2017 through International Collaboration Project financed by International Atomic Agency Technical Cooperation Department and National Science Project funded by Science Ministry of Cuba, currently is part of REMARCO (Marine and Coastal Stressors Research Network in Latin America and The Caribbean, www.remarco.org). The observatory has different sections focused on the i) measurement of carbonate cycle variables (pH, AT) in seawater, ii) use of natural archives to reconstruct temperature and pH profiles and iii) laboratory experiments to assess the effect of OA over local marine species. Results of the observatory include an annuals data set submit to IOC/UNESCO as part of national compromise with SDG 14.3.1., satisfactory participation in international intercomparison activities, study coral calcification and reconstruction of temperature in coral cores using of isotopes. Challenges for regular functioning of the observatory are related with the access to Certified Reference Materials, the calibration and maintenance of in situ probes and networking collaboration at national and international level.

Key words: Ocean Acidification; Coral; Monitoring; SDG14.3.1; Cuba

Ocean Acidification observation network in the Canary Islands Region

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The Canary Islands, with more than 90% of their economical activity related with their surrounding waters, must know what are their ocean acidification specific trends to be able to take actions and adapt to future changes that the increase in human activity will produce in this region. Since 1995, the trends of the different CO_2 parameters have been measured in the oceanic ESTOC station, located 60 miles north of the Canary Islands, but there is no data on the evolution of these in coastal areas. In comparison with the open ocean, the coastal systems are affected with greater intensity by the hydrodynamics of the area (tides, upwelling) and the contributions of natural and anthropogenic land origin processes which would show a higher variability in the carbonate chemistry at an annual level complicating the detection of acidification, hence the need to conduct studies covering a broader area that could be representative.

A new ocean acidification observation network is presented, CanOA, establish in the Canary Islands, and as a result of public-private financing by the Canary Islands Government and the Loro Parque Foundation, with the collaboration of the FRED Olsen shipping company.

The main objective of the CanOA project is to study the process of ocean acidification in the waters of the Canary archipelago by creating a regional network of combined observation that covers the Canary region. To get this, two coastal time series stations will be established in two buoys together with oceanic measurements along the archipelago with a high frequency of analysis using VOS lines. The coastal environment is highly fragile and requires a high frequency of sampling and research that allows, with this database, to understand the response of the Canary region to anthropogenic carbon accumulation and its consequences due to acidification.

Key words: Ocean acidification, VOS line, Canary Islands, CanOA, ESTOC

Ocean Acidification Monitoring in Vanuatu: Introduction and Capacity Building

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Climate change impacts are evident all over the world and more evident in the small island Pacific nations. Vanuatu, a small Pacific Island nation with an archipelago of 83 islands surrounded by narrow fringing reefs has been witnessing the catastrophic events as a result of climate change. Its blue economy, the driving source of the country, has begun to experience the impacts of climate change in terms of reduced fishing output, vanishing species, dying coral reefs, decreasing mangrove growth, and coastal erosion. These changes are threatening the very existence of Vanuatu.

The impacts of climate change have triggered government and public debate about ocean health and the steps needed to save the islands. Although the efforts were made to highlight the issues but Ocean Acidification (OA) has received very little attention in the country. To instigate OA and its communication in the country, The University of South Pacific's Emalus Campus in the capital Port Vila collaborated with The Ocean Foundation. An OA monitoring lab was set up in the campus for continuous monitoring of alkalinity and pH in the shores of Erakor lagoon in the capital. Stakeholder workshop with student training activities were part of the capacity building besides the current monitoring program started in 2018. In-spite of several challenges ranging from lack of expertise and capacity, the monitoring is currently going successfully with the help of The Ocean Foundation. It is hoped that a better understanding of variabilities in the coastal ecosystems and further communication of OA in the country would be achieved in near future that would lead to better policies in combating climate change impacts. It is also hoped that the baseline data being generated would be useful for international use as per GOA-ON goals.

Key words: Ocean Acidification Monitoring, Capacity building, Vanuatu

Addressing Ocean Acidification through Polycentric Governance: Shifting the Focus to Regulation of Ocean Acidification Response Strategies

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Ocean acidification has increasingly gained significance at international and domestic scales. Knowledge on its occurrence and impacts has continued to grow amongst different stakeholders including scientists, policy makers and vulnerable industry players. This increased attention has been significant in raising the profile of the problem beyond the scientific realm into the arena of policy and governance. Global ocean acidification is a problem that sits along with other threats such as warming as a threat multiplier. It is a complex problem that requires numerous responses at different levels and contexts. For instance, at global level, carbon dioxide emission reduction remains a primary area of focus, while at the local level, reducing local sources of land and vessel-based pollution is critical, enhancing marine ecosystem resilience and the adaptive capacity of vulnerable communities is important. From a governance perspective, ocean acidification sits in the cracks of multiple policy domains. This is epitomized by numerous overlapping environmental regimes that find relevance in governance of the problem at multilateral, regional and domestic levels. This has created a de facto regime complex for ocean acidification. Addressing such a compound problem in the midst of a regime complex therefore becomes a critical area of focus. This paper argues that governance for addressing ocean acidification will need to move beyond addressing it as a discrete issue and focus on regulation of available response strategies, including at national and regional level. Consequently, approaching the problem from a polycentric perspective could be necessary to advance governance responses to the problem. Such an approach could harness the fragmentation and overlap in governance regimes particularly at regional and domestic level, especially given the difficulty in creating singular or integrated institutions to manage the issue, level of implementation of response strategies and the domestic and regional context that underpins environmental governance.

Key words: polycentric governance, regime complex, ocean acidification

The OSPAR Assessment of Ocean Acidification in the North-East Atlantic

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The OSPAR Convention is the mechanism by which 15 Governments and the EU cooperate to protect the marine environment of the North-East Atlantic. OSPAR's 2020 - 2030 North-East Atlantic Environment Strategy established objectives for four themes to achieve *clean, biologically diverse, productive and sustainably used* seas that are *resilient to climate change and ocean acidification*. As a contribution to OSPAR's benchmark Quality Status Report (QSR) 2023, an expert group undertook a comprehensive assessment of ocean acidification (OA) for the OSPAR Maritime Area. OA variability and trends were assessed using multiple approaches including observational data, regional reconstruction synthesis products, and a regional hindcast simulation. An overall picture emerged of ocean acidification occurring across all OSPAR regions, with pH and Ω_{Arag} rates varying widely, depending on location and assessment tool used. There were few time-series stations of sufficient temporal coverage and length for assessing trends

and many of these are in inshore areas and do not measure sufficient parameters to calculate the full inorganic carbon system.

Two regional coupled hydrodynamic-biogeochemical models (the AMM7 NEMO ERSEM and NOREWCOM.E2E, the domains of which together, spanning from the Bay of Biscay to Arctic waters, cover much of the OSPAR area) were used to project ocean acidification trends on a mid-century time horizon, for medium and high emission scenarios (RCP 4.5 and 8.5). OA is projected to progress in all four OSPAR regions assessed but with high spatial variability within the regions. Our assessments highlighted that multiple stressors will continue to cumulatively exert pressure on marine species and ecosystems, with repercussions for ecosystem services in the OSPAR Maritime Area. This work considered the potential impacts of OA, including on protected species and habitats as designated by OSPAR and on species of commercial importance, and possible responses, including mitigation and adaptation.

Key words: OSPAR Assessment, Acidification, North-East Atlantic

Caribbean Ocean Acidification Community of Practice

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Ocean acidification (OA) threatens Caribbean marine and coastal ecosystems, as well as the goods and services they provide (e.g., food security, protection of coastal infrastructure and habitat, employment, etc.). Both regional bodies of the Intergovernmental Oceanographic Commission (IOC) and United Nations Environment Programme (UNEP) have highlighted the need for greater OA monitoring capacity, as well as multidisciplinary/inclusive stakeholder engagement in the region, including through a resolution passed at the Cartagena Convention Conference of the Parties in 2019 that called for regional collaboration and action. In December 2021 an OA Caribbean Community of Practice (CoP) was established with the goal of strengthening capacity for research, monitoring, mitigation, and adaptation to OA and associated stressors in Caribbean Islands, and in particular, Caribbean Small Island Developing States (SIDS). Working in tandem with existing efforts led by The Ocean Foundation in the Caribbean and Latin America, this effort has brought together ocean practitioners from diverse backgrounds and perspectives, including intergovernmental bodies, academics, researchers, and administrators. During the first year, the CoP has leveraged connections to pursue funding for primary initiatives such as an online OA training for researchers and policymakers. Such training not only raises awareness of OA in the region, but will also allow the CoP to develop relationships with diverse stakeholders from SIDS to better identify the socioeconomic impacts of OA in the Caribbean. OA in Caribbean islands is expected to exacerbate the impacts of the stressors islands face today. This CoP can help to build the ability to monitor OA through in-person training and standardizing monitoring efforts. However, perhaps more importantly, the CoP can help build resilience and strengthen the connections between island communities facing similar climate threats.

Key words: Caribbean, ocean acidification, community of practice, capacity building, small island developing states (SIDS)

The Ocean Acidification Information Exchange: an Online Community Connecting Questions with Answers

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Ocean and coastal acidification (OCA) research is, relatively speaking, new; the global scope of the problem, advances in understanding and rapidly changing conditions make the sharing of resources vital for fostering prepared, resilient communities.

Recognition of the importance of information sharing led to the creation of the Ocean Acidification Information Exchange , an online community for professionals involved with or interested in OCA. Launched in February 2018, the community's mission is to respond and adapt to OCA by promoting the collegial exchange of information across disciplines and geographical boundaries, with the ultimate goal of facilitating the creation of more holistic, more effective response strategies.

Instead of pushing one-way transfers of information to the website reader, the OA Information Exchange focuses on interaction and sharing. Members share "Updates" on which other members can comment. By tagging updates with topic Key words, information can be easily retrieved using the site's powerful search feature. In addition to a community-wide discussion feed, the site is divided into "teams", which are smaller, more focused discussion groups; about half of these teams focus on a geographic region. Any member can share files, including documents, videos and presentations, and add events (both in-person and virtual) to the site's calendar. The OA Information Exchange's tools provide members with a single hub that satisfies multiple information needs while also promoting profound person-to-person connections.

Since its inception, the OA Information Exchange has grown to more than 1,000 members, approximately 20% of which hail from outside Northern America. We encourage even greater involvement by the global OCA community, and hope to build our international member base. We aim to serve as the platform on which the online OCA community can affect real-world change.

Key words: Community building, online community, science of team science, engagement, information sharing

The Global Ocean Acidification Observing Network, GOA-ON: Ten years later and one hundred countries strong

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The Global Ocean Acidification Observing Network, GOA-ON, seeks to improve our understanding of ocean acidification (OA) conditions, ecosystem response to ocean acidification, and to facilitate exchange of data and knowledge necessary to optimize modelling and other products for assessing ocean acidification and its impacts. GOA-ON, established in 2012, reaches members world-wide who are researching OA at local through global scales. Thanks to active capacity building efforts, membership has swelled from 23 countries to 105, with over 900 scientists involved. A key part of achieving GOA-ON's goals at a truly global scale is the emphasis it has placed on capacity building. Successful practices have included trainings, mentoring, resource opportunities, regional hubs, and a strong communication network. The continued growth in membership shows the remarkable willingness of the members to collaborate and contribute their expertise to build the network given the significance of the issue. While we place emphasis on local measurements, our mission is also globally focused for three important reasons: 1) We need information and data products that can inform policy and the public with respect to ocean acidification and implications for the overall ecosystem health of the planet. 2) OA processes are occurring at global scales, so we need to place local measurements in context of global drivers. 3) Insufficient observations and understanding of OA on local through global scales impedes development of robust predictive skills regarding OA and impacts. GOA-ON's strong international coordination allows for connection of local observations within a global context and to international assessments. Through shared expertise and growing ranks, GOA-ON seeks to stimulate data available for the United Nations Sustainable Development Goal 14.3.1. Most recently, GOA-ON will direct attention on OA research through its UN-endorsed ocean decade programme "Ocean Acidification Research for Sustainability" (OARS), which focuses on achieving outcomes serving scientific and societal goals.

Key words: ocean acidification observations, impacts, capacity building

Building capacity and supporting workforce development through ocean acidification literacy

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Ocean literacy is essential for effective, responsive, science-based policy. The United States National Oceanic and Atmospheric Administration (NOAA) Ocean Acidification Program (OAP) maintains an education mini-grant program providing federal financial support to engage diverse audiences, match education and outreach needs with existing research, and promote innovative ways of engaging communities. Presented here are education and outreach resources that increase ocean acidification (OA) literacy, stewardship, and workforce development through community science, professional development, informal and formal education and multimedia tools. These assets bolster diversity, equity, inclusion and accessibility to information about ocean acidification causes, impacts, and solutions, which builds capacity to respond to OA on local, regional, and national scales.

Key words: Capacity building, education, ocean literacy, outreach, workforce development

Canada's Ocean Acidification Community of Practice

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The need for science-informed decision making in the face of climate change is ever increasing, with knowledge users ranging from scientists, governance, stakeholders, rightsholders and the general public. To increase knowledge sharing and mobilization on ocean acidification (OA) in Canada, the MEOPAR (Marine Environmental Observation, Prediction and Response) Network of Centres of Excellence formed an OA Community of Practice (CoP) in 2018, which is open for any interested parties to join (www.oceanacidification.ca). OA CoP objectives include the development of knowledge transfer and community engagement via accessible content; resources, and databases; best-practices for data collection, and; interdisciplinary knowledge sharing. We will present some of our key activities to date, our new online resources and blog series aimed at increasing OA awareness, membership diversification and engagement, research projects such as low-cost OA sensor package to aid aquaculture operations and larger monitoring efforts in coastal zones, our role in the facilitation of OA climate adaptation plans and linkages to other national and international OA initiatives.

Key words: Ocean Acidification, Canada, Communication, Coordination, Interdisciplinary

Ecosystem Protection Plans and Application of Neural Networks for pH Prediction in the Gulf of Aqaba-Jordan Coastal Water

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The ecosystem of the Gulf of Aqaba-Jordan is still preserved and unaffected by environmental changes and industrial consequences. Due to water scarcity in Jordan, desalination projects must be planned in the foreseen future to secure pure water to the Jordanian society. Desalination of Red Sea water might result in harmful effects to the marine life and environment. For this reason and other possible future sources, plans and policies are being carried out to protect the ecosystem at the precious Gulf of Aqaba Coast. Among those plans are the establishment of Aquarium Marine Park and OceanXplorer Expedition which include multidisciplinary activities involving education, research, tourism and policy making. Part of the objectives is to design measurement systems, collect and analyze valuable data in order to predict water quality, sea life important features and nature behavior. The OceanXplorer is a well-equipped high tech scientific exploration vessel for marine activities landing in Aqaba in July 2022 for expedition and capacity building purposes as will be described.

Available relevant seawater measurements at the Gulf of Aqaba allows prediction of the pH value which is an indication of the quality of water and possible undesired acidification which should be avoided. The measurements include data about 30 different locations in the Gulf of Aqaba Coastline. At each location, the data consists of pH, electrical conductivity (EC), total dissolved solids (TDS), total alkalinity (TA), and concentrations of Cl^-, NO_3^-, SO_4^{2-},PO_4^{3-}, NH_4^+, Ca^{2+}, Mg^{2+}, Na^+, K^+, Sr, Cd, Co, Cr, Cu, Fe, Mn, Pb, and Zn. An artificial neural network (ANN) is trained and tested with the 30 data sets to provide an attractive model for predicting the pH value of the Red Sea water in Aqaba. Furthermore, future measurements available by the described projects above can be utilized by the ANN model to give information about the quality of seawater so that appropriate measures and actions can be taken to protect the ecosystem.

Key words: Red Sea, Capacity Building, pH Prediction, Neural Networks, Measurements

Ocean Acidification Research in Latin America and The Caribbean by the REMARCO Network

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REMARCO (Marine and Coastal Stressors Research Network in Latin America and The Caribbean, www.remarco.org) is a collaborative network in science and communication that connects institutions and scientists of 18 countries to provide solid regional scientific information on chemical and microplastics contamination, eutrophication, harmful algal blooms and ocean acidification (OA), to decision-makers and society. REMARCO aims to strengthen capabilities to measure the marine carbonate system and to generate scientific knowledge in the region. Since 2014, the IAEA has supported regional projects that included OA, leading to implementing coastal stations to monitor OA and contributing to SDG 14. We have defined and are distributing the REMARCO-OA kit, and have published freely available methodological manuals in Spanish for specific equipment and procedures (including estimation of analytical uncertainties), adapted to some common regional conditions and constraints. This knowledge is shared through in-person and virtual meetings, courses, and scientific visits by experts. Results are disseminated in international conferences, published in scientific journals, and shared with decision-makers and society by the communications working group. Since 2021, three laboratories successfully participate in international intercomparison activities and submit data to IOC/UNESCO to contribute to the SDG 14.3.1 indicator (marine acidity). Joint work with national decision-makers for reporting the indicator has been achieved in most countries. Some ongoing activities include developing a regional capability for the purification of m-cresol purple, evaluating the effect of dissolved organic matter in the measurement of the carbonate system, studying open ocean waters, using isotopes to study coral calcification and sediment cores to reconstruct pH conditions, and laboratory experiments with marine organisms. The work by REMARCO provides new knowledge on our marine and coastal region, where processes affected by OA remain still largely unknown.

Key words: ocean acidification, coastal acidification, carbonate chemistry, capacity building, communication

Ocean acidification and the UN Sustainable Development Goal 14

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The United Nations 2030 Agenda, its Sustainable Development Goals (SDGs) and the UN Decade of Ocean Science for Sustainable Development (2021-2030), are major initiatives aimed at delivering information and knowledge for maintaining ocean and human health. SDG14 "Conserve and sustainably use the oceans, seas and marine resources" comprises ten targets. The objective of target SDG14.3 is to "Minimize and address the impacts of ocean acidification, including through cooperation at all levels". The establishment of ocean acidification (OA) as an SDG target shows the commitment by UN Member States to address the growing concerns about the ecological and socio-economic impacts of OA. The Intergovernmental Oceanographic Commission (IOC) of UNESCO as the custodian agency for the respective SDG Indicator 14.3.1, calling for "Average marine acidity (pH) measured at agreed suite of representative sampling stations", supports Member States together with its partners such as GOA-ON in this. The Commission coordinated the development of the SDG Indicator 14.3.1 Methodology, which provides the necessary guidance to scientists and governments on how to conduct OA observation, what to measure and how, and offers best practice and methods approved by the scientific OA community. The collection of data used to assess the Indicator 14.3.1 relies on submissions by national agencies in Member States, supported by data managers and individual researchers. To facilitate the collection of data towards the SDG 14.3.1 Indicator, IOC and its International Oceanographic Data and Information Exchange have launched an online data portal in 2020. This SDG 14.3.1 Data Portal satisfies the need by countries with limited data management capabilities to submit, validate, store and share OA data and metadata, based on the guidelines set out in the Methodology. Together, the Methodology and the portal allow to collect and compare OA data globally and, ultimately, hopefully contributes to achieving SGD 14.

Key words: United Nations Sustainable Development Goals; SDG 14.3.1; ocean acidification; data collection

Pacific Islands Ocean Acidification Centre: Building Monitoring Capacity from Local to Regional Scales

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Ocean acidification (OA) is a global issue that affects local marine ecosystems. The Pacific Islands region is especially vulnerable to OA because community livelihoods are directly connected to thriving coastal ecosystems. However, at present, the capacity to research and monitor OA in the Pacific Islands is limited. The Pacific Islands Ocean Acidification Centre (PIOAC) was formed in 2021 through combined international and localized efforts to house, maintain and distribute research equipment tailored to regional needs, host regional training activities in order to develop monitoring expertise, support new and ongoing OA monitoring activities, ensure regional OA data are accessible, and provide training support and technical assistance through an international community of practice. This presentation details how the PIOAC could serve as a model for building locally-owned capacity for OA research through public-private partnerships for Small Island Developing States (SIDS). This presentation will also speak to the challenges and future outcomes of OA research in the Pacific Islands region.

International Alliance to Combat Ocean Acidification: Governments Working Together to Increase Ambition to Reduce Carbon Dioxide Emissions and Implement Strategies to Assess and Prepare for Impacts of Ocean Acidification

Ms. Jessie Turner

Secretariat, International Alliance to Combat Ocean Acidification

The International Alliance to Combat Ocean Acidification (OA Alliance) was launched by the four North American West Coast governments of California, Oregon, Washington and British Columbia, Canada in direct response to the observed impacts of ocean acidification on oyster hatchery production across the North American West Coast during the mid-2000s.

Today, the OA Alliance is comprised of over 100 members, including 13 national governments, 9 states, 2 provinces, 6 tribal and sovereign nations, and 4 cities, along with local research institutions, monitoring networks, businesses, affected industry partners and NGO.

Under the leadership of its diverse members, the OA Alliance is harnessing growing scientific knowledge about impacts of ocean acidification and transforming it into increased urgency for climate change mitigation and outlining tangible and innovative actions that will help communities and industries adapt.

National, subnational, regional and tribal governments are proactively responding to the impacts of ocean acidification as they create OA Action Plans.

OA Action Plans help governments identify key species and ecosystems within their region (economically, culturally, or otherwise), assess potential vulnerabilities and develop strategies to protect them. The development of OA Action Plans also engages policymakers and heads of state (ministers, governors, premiers, agency directors, mayors and tribal chairs) in leadership roles, helping to elevate climate-related impacts to our ocean and the forecasted catastrophic impacts if we do not act quickly.

Together, members are calling for emissions reductions and ocean adaptation actions under international and national climate frameworks like the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Sustainable Development Goals (UN SDGs.)

Key words: Government, UNFCCC, UN SDG, mitigation, adaptation

Equity in Ocean Acidification Research: Development of a Low-cost Kit for OA Monitoring

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Despite consistent growth in research and monitoring focused on ocean acidification (OA), significant portions of the ocean, including the islands and coastal areas most vulnerable to the socioeconomic impacts of OA, remain unstudied. A primary barrier to conducting research has been the cost of monitoring systems. To remove this barrier, the project partners designed a low-cost suite of equipment for labs with limited or no equipment to enable monitoring pH and total alkalinity at weather-quality (per the Global OA Observing Network (GOA-ON's) Requirements and Governance Plan). The kit, called "GOA-ON in a Box," contains: materials for collecting and preserving discrete samples, including all necessary glassware and sampling materials; an iSAMI pH sensor and a Van Essen CTD diver for in situ continuous monitoring; a spectrophotometer and necessary equipment to conduct spectrophotometric determination of pH in discrete samples; a manual titration system to measure total alkalinity in discrete samples; a computer and required software for QA/QC and reporting, including the SDG 14.3.1 metadata template; and a series of tools and items for maintenance of kit components. The total cost of all items in the kit is approximately $20K USD, which represents a 10-fold decrease in price from conventional monitoring systems.

To date, 17 GOA-On in a Box kits have been deployed in 16 countries. Project partners are currently conducting a long-term assessment of the relative uncertainties associated with measurements from the kit when the kit is operated by those without prior experience in chemical oceanography and OA. To date all kits have been procured and delivered by The Ocean Foundation. A full list of items in the kit is publicly available and all SOPs used in the kit are open source.

Key words: Ocean Acidification, Monitoring, Capacity Building, Low-Cost, GOA-ON