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Expanding ocean observation and climate services to build resilience in West African fisheries Comment

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Abstract :

The Canary Current is a potential hotspot for climate change impacts on the oceans where 63 million people depend upon marine resources for national economies and livelihoods. Their unique vulnerability highlights the key roles of climate services and capacity building in order to develop effective adaptation measures.

Main text

Eastern boundary upwelling ecosystems (EBUEs) are among the world's most productive ocean ecosystems, a consequence of the upwelling of cold and nutrient-rich waters, providing around 20% of global fish catches and directly supporting livelihoods in coastal communities.[1] Given the importance of EBUEs to global fisheries and livelihoods, understanding, projecting, and adapting to the impacts of climate change on them warrants robust climate services, namely, scientifically based information and products to assist decision-making.

EBUEs are potential hotspots climate change, manifest as rising temperatures, ocean acidification (OA), and ocean deoxygenation (OD), which will affect marine life from molecular processes to organisms and ecosystems in ways that we are only beginning to fathom, and that are irreversible on the scale of human societies.[1] Ocean warming will affect ocean ecosystems and biogeochemical processes directly, as temperature plays an essential role in the chemistry, biology, ecology and distribution of marine organisms.[1] Oxygen is fundamental to biological and biogeochemical processes in the ocean.[2] Rising global temperatures decrease oxygen solubility in water, increase the rate of oxygen consumption via respiration, and are predicted to reduce the introduction of oxygen from the atmosphere and surface waters into the ocean interior by increasing stratification and weakening ocean overturning circulation.[2] A growing body of evidence reveals the impacts of OA across corals, echinoderms, mollusks, crustaceans and fishes.[1] EBUEs are naturally low in pH and carbonate ion concentration resulting in aragonite saturation states (Ω_{arag}) close to 1, below which water is corrosive and unprotected aragonite shells will begin to occur.[1] These three stressors—ocean warming, OA and OD—are acting simultaneously as they are fundamentally driven by the same underlying process: the increase in atmospheric CO_2 and the resulting changes in the Earth's radiative forcing.[2]

Of the planet's four EBUEs, the Canary Current Large Marine Ecosystem (CCLME) is the least studied—yet is a region where social and climatic factors intersect to create a particular climate vulnerability for the roughly 63 million residents of the bordering West African countries who are highly dependent upon marine resources for food security, national economies, and livelihoods[3,4] (Figure 1). The CCLME extends along the northwest African coast, from the northern Atlantic coast of Morocco to Guinea-Bissau (Figure 1). Artisanal fishing is the main livelihood of coastal populations in the CCLME.[3] In addition to the threats from climate change discussed above, fisheries in the region face challenges from legal and illegal distant-water fishing vessels, overcapacity of national fisheries and weak monitoring, control and surveillance, offshore oil and gas extraction, land-based pollutants, and a global demand for fishmeal that is likely to increase.[3,4] Small pelagic fishes are the most abundant fish stocks in the CCLME and are key species for food security in Northwest Africa.[3] Their importance extends beyond the countries bordering the CCLME, providing animal protein to the most vulnerable communities in sub-Saharan Africa, nearly 200 million people,[3] yet most small pelagic fish stocks off Northwest Africa are over-exploited.[4] West African agriculture is highly vulnerable to climate change due to its reliance upon rain, the region's climate variability, and limited economic and institutional capacity to respond to climate change, which will likely lead to a greater dependence on fish for food security and livelihoods in the region, a dependence that will be exacerbated by population growth.[3]

The first observation of a nearshore anoxic event on the West African shelf, which occurred in March of 2012, was recently reported by Machu et al.[7] The detection of this anoxic event, combined with observations such as the millions of dead fish that were washed ashore in Mauritania in September of 2020, which local scientists attributed to a lack of sufficient oxygen,[8] suggest that the CCLME may well be a hotspot for climate change impacts. Effective climate services would put these observations into the context of climate change impacts on the broader CCLME, in particular, changes in temperature, OA and OD, providing actionable information for resource managers to the benefit of fishermen and the people that depend upon those resources for food security and livelihoods. Figure 2 shows the assets of the Global Ocean Acidification Observing Network (GOA-ON) for the two Pacific Ocean EBUEs - the California Current System (CCS) and the Humboldt Current System (HCS) - and those of the CCLME, revealing a stark difference in the resources available to provide climate services in the three EBUEs.

Effective climate services in the CCLME will require accurate, *in situ* data on the key manifestations of climate change on the oceans, rising temperatures, OA, and OD, and on a scale that reflects the region's geographical and oceanographic diversity, which is currently lacking. At present, the two permanent assets for the monitoring of OA nearest the coastal upwelling zone of the CCLME are on moorings located in the Canary Islands (Figure 2). While the islands are oceanographically and biologically connected to that zone, the distance between the sensors and the coast means that they cannot effectively monitor OA in the upwelling zone, the region of greatest importance to fisheries in the CCLME. The moorings in the Canary Islands also monitor dissolved oxygen, among other parameters. The sole permanent asset for monitoring dissolved O_2 levels in the upwelling zone of the Northwest African CCLME is the Melax buoy located off the coast of Senegal (14°20'N, 17°14'W).

Climate change impacts on the HCS and CCS

It is instructive to consider the observations and projections of climate change impacts on the CCS and the HCS EBUEs, where the magnitude and impacts of OA and OD are better characterized than in the CCLME. *In situ* data on OA and OD have underpinned climate services in these EBUEs, helping policy makers, scientists, and resource users understand, adapt to, and project the impacts of climate change in these EBUEs.

In 2006, anoxic waters upwelled to depths of <50 m within 2 km of the shore in the CCS, the first such report, resulting in unprecedented large-scale mortality of benthic macro-invertebrates, constituting a "stark expression of an unanticipated climate change impact".[9] In 2007, waters that are corrosive to calcium carbonate ($\Omega_{aragonite} < 1$) reached the surface ocean during upwelling events, which was subsequently linked to unprecedented levels of mortality of larvae of the Pacific oyster, *Crassostrea gigas*, in U.S. West Coast hatcheries,[10] which provide the seed for a shellfish farming industry that supports over $270 million in economic activity and over 3,000 jobs. Shellfish growers have worked in partnership with scientists to monitor, adapt to, and partially mitigate, the impacts of OA on bivalve seed production and to develop long-term strategies to adapt to further declines in water quality.[10] Also in the CCS, large portions of the shelf waters were found to be corrosive to the dominant pteropod species, *Limacina helicina*, prey species for ecologically, economically, and culturally important fish species, such as pink, chum, and sockeye salmon,[11] while severe carapace dissolution and destabilized mechanoreceptors were observed in the larval Dungeness crab (*Metacarcinus magister*), a fishery that generates annual revenues up to $220 million in the U.S.[12] *In situ* data on OA has been used for regional-scale model studies in the CCS by Gruber et al.[13] in order to project its progression in the region. They projected that by ~2035, nearly the entire twilight zone of the central California coast will be undersaturated with respect to aragonite year-round and recommended that specific attention should be given to the development of OA in all EBUEs. The importance of climate services in the CCS is evident in documents such as "Readying California Fisheries for Climate Change,"[14] which was designed to provide scientific guidance to the California Department of Fish and Wildlife.

The HCS extends along the west coast of South America and is characterized by a broad diversity of habitats and oceanographic influences, giving rise to significant variability in carbonate chemistry. A consequence of this variability are intraspecific differences in molluscs in response to OA across the HCS.[15] Chilean researchers have taken advantage of these differences to identify shellfish strains that show greater relative OA-tolerance in the species *Mytilus chilensis*, the most widely cultivated shellfish species in Chile, and the economically important carnivorous gastropod, *Concholepas concholepas*.[15] A complementary study identified the oceanographic and carbonate system variability in three bivalve aquaculture areas across the HCS, which may allow researchers to match organismal performance with optimal habitats.[16] In the case of these ecologically and economically important molluscs in Chile, climate services have played key roles in the identification of shellfish strains, and of the optimal habitats for their growth, that may allow for the cultivation of these economically and ecologically important species in a future, and likely more acidic, ocean. *In situ* data on OA and OD in the CCS and HCS were also reflected in the highly influential IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC), which is meant to provide the best available scientific knowledge to empower governments and communities to take action.[1] The SROCC Summary for Policymakers states that "increasing OA and oxygen loss are negatively impacting two of the four major upwelling systems: the California Current and Humboldt Current (high confidence)," a conclusion that was underpinned directly by *in situ* data, or indirectly through regional model studies that were forced by such data.[13]

Climate services in the context of the CCLME

The CCS and HCS provide examples of how climate services that are underpinned by rigorous *in situ* data on OA and OD can identify threats to economically important fisheries and aquaculture, inform adaptation efforts, and identify relatively OA-resistant shellfish species and optimal habitats for their aquaculture. Knowledge that ocean chemistry is unfavorable to the presence of an economically important species is valuable information to any government, donor, or resource user, irrespective of differences in governance, threats, or socioeconomic circumstances in the countries bordering EBUEs. Similarly, anticipatory, data-driven adaptation would be much more cost-effective than reactive adaptation in any setting. Belhabib et al.[4] have described factors that contribute to the low capacity of West African fisheries to adapt to climate change and described actions that could enhance their resiliency, including the generation of data that would elucidate the impact of climate change effects on fisheries. Among the adaption measures to consider in the CCLME is the development of shellfish aquaculture. Shellfish that are adapted to oceanographic conditions of the CCLME have been harvested in Senegal for at least 5,000 years.[17] Like the HCS, the CCLME has broad diversity of habitats and oceanographic influences, habitats which may reveal strains that are relatively resistant to OA and suitable for cultivation. Development of shellfish aquaculture in the CCLME could draw upon the wealth of experience in the CCS. But any path for adapting fisheries or aquaculture in the CCLME must be underpinned by climate services which are based upon rigorous, *in situ* data on OA, OD, and temperature.[1]

Writing about the climate change impacts, vulnerabilities and adaptations in East Central African fisheries, Kifani et al.[3] note the need to "build or further develop institutional research capacities (competence and research infrastructure) in marine and fisheries sciences and other scientific branches that produce relevant and impactful knowledge, services and tools responding to societal needs." In the CCLME, capacity building should result in the training of Ph.D.-level West African scientists with expertise in physical and biogeochemical oceanography, either through novel North-South or South-South partnerships among institutions of higher education or through the strengthening of existing international partnerships. Examples of existing partnerships include the French government's Research Institute for Sustainable Development, the German government's West African Science Service Centre on Climate Change and Adapted Land Use program, and the Norwegian government's NANSEN program. Locally trained scientists would be best suited to address context-specific adaptation measures, and to incorporate climate services into national policies and legislation.[1] Increased financial support for capacity building and instrumentation, which international donors are often reluctant to support, will be essential.

The data generated from *in situ* monitoring should be of "climate quality," i.e., suitable for international databases such as NOAA's National Centers for Environmental Information and the GOA-ON. Data of this quality would provide an accurate picture of climate change impacts on the CCLME, facilitate comparisons between those impacts and other regions on the planet, and allow policy makers and resource managers to make informed and defensible management decisions. *In situ* biogeochemical data would also provide the basis for forcing regional-scale model studies in the CCLME comparable to those carried out in the CCS[13] allowing scientists to better project future climates which would benefit resource managers and policy makers. On a regional scale, coastal African countries would benefit from a flagship program for monitoring climate change impacts on the oceans that would provide training opportunities for African scientists and promote regional and international cooperation, contributing to global networks such as GOA-ON. Internationally, the data from monitoring would enhance our understanding of climate change impacts on EBUEs, providing data that can be used to force model studies, drawn upon by the IPCC, and inform donor decisions. Wealthy nations rely upon the data from biogeochemical monitoring programs to develop models and policies-that provide guidance to industries and local stakeholders. The West African countries bordering the CCLME, and those of developing countries for whom ocean climate services could impact livelihoods, food security and development outcomes, deserve no less.

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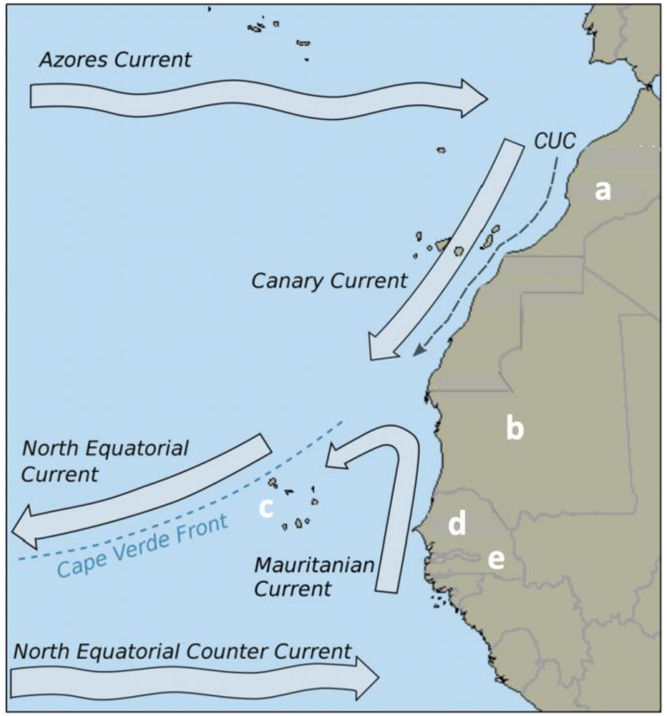
Figure 1. The CCLME and the importance of marine resources for the bordering countries.
(A) Map of the major currents of the CCLME (arrows) and examples of the importance of fisheries in the bordering countries. CUC, Canary Upwelling Current. (a) Fisheries constitute an economic sector of prime importance in Morocco (Morocco maintains a disputed jurisdiction over Western Sahara, which extends southward to approximately 21°N; https://www.cia.gov/the-world-factbook/countries/morocco/map). (b) The marine fisheries sector is one of the main pillars of the Mauritanian economy. (c) Fish constitute about 12% of total animal protein in Cape Verde. (d) Fisheries provide 75% of the animal protein for the Senegalese people and employ about one-fifth of the working population. (e) Fish is the cheapest source of animal protein in The Gambia and traditional processing methods are important for making it available to consumers, especially in rural areas.
(B) Table summarizing the importance of fisheries for each of the countries bordering the CCLME.

Data are from FAO Fishery and Aquaculture Country Profiles and World Bank Open Data (A, a–c and e) and from Belhabib et al.[5] (A, d). Adapted from Lovecchio et al.[6]

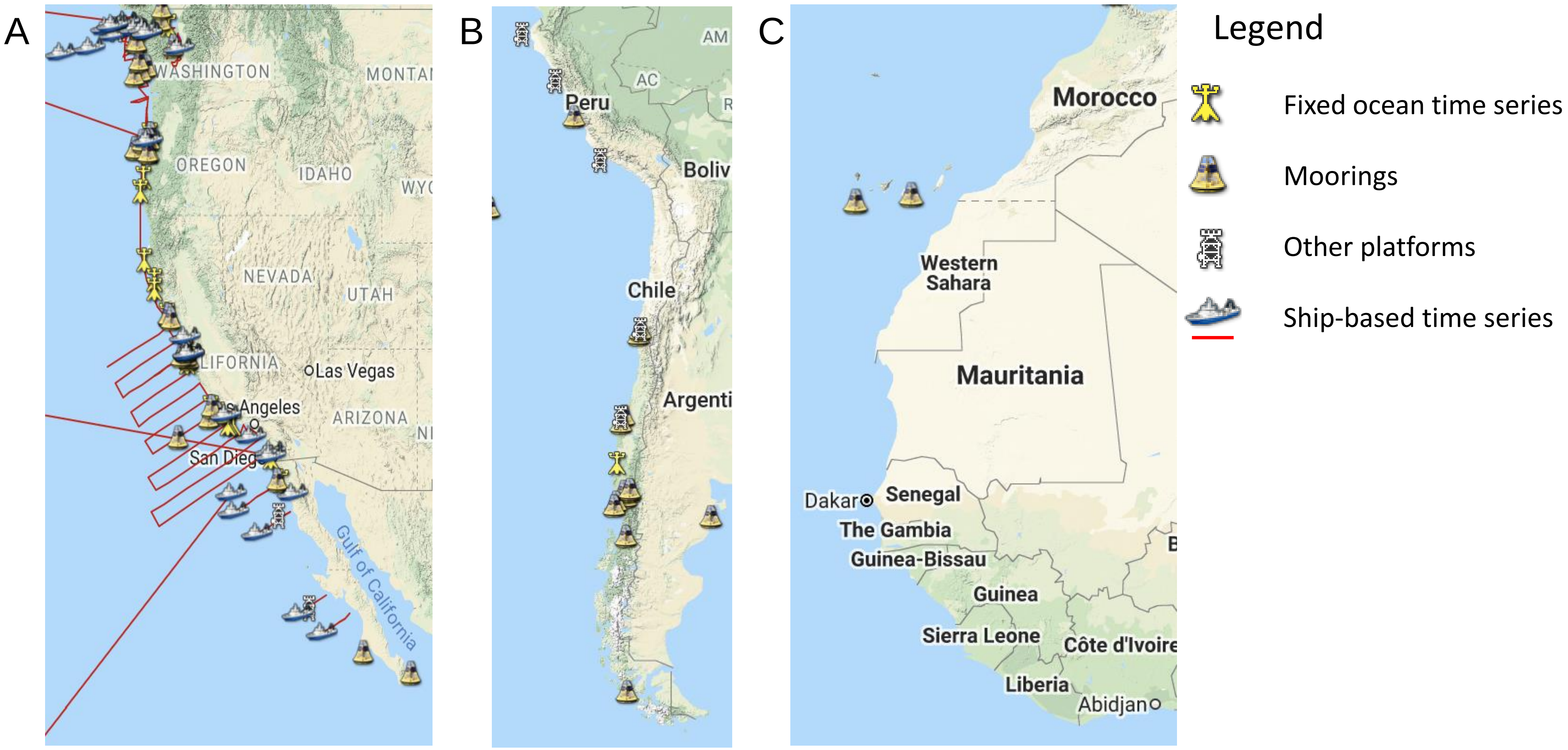
Figure 2. Comparison of the assets of the Global Ocean Acidification Observing Network and collaborators for monitoring parameters associated ocean acidification in EBUEs
(A) California Current System.
(B) Humboldt Current System.
(C) Canary Current Large Marine Ecosystem.
Source: https://portal.goa-on.org/Explorer.

A



B

	Population (millions)	GDP (billions, USD)	Revenue from fisheries (millions, USD)	%GDP fisheries	People employed in fisheries	Fisheries capture (tons/year)	Fish consumption (kg/year/person)
Morocco	36.9	112.9	2,200	2	111,464	1,400,000	20.3
Mauritania	4.7	7.8	828	10.6	180,400	967,706	10-20 (depending upon location)
Senegal	16.7	24.9	353	1.8	600,000[ii]	395,400	36[ii]
The Gambia	2.4	1.9	3.4	Not available.	3237	55,686	28.3
Guinea Bissau	1.97	1.4	53	3.7	1800	6,550	1.3
Cape Verde	0.56	1.7	37.6	3.7	6,283	26,580	11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Dakar
Senegal
The Gambia
Guinea-Bissau
Guinea
Sierra Leone
Côte d'Ivoire
Liberia
Abidjan
Legend
Fixed ocean time series
Moorings
Other platforms
Ship-based time series