environmental sciences proceedings

Collective understanding and sustainability of oysters, coastal climate systems and SDGs toward global futures†

Doe, S.S.P[1, 2]*, Walsh, P.P.[2] and Otto, I.M.[3,]

[1] Earth System Governance Project, Utrecht University, The Netherlands;
[2] UCD Centre for Sustainable Development Studies, School of Politics and International Relations, University College Dublin (UCD), Newman Building, Belfield, Dublin 4, Ireland;
[3] Social Complexity and System Transformation Research Group, Wegener Center for Climate and Global Change, University of Graz, Brandhofgasse 5, 8010 Graz, Austria;
* Correspondence: doesylvan@yahoo.com ; ORCID: https://orcid.org/0000-0002-9525-9757)
† Presented at the ICSD 2023: 11th International Conference on Sustainable Development, 18–20 Sep 2023.

Abstract: This study adopts Sustainability Inventory Analysis (SIA) to investigate socio-ecological evidence of how oysters indicate climate change, biodiversity and resilience in relation to the SDGs. The fieldwork was conducted at the Volta River Estuary (VRE) adjoining the Atlantic Ocean, giving global significance to this research. The SIA engages 60 respondents along the oyster value chain in southeastern Ghana. The respondents perceived oysters to sharply decline by 81.67%, indicative of dangerous climate impacts as cumulatively substantiated by 76% of 10 categorised attributes. The most harming sub-attribute is sea level rise (34%). The analysed data shows only 13% of the respondents has ever seen or heard information about the SDGs. The meaning of the 13% at SDG midpoint is that it provides clearer picture of SDG awareness enabling policymakers and development actors to collectively understand, decentralise and intensify public education on the finest global goals to quickly reach diverse audience at the grassroots. We therefore suggest tipping interventions, including sustainably financing climate action and SDG learning,

Keywords: Oysters, climate change, SDGs, socio-ecological systems, sustainability

1. Introduction

A powerful struggle to achieve global sustainability and climate neutral society culminated in endorsement of the Paris Agreement and the UN Sustainable Development Goals (SDGs) (Otto *et al*., 2020; Walsh, 2021; UN, 2015; Clémençon, 2021). To date, the 17 SDGs are the world's finest transitional roadmap that aims to collaboratively transform the World-Human-Earth System to put humanity on a resilient, greener and sustainable path towards economic prosperity, human security and healthiest planet (Sachs *et al*., 2023; Sachs *et al*., 2021; Pradhan *et al*., 2017; Walsh, 2021). The SDGs must succeed to help actualize human satisfaction, happiness, safety and good Anthropocene futures. But for these all-important global goals to materialise in the coast, oyster ecological improvement and sustainability actions must progress at a faster speed from now till 2030 and beyond.

The oysters are excellent low-carbon foods that provide huge eco-benefits, nutritional values and informally contribute over US$10 million annually to the local Ghanaian economy (Abreu et al., 2022; Doe, 2022; Torell *et al*., 2019). In the coastscapes of Ireland, India, South Africa, Germany, Australia, US, Canada and other countries, oysters are ecologically significant species supporting livelihoods and general human well-beings (Weissberger and Glibert, 2021; Pogoda, 2019). Sustaining the 'livelihoods depend on the long-term sustainability' (Berkes, 2007, p. 15189) of oyster ecosystem resources, which are vital for scalar-driving and advancing the 17 SDGs in the coastal regions. The pressing concern, however, is that oysters are fast-disappearing due to climate change, thereby putting the SDG vision at risk. Oysters are integral to a complex socio-ecological systems (SES) and, as such, demands a purposeful sustainability transformation towards delivering the SDG targets now and in the future. SES is defined

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

Copyright: © 2023 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

as an 'integrated system of ecosystems and human society with reciprocal feedback and interdependence' (Folke *et al*., 2010, p. 4).

Globally, oyster was studied by several scholars for varied scientific reasons (Fleury *et al*., 2020; Abreu *et al*., 2022), including salinity (Rybovich *et al*., 2016) but how oysters fit in the SDG framework has never been specifically attempted. The state of the current oyster ecology and the scientific information surrounding the interactions of oysters, climate and SDGs is lacking. The first step in this direction is to explore system dynamics of oysters and SDGs through the SES lenses. Such system knowledge is needed at this crucially transitional midpoint of the SDG stocktaking as it can help to understand and mobilise resources and peoples to manage, govern and implement inclusive policies to support sustainable production and consumption of oysters in favour of the SDGs.

The problem statement, research objective and research question

Oysters serve as a delicacy for many people. During the COVID-19 pandemics, pro-poor local population depends on oysters to survive strict imposition of lockdowns. Yet, climate change is altering oyster ecosystems leading to degraded habitats and biodiversity loss that are constraining SDG progress. In some coastal communities, the oysters have completely disappeared, extinct or migrated. Formulating decisions to rebuild sustainable oyster ecology through partnership and policy must be grounded on evidence-based information that is readily accessible (Cooke *et al*., 2017) to SDG decision-makers. Against this background, this research assesses socio-ecological evidence of the climate change impacts on oysters and its ecosystems to understand the connections and implications for the SDG framework. Additionally, we examine new tipping pathways for contributing to oyster ecological improvements to advance and sustain the SDG progress. Are there challenges constraining SDG progress at the socio-ecological level? Are people at the grassroots aware of the SDGs?

The scope and justification of the SDG study

While the scope of the study encourages simulation of oysters and all the 17 SDGs, the targeted SDG goals in this study are SDG #1, #2, #12, #13, #14, #15 and #17 (Figure 8). The study is premised on the concept of sustainability science (Kates, 2011) described here as 'a field of research that brings together scholarship, policy and practice, global and local perspectives...' (Haider *et al*., 2018, p. 192). The science of sustainability recognises biodiversity conservation as an essential strategy for managing environmental and climate risks (Mupepele *et al*., 2016; Berkes, 2007) to avert extinction of all kinds of species and, in the context of this study, oysters. The oysters are depleting and becoming a serious setback for the SDG vision and future. Surprisingly, new information to assist actors to understand and identify real needs, plan and implement innovative nature-based solutions and policies to sustainably protect or restore oysters are missing. No scientific data is precisely known about the extent oysters fit in the cross-scale SDG spaces in Ghana and the Global South. A baseline assessment that sparks new discourses around oysters, climate and biodiversity (Mupepele *et al*., 2016) and, perfectly, aligns with the Convention on Biological Diversity, Paris Agreement and the SDG#13 is indispensable.

2. Methodology

Study area and its significance

The research fieldwork was conducted in a shared VRE that covered 45-60 km2 of south-eastern Ghana. The VRE starts from the Lower Volta Bridge at Sogakope (South Tongu District) towards downstream near Ada-Foah (Ada East District) and Fuveme (Anloga District) where the Volta River and the Atlantic Ocean meet. The temperature in the coastal estuary alternates around 23-31^{0}C. The area lies within latitude 11.50N and 4.50S and longitude 3.50W and 1.30E (Republic of Ghana, 2020). The three districts are inhabited by 284,420 people (Ghana Statistical Service, 2021). For those aged above 12yrs in South Tongu District, access to mobile phone, internet and desktop/laptop computer was 39.4%, 2.7% and 2.7% respectively (Ghana Statistical Service, 2014).

Geographically, the Volta River spans six countries in the western coast of Africa, namely Ghana, Togo, Benin, Burkina Faso, Mali and Cote d'Ivoire. Thus, the river is servicing food, energy, water, transportation and livelihood needs of approximately 120 million people. On this basis, whatever climate and human-ecological changes that happen at the VRE are of regional and international interests.

Methods, tools and materials

Considering the interdisciplinary character of oyster-human relations and multidimensional nature of the SDGs, this study employs Sustainability Inventory Analysis (SIA) that is flexible and hybrid enabling conceptual modelling and integration of other scientifically suitable methods such as SWOT analysis to elicit accurate evidence from triple-bottom-line context. SIA integrates rapid action assessments comprising field visits, tele-engagements, observations, and interviews. It allows calibrating the 17 SDGs that often go with complex system interactions (Lim *et al*., 2018), and uniquely embraces sustainability assessment tools such as the Ecosystem Services and PRISM (Dickson *et al*., 2017) imperative for identifying evidence to enrich conservation decisions (Bilotta et al., 2014). In researching internet-based datasets, a modem, laptop for word processing, data auditing, analysis as well as documenting the final research report were employed. Digital camera aided capture of visible evidence of coastal ecological changes. We used SDGs factsheet to support open discussions during face-to-face interviews.

Data collection, sources and analysis

The fieldwork data was collected in the second half of year 2021. In all, 60 respondents were interviewed using open questions. The data collection focused on divers, oyster processors, traders, consumers and two government employees. Gathering the data consisted monitoring oyster habitats and estuary catchments. Oyster shell sizes were sorted and measured. This was followed-up with interviews at Azizanya, Sogakope, Big Ada, Ada-Foah, Agorta, Ada-Junction, Sokpoe and Dabala. Due to COVID-19 restriction, the face-to-face meetings were "rapid". Additionally, secondary data was retrieved from credible journals and online datasets using Google search. To understand the distribution of divers and communities, the study utilised MS Excel to code and analyse basic statistical data. Expert consultation was used to refine and validate the data.

Limitations

Some specific local features mentioned by respondents to buttress climate impacts or socio-ecological change indicators could not be incorporated in this study due to limited time and finance amidst tight COVID-19 restrictions. The research processes were also challenged by poor access to the internet, computing services and interrupted electricity that lowered the pace to organise research materials and to reach wider respondents.

3. Results

- *Basic socio-ecological characteristics*

  The findings of this research indicate that over 80% of the respondents were aged below 40 years and 60% of them were mobile, meaning that they temporally migrated (intercommunity migration) in order to pick oysters. Although women predominated the trading and processing of oysters by 75%, the men controlled diving spaces (99.5%). The newest respondent to dive for oysters had six months of experience while the oldest had retired from diving after 35 years. Only two respondents stated that they belonged to associations, which were not related to oysters, confirming 97% informality of the oyster value chain. Oysters in Big Ada were comparatively smaller in size than the same species in Sogakope. The largest oyster measured during this study was 9.3 cm in height and 11.5 cm in length/breadth.
- *Local society, awareness and SDGs*

  The analysed data demonstrates that awareness of the SDGs among actors along the oyster value chain was very low. Only eight out of the 60 respondents, representing

13%, had seen, received or heard some information about the SDGs. This result was based on the response to interview questions, including ‘have you seen or heard about the UN Sustainable Development Goals?’ The 13% were respondents who had basic formal education. The main sources from which the 13% of respondents heard the SDGs mentioned for the first time were (i) local FM Radio and TV, (ii) high college teacher, and (iii) one-time off workshop organised by GIZ. With an exception of a staff of a local government assembly and a former Ramsar Site Manager, the rest of the 13% failed to correctly pinpoint the SDG icons made available to them by the SDG Researcher. Also, the respondents could not give additional information or further explain the SDGs. The observation was that messages about the SDGs were not fairly disseminated to reach vulnerable groups at the grassroots and the ELICs.

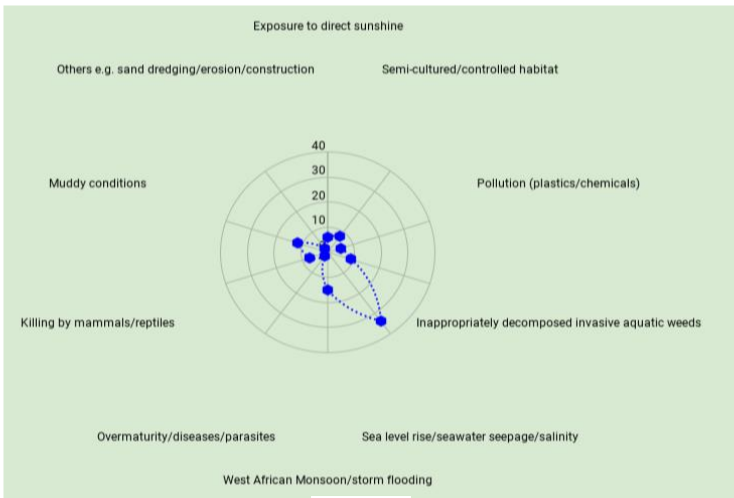
- *Human-ecological concerns and drivers of oyster population*

The physical damage to intertidal zones at Azizanya provides visible evidence of the extent climate change risks such as erosion or weathering after storm floods or tidal waves could displace or destroy coastal biodiversity (Figure 1a). Also, water-land-use activities such as agro-chemicals, sand dredging, microplastics, and liquid wastes emerging from domestic/industrial and tourism facilities often pollute river waters to terminate the life cycle of oysters and related species. At Azizanya, sea level rises push seawater (“saltwater”) to flow into the VRE. The resultant high salinity content of seawater entering the river water kills oysters.

The causes of oyster deaths and drivers of oyster population are varied but oyster mortality is inextricably connected to climate change. Generally, some scholars found the imbalance of both biotic and abiotic parameters such as species density, seawater, feed, sea heat, rainfall and wind to be responsible for oyster growth, survival or mortality (Fleury et al., 2020; Rybovich et al., 2016). In Figure 1b, more than five out of the 10 categorised attributes totalling an excess of 76% were directly caused by climate impacts, including invasive weeds. A rising sea level (34%) is the greatest harming sub-attribute in the VRE that undermines the vision of the SDGs

Figure 1a. Eroded estuary boundaries by tidal waves; (**1b**) Drivers of oyster population and mortality; Source: Doe, 2021.

(1a)



(1b)

4. Discussion

In evaluating to understand how the SDGs are challenged or have progressed at a transitional midpoint of implementation, it is reasonable to consider how the interactions of oysters, ecosystems and climate connect to human society. This study identifies interlocking challenges that must be urgently resolved through policy, innovation and technology to smooth transformational changes and transitional processes toward maximising the contribution of oysters to the SDG agenda (Figure 2). For example, we identified potential eco-conflict at this midpoint of implementing the SDGs. Eco-conflict occasionally occurs among divers as a result of their competition to spawn and own "oyster beds'' beneath the river. The competition is happening because diving spaces are squeezed or shifted giving rise to conflicts ("eco-conflicts") and ethnic tensions among divers in Sogakope and Big Ada. Such eco-conflicts has ruined societal relationships necessary for seeding local network capitals to promote mangrove restoration and best conservation practices. The problem of eco-conflicts could be solved by encouraging participatory monitoring of divers' movements and customising legal regulations to stop discriminatory attitudes within diving spaces. This approach should include nurturing healthy interrelationships around the SDG#17 as a pivotal goal to mobilise business-science-policy actors and allow imbedding of innovative peace-building mechanisms, strategies and technologies that "leave no one behind"

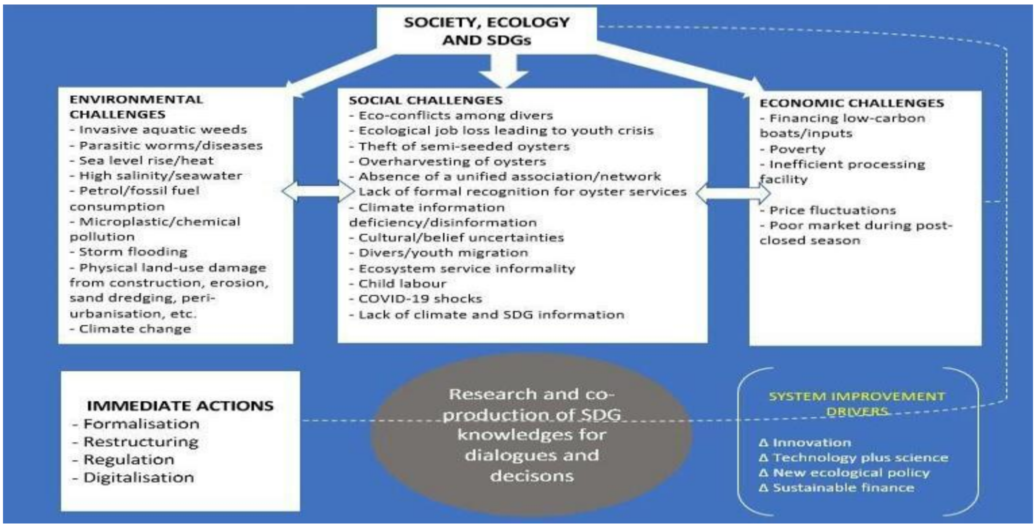


Figure 2: Navigating oyster SES and SDG future challenges. **Source**: Doe, 2021

In the 1970s, oysters were picked manually from the wild aquatic systems mostly by rural women. Absolutely no fossil fuel was used then to power fishing boats. Today, the storyline has considerably changed. Diving is merchandised and taken from the hands of the women. The motorised boats are expensive. The women are marginalised and squeezed from rive spaces for diving or harvesting oysters, creasing socio-ecological inequality (SDG#10) that deserve policy attention. Even though the gender role of women at local markets remains significant (75%), breakthroughs to enable women have equal voices and access to diving spaces is advocated here.

Environmentally, over 90% of the fishing boats are presently powered by "outboard motors" and technically operated by men using premix fuel responsible for emitting carbon dioxide (CO_2) into the atmosphere. An increase in fossil-fuel powered boats is ecologically unwise. In the case of Ghana, this practice will not take the SDG progress a step further since it will increase existing emissions of 42.2 $MtCO_2e$ (Republic of Ghana, 2020). Exponentially increased CO_2 emissions will quicken microclimate heating and, eventually, trigger recurrent seawater spillover to kill and collapse the oyster stock. This is a red-alert issue that favours none of the 17 SDGs, especially SDG#13, SDG#14 and SDG#15, SDG#1 and SDG#2. The suggestion here is to strategically decarbonise oyster value chain by adopting sustainable nature-based solutions (Doe, 2022), including the deployment of renewable energy technologies as part of the "Sustainable Energy for All" linked to SDG#7. This should comprise introducing carbon-neutral boats.

Additionally, this study finds that oyster population has drastically reduced (81.67%) due to climate change. Narrative reveals that the existing oysters were not big in size presently as compared to the 1970s. The oyster shells sampled during this study showed that oyster sizes proportionally decreased toward the downstream. The shrinking shell size correlates or is linked to frequent sea level rises. In addition, the divers' view that extreme climate events (e.g. West African Monsoon) tended to abnormally dilute salinity content of blackish water in the estuary to hinder oyster growth is not different from hydrodynamics observed by Rybovich *et al*. (2016). Also, a controlled habitat (Figure 1b) contributes to oyster deaths, which supports the view that oysters in farmed condition could experience mortality (Fleury *et al*., 2020). All these are setbacks holding back the space at which oyster ecosystems can contribute to SDG progress.

Climate change tends to disrupt large-scale ecosystem resilience (Chambers *et. al*., 2019) in the same way it is altering oyster biosystems. In the VRE, the relevance of oysters in sustaining human-ecosystem resilience cannot be overemphasised socio-ecologically. The benefit of oysters for divers and women ascertain its importance in rebuilding societal resilience and adaptation to cope with climate shocks. For instance, in 2020, nearly 1,500 vulnerable girls, women and youth suffered from politically strict COVID-19 lockdowns. They had no choice than to dive, process or retail oysters to escape joblessness and starvation. Thus, oysters empowered the youth to adapt to climate and COVID-19 crises.

There is ample evidence regarding the extent oysters indicate climate change and the extent climate influences oyster population, habitat and mortality is substantiated in Figure 1b. This study finds seawater flows linked to the Atlantic Ocean circulation leading to sea level rises and, subsequently, tidal waves as the biggest cause of massive oyster deaths. One important data missing in scientific literature, which this study discovers, is that the current oyster mortality is only measured by divers in the light of dead oysters washed offshore (Doe, 2021; Doe, 2022). The casualty level of premature ("young") oysters at the microscopic larvae or egg stage is horrifying, which scientists must calculate to illuminate interlinked climate and SDG discourses.

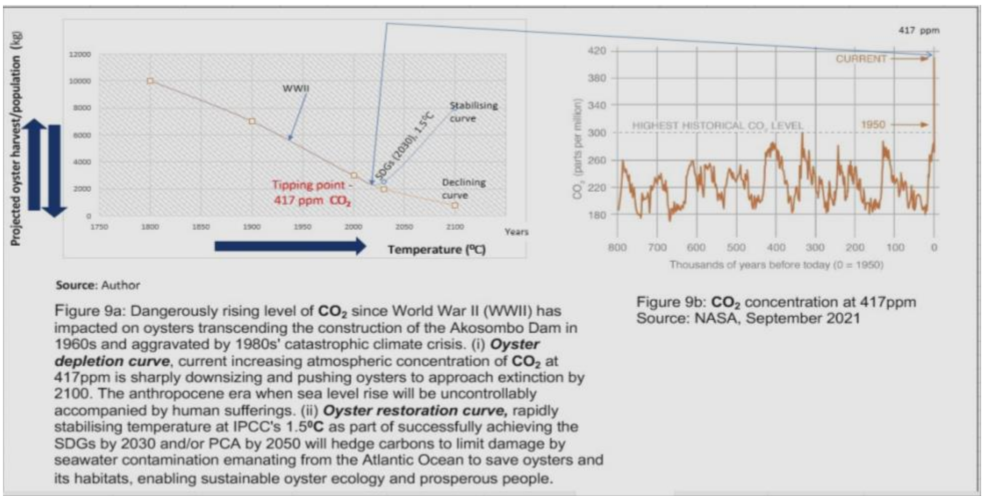


Figure 3: Oyster depletion vs restoration curve. **Source**: **Source**: (9a) Doe, 2021; (9b) NASA, 2021[1]

For a tiny section of the respondents, more oysters exist presently than in the past (11.67%). Yet, this research contradicts such a climate denial and agrees with the evidence from the Florida Bay by Weissberger and Glibert (2021). This study contests that 4,000 kg of harvested oysters per a day or week perceived to justify abundance presently was picked after technically-assisted navigation of a distance of nearly 50km and diving to 10m deep. Without even burning fossil-fuel, the same 4,000 kg of oysters could have been hand-picked from 0.25km and 1.41m deep of the river if the oyster population was not dwindled. Oysters had depleted at an alarming ratio of 1:3 in the last 6 decades, demanding proactive climate solutions to stop a glaring oyster extinction catastrophe by 2100 (Figure 3).

The commitment of government and development actors to limit global warming to 1.5^{0}C through the SDGs or Paris Agreement by 2030 or 2050 respectively must be reactivated globally since sea level rise is not only local but also global in character. According to IPCC, from 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m' (IPCC, 2013, p. 11). Even during the period of this study, climate-induced sea level rise occurred in Azizanya and Fuveme in November 2021, which was widely published in the international media such as the BBC and France24 (Doe, 2023; BBC, 2021; France24, 2021). The tidal waves exposed 4,000 people to sustainability crises such as hunger, poverty and insecurity in Anlo communities within the VRE. The repeated climate impacts have left the resilience of the larger coastal ecosystem very fragile. In the coast, the resilient capacity of oyster ecosystem is often manipulated by environmentally diverse parameters, including pH and salinity.

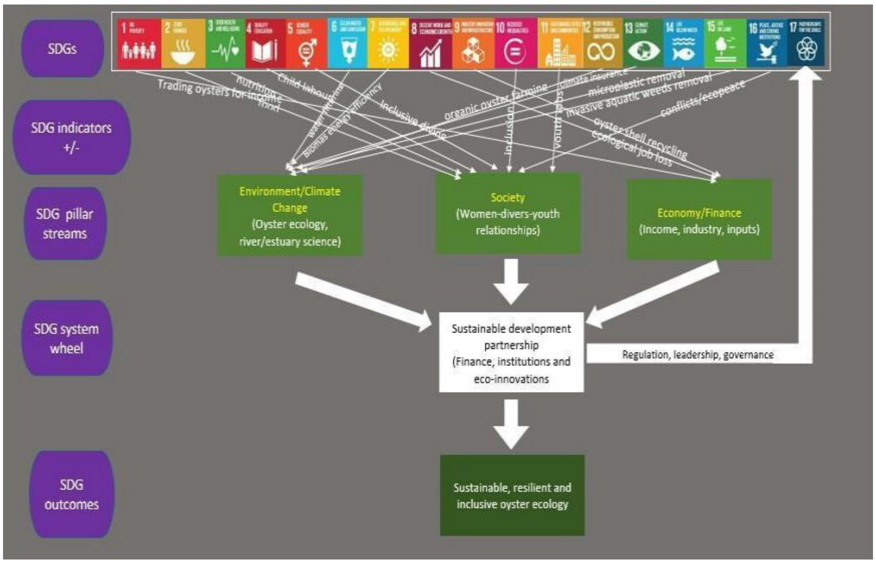
At the SDG midpoint, it is important to realise that if climate inaction by political leaders who controlled governance of large coastal ecosystem resources persists, then child labourers and divers' behaviour in die search for bigger oysters, which often spark eco-conflicts, may aggravate.

5. Conclusion

At a midpoint of critically reflecting on the feasible ways to minimise challenges to accelerate SDG progress, the result of this study has become increasingly imperative for collective understanding of climate issues pertaining to the coastal environments, including VRE. For example, the result clearly demonstrates that 13% of the respondents ever hearing a message about the SDGs is scientifically a progress, but such a progress is not practically encouraging if the entire SDGs is to be achieved by 2030. The main factors responsible for the poor SDG coverage were identified as: (a) inadequate access to SDG information in local languages, and (b) insufficient investment in civic education on the SDGs by responsible government entities. Also, the study finds that the challenges constraining oyster impacts on SDGs are intertwined, which re-echoes the need for multiscalar cooperation and public-private partnership for the SDGs. The Figure 4 illustrates non-linear SDG and oyster interactions to buttress the idea that collaboration among institutions and communities is strongly needed to appropriately realign oyster ecosystem services toward the 17 SDG goals and 169 targets.

The strong interconnectedness of the SDGs mean that financially investing in one indicator or action will not be enough to remarkably solve climate or socio-ecological challenges to generate optimal eco-benefits in favour of the SDGs. The underlying rationale is that climate heating has negatively damaged coastal ecosystem resources, including oysters, to limit speed of the SDG progress. Clémençon (2021) alerts that financing, for example, is not a panacea to sustainably conserve biodiversity, but elsewhere Lim *et al*. (2018) reiterates finance as an ideal leveraging ingredient to effectively implement the SDGs, including conservation targeting SDG#13, SDG#14 and SDG#15. In this sense, triangulating the oyster ecology and SDGs reproduces a gamut of overlapping trade-offs and synergies (Pradhan *et al*., 2017) and dynamics that must be concurrently intervened according to sustainability principles (Berkes, 2007) before the SDG progress can be fast-tracked in its last phase.

Figure 4: SDG interactions in relation to oyster ecosystems. **Source**: Doe, 2021



Based on the analysed data, this study evidently states that oyster population is significantly downsized, unstable and prone to climate change. The rate of coastal erosions, oyster deaths and biodiversity losses due to combined effects of storm flooding and ocean effects is alarmingly widening. This result is consistent with marine species extinction and 33% of coral reefs decline warned by scientists (Rockström *et al*., 2009) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Clémençon, 2021). The recurrent destruction of oyster habitats and human-environments by unpredictable tidal waves poses the greatest threat to a greener and healthier futures at the coast promised by the SDGs. This threat demands a collective understanding, stewardship and attractive bottom-up partnership that give equal voices and rights to all actors, including women, to participate in climate governance and SDG actions. In this sense, five socio-ecological tipping elements and interventions capable of forcefully transforming SES to enable the SDGs and other common sustainability goals to succeed are summarised in Table 1. Ideally, the tipping interventions should be simultaneously implemented alongside the six major transformations needed to realise the SDGs (Sachs *et al*., 2019) and the six social tipping interventions suggested to stabilise the Earth's climate by 2050 (Otto *et al*., 2020). In sum, how science-based ecological policy, cooperation and partnership can translate, achieve and sustain real plans and actions beyond the SDGs deserve transnational scientific research in the nearest future.

Table 1: socio-ecological tipping elements

Tipping elements	Tipping interventions
Sustainable finance	Investing in low-carbon emission boats and safety services Investing in efficient certifying, processing and packaging Investing in climate action, SDG education and microinsurance
Partnership	Promoting transnational cooperation and SDG partnerships Co-researching innovation to inform interdisciplinary solutions Advanced skills training in ecological and sustainability sciences
Ecological policy and technology	Deploying renewable energy to decarbonise oyster economy Digitalising, greening and professionalising oyster value chain Facilitating gender breakthroughs in accessing diving spaces

Entrepreneurship and eco-innovation	Promoting participatory socio-ecological monitoring Creating oyster reserve as an alternative to closed season Enhancing oyster product efficiency, circularity and sustainability
Traditional ecological knowledge and leadership	Networking divers, women and youth for SDG learning and exercising stewardship Decentralising climate and SDG information through local authorities Streamlining community level civil societies, indigenous and youth groups to re-localise SDGs

Source: Doe, 2021

Author Contributions: "Conceptualization, Doe, S.S.P.; methodology, Doe, S.S.P.; software, Doe, S.S.P.; validation, Doe, S.S.P., Otto M.I. and Walsh P.P.; formal analysis, Doe, S.S.P.; investigation, Doe, S.S.P.; resources, Doe, S.S.P.; data curation, Doe, S.S.P.; writing—original draft preparation, Doe, S.S.P.; writing—review and editing, Doe, S.S.P., Otto M.I. and Walsh P.P.; visualization, Doe, S.S.P.; supervision, Otto M.I. and Walsh P.P.; project administration, Doe, S.S.P. All authors have read and agreed to the published version of the manuscript."

Funding: This research received no external funding.

Informed Consent Statement: Consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable

Acknowledgments: The warm reception from the respondents during the research are honestly appreciated. The organisers and moderators of the 2021, 2022 and 2023 International Conference on Sustainable Development (ICSD) who consecutively accepted and embraced the abstracts and papers of the Lead Author are not left out. The impressive certificate from the MDP Global and the UN SDSN at the ICSD 2021 is ever-cherished. My sister Fafali A. Doe-Glover has been an outstanding meristemer throughout. A very deep thank you to everyone who helped (in)directly.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Abreu, A., Bentil, H., Okronipa, H., Fiorella, K., Vadiveloo, M., Gomez-Chiarri, M., Whewell, A., Adu-Afarwuah, S. and Oaks, B. 2022. Association between oyster consumption and hemoglobin concentrations among Ghanaian women. *Current Developments in Nutrition* 6, 1, 543. https://doi.org/10.1093/cdn/nzac060.001.
2. BBC (2021) Can Ghana protect its coasts from tidal waves? https://www.bbc.co.uk/programmes/p0b4ngg4 [Accessed on 06.06.2023].
3. Berkes, F. (2007) 'Community-based conservation in a globalised world', *PNAS* 104(39), pp. 15188 -15193.
4. Bilotta, G.S., Milner, A.M. and Boyd, I.L. (2014) 'Quality assessment tools for evidence from environmental science', *Environmental Evidence* 3(14). https://doi.org/10.1186/2047-2382-3-14.
5. Chambers, J.C., Allen, C.R. and Cushman, S.A. (2019) 'Operationalising ecological resilience concepts for managing species and ecosystems at risk', *Frontiers in Ecology and Evolution* 12. https://doi.org/10.3389/fevo.2019.00241.
6. Clémençon, R. (2021) 'Is sustainable development bad for global biodiversity conservation?' *Global Sustainability* 4, E16. doi:10.1017/sus.2021.14.
7. Cooke, S.J., Birnie-Gauvin, K., Lennox, R.J., Taylor, J.J., Rytwinski, T., Rummer, J.L., Franklin, C.E., Bennett, J.R. and Haddaway, N.R. (2017) 'How experimental biology and ecology can support evidence-based decision-making in conservation: avoiding pitfalls and enabling application', *Conservation Physiology* 5(1):cox043; doi:10.1093/conphys/cox043.
8. Dickson, I. M., Butchart, S. H. M., Dauncey, V., Hughes, J., Jefferson, R., Merriman, J. C., Munroe, R., Pearce-Higgins, J. P., Stephenson, P. J., Sutherland, W. J., Thomas, D. H. L. and Trevelyan, R. Q. (2017) *PRISM – Toolkit for evaluating the outcomes and impacts of small/medium-sized conservation projects*. Version 1. Available from www.conservationevaluation.org.
9. Doe, S.S.P. 2022. Connecting innovative eco-entrepreneurship model and sustainable nature-based solutions to advance climate action, biodiversity and SDGs. *Environmental Sciences Proceedings* 15, 53. https://doi.org/10.3390/environsciproc2022015053.
10. Doe, S.S.P. (2008). Fire management policy and environmental NGO movement: Critical contemporary perspectives, indicators and prospects in savannas, Ghana. *GeoJournal* 71(2/3), 159–170.
11. Fleury, E., Barbier, P., Petton, B., Normand, J., Thomas, Y., PouRVEau, S., Daigle, G. and Pernet, F. (2020) 'Latitudinal drivers of oyster mortality: deciphering host, pathogen and environmental risk factors', *Scientific Reports* 10, 7264 (2020). https://doi.org/10.1038/s41598-020-64086-1.

12. Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T. and Rockström, J. (2010) 'Resilience thinking: integrating resilience, adaptability and transformability', *Ecology and Society* 15(4), 20. [online] URL: http:// www.ecologyandsociety.org/vol15/iss4/art20/.
13. France24 (2021) Almost 4,000 people displaced by tidal surge in Ghana. https://www.france24.com/en/live-news/20211110-almost-4-000-people-displaced-by-tidal-surge-in-ghana [Accessed on 06.06.2023].
14. Ghana Statistical Service, (2014) *2010 population and housing census*. South Tongu District Analytical Report, Accra.
15. Ghana Statistical Service, 2021. The Ghana 2021 population and housing census. General Report Volume 3A, Population of Regions and Districts, Accra. https://statsghana.gov.gh/gssmain/fileUpload/pressrelease/2021%20PHC%20General%20Report%20Vol%203A_Population%20of%20Regions%20and%20Districts_181121.pdf [Accessed on 12.07.2023]
16. Haider, J.L., Hentati-Sundberg, J., Giusti, M., Goodness, J., Hamann, M., Masterson, V.A., Meacham, M., Merrie, A., Ospina, D., Schill, C. and Sinare, H. (2018) 'The undisciplinary journey: early-career perspectives in sustainability science', *Sustainability Science* 13, pp. 191-204.
17. IPCC. (2013) *Summary for policymakers. In: climate change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. (eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
18. Kates, R. W. (2011) 'What kind of a science is sustainability science?' *PNAS* 108(49), pp. 19449-19450.
19. Lim, M. M. L., Jørgensen, P.S. and Wyborn, C. A. (2018) 'Reframing the sustainable development goals to achieve sustainable development in the Anthropocene—a systems approach', *Ecology and Society* 23(3), 22.
20. Mupepele, A-C., Walsh, J.C., Sutherland, W.J. and Dormann, C.F. (2016) 'An evidence assessment tool for ecosystem services and conservation studies', *Ecological Applications* 26(5), pp. 1295-1301.
21. Otto, I.M., Donges, J.F, Cremades, R., Bhowmik, A., Lucht, W., Rockström, J., Allerberger, F., Doe, S. S. P., Hewitt, R., Lenferna, A., McCaffrey, M., Moran, N., Vuuren, D. P. and Schellnhuber, H.J. (2020) 'Social tipping dynamics for stabilizing Earth's climate by 2050', *PNAS* 117(5), pp. 2354-2365.
22. Otto, M.I., Reckkien, D., Rayer, C.P., Marcus, R., Masson, V.L., Jones L., Norton, A. and Serdeczny, O. (2017) 'Social vulnerability to climate change: a review of concepts and evidence', *Regional Environmental Change* 17(6), pp. 1651-1662.
23. Pogoda, B. (2019) 'Current status of European oyster decline and restoration in Germany', *Humanities* 8(9), doi:10.3390/h8010009.
24. Pradhan, P., Costa, L., Rybski, D., Lucht, W., and Kropp, J.P. (2017) 'A systematic study of sustainable development goal (SDG) interactions', *Earth's Future* 5(11), pp. 1169-1179.
25. Republic of Ghana, (2020) *Ghana's fourth national communication to the United Nations Framework Convention on Climate Change*. National Climate Change Report May 2020, EPA, Accra.
26. Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S. el al. (2009) 'A safe operating space for humanity', *Nature* 461, pp. 472-475.
27. Rybovich, M., La Peyre, M.K., Hall, S.G. and La Peyre, J.F. (2016) 'Increased temperatures combined with lowered salinities differentially impact oyster size class growth and mortality', *Journal of Shellfish Research* 35(1), pp. 101-113.
28. Sachs, J.D., Lafortune, G., Fuller, G. and Drumm, E. (2023) *Implementing the SDG Stimulus. Sustainable Development Report 2023*. Paris: SDSN, Dublin: Dublin University Press. 10.25546/102924.
29. Sachs, J., Kroll, C., Lafortune, G., Fuller, G. and Woelm, F. (2021) *The decade of action for the sustainable development goals: sustainable development report 2021*. Cambridge: Cambridge University Press.
30. Sachs, J. D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N. and Rockström, J. (2019) 'Six transformations to achieve the sustainable development goals', *Nature Sustainability* 2(9), pp. 805-814.
31. Torell, E., Bilecki, D., Owusu, A., Crawford, B., Beran, K., and Kent, K. (2019) Assessing the impacts of gender integration in Ghana's fisheries sector, Coastal Management, 47:6, 507-526, DOI: 10.1080/08920753.2019.1669098
32. UN. (2015) *Transforming our world: the 2030 agenda for sustainable development*. Resolution A/RES/70/1, adopted by the General Assembly on 25 September 20, 2015.
33. Walsh, P.P. (2021) *The political economy of sustainable development.* The economy of Ireland: policy making in a global context, p.136.
34. Weissberger, E. J. and Glibert, P. M. (2021) 'Diet of the eastern oyster, *Crassostrea virginica*, growing in a eutrophic tributary of Chesapeake Bay, Maryland, USA', Aquaculture Reports 20(2021) 100655. https://doi.org/10.1016/j.aqrep.2021.100655.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.