KELP AS A NATURAL CLIMATE SOLUTION

Highlighting Kelp Adaptation and Mitigation Opportunities and Gaps

CONSERVATION SOUTH AFRICA
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Climate change is a challenge that threatens sustainable development and ecological security globally (Yin et al., 2023). Greenhouse gas emissions (carbon dioxide [CO_2], methane [CH_4] and nitrous oxide [N_2O]) from fossil fuels, deforestation, unsustainable farming methods and other anthropogenic activities contribute to the effects of climate change (Evseeva et al., 2021). Climate changes can lead to various environmental impacts globally, such as sea-level rise, changes in weather events (e.g. flooding, droughts, ocean acidification, heat waves) and changes in biodiversity/extinction episodes (Evseeva et al., 2021). According to the National Oceanic and Atmospheric Administration (NOAA) Annual Climate Report of 2023, the average rate of land and oceanic temperature combined has increased by 0.06°C per decade since 1850. The Intergovernmental Panel on Climate Change (IPCC) has also noted that greenhouse house gas emissions via human activities have caused increases in global surface temperatures to 1.1°C (IPCC, 2023). To keep the global surface temperatures below 2°C, there needs to be a reduction in emissions and the removal of GHGs from the atmosphere (Waring et al., 2023). Finding various strategies to adapt to as well as mitigate (Figure 1) the impacts of climate change is important for the effective management and conservation of our ecosystems (Patel et al., 2024). Adaptation strategies refer to the actions that can contribute to reducing the vulnerability and enhancing the adaptive capacity of ecosystems and people to climate change, whereas mitigation strategies prevent or decrease the amount of greenhouse gas (GHG) emissions emitted into the atmosphere to reduce the impacts of climate change.

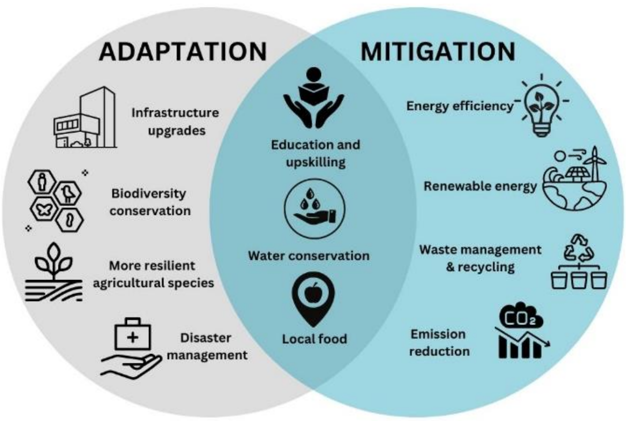

Figure 1: Adaptation and mitigation strategies for reducing the effects of climate change.

South Africa's Commitment to Oceans and Climate Change

The United Nations (UN) Convention on Biological Diversity (CBD) developed the Kunming-Montreal Global Biodiversity Framework, which has been adopted by over 200 countries worldwide to address the biodiversity crisis and the overall effects of climate change (Gurney et al., 2023). South Africa is committed to achieving Target 3 of this framework, which aims to conserve 30% of Earth's marine and terrestrial areas by 2030 (30x30 target) (Eckert et al., 2023; Gurney et al., 2023). By applying the 'White Paper on Conservation and Sustainable Use of South Africa's Biodiversity' policy, South Africa is also committed to conserving the country's rich biodiversity and ecological structure that supports ecosystem functioning for the livelihoods and well-being of people and nature. South Africa has the third highest level of marine species endemism in the world and homes over 900 species (Amosu et al., 2013). Like many coastal regions, South Africa depends on ocean resources to support its economic development (Loureiro et al., 2022). South Africa aims to achieve an estimated national gross domestic product (GDP) contribution of up to ZAR 177 billion and provide between 800 000 to one million jobs by 2033 (Vrey, 2019; DFFE, 2020; Loureiro et al., 2022).

The sustainable use of South Africa's oceans and coasts has the potential increase GDP by approximately $9 billion. South Africa's coastline spans almost 3000 km and an Exclusive Economic Zone (EEZ) that ranges nearly 1.5 million square kilometres, to promote ocean economic expansion that drives economic development and food security as well as contributes to the overall National Development Plan (NDP) (Vrey, 2019). In 2014, the South African government developed an initiative called Operation Phakisa which aims to unlock the socio-economic potential of the country's seascapes by implementing policies and programmes more efficiently and effectively to generate employment as well as alleviate poverty and social inequality (Findlay and Bohler-Muller, 2018; Vrey, 2019; Loureiro et al., 2022). By 2019, through the Operation Phakisa initiatives, the government unlocked investments of almost ZAR 30 billion and over 7000 jobs were created in the ocean economy (SAIMI, 2021). This initiative strategically prioritises an environmentally sustainable, adaptable, low-carbon economy and society (Loureiro et al., 2022).

Blue carbon ecosystems in South Africa have been estimated to cover a total area of ~19 800 ha, for mangroves (2 087 ha), salt marshes (14 713 ha) and macrophytes (3 039 ha). The IPCC recognises blue carbon ecosystems for their climate mitigation value, these ecosystems meet the requirements for actionable climate mitigation policies and can be included in international climate action plans. Countries that have accepted the Paris Agreement compile the Nationally Determined Contributions (NDCs), which describe their efforts to address mitigation and adaptation of climate change. The NDCs outline the actions to be taken by a country to meet the voluntary commitments to reducing GHG emissions or increase rates of carbon sequestration. South Africa does not specifically include blue carbon ecosystems as part of mitigation or adaptation strategies in their NDC, however, coastal wetlands are included in the adaptation section of the NDCs. There is a focus on conservation and management, protection and restoration of these ecosystems in the NDC. Furthermore, international and national commitments have been made by South Africa towards GHG mitigation and a revised NDC target of 398–510 $MtCO_2e$ for 2025 and 350–420 $MtCO_2e$ for 2030 has been submitted. As part of the visionary statement of the country's long-term strategy, South Africa had stated its intention to commit to a net zero CO_2 target by 2050 (DFFE, 2021).

What is a Natural Climate Solution?

In 2017, a Natural Climate Solution (NCS) concept was developed by researchers and conservation practitioners to assist in adapting existing knowledge to climate change action plans (Ellis et al., 2023). Natural climate solutions are initiatives aiming to protect, restore and improve the management of our environment (Figure 2) (Schulte et al., 2022; Ellis et al., 2023). This concept also addresses sustainable development goals (SDGs) and encourages the empowerment of local communities (Duarte et al., 2021; Howard et al., 2023; Waring et al., 2023). Encouraging the local communities to engage with the NCS initiatives not only contributes to human capacity development but can also enhance their environmental outcomes (Waring et al., 2023).

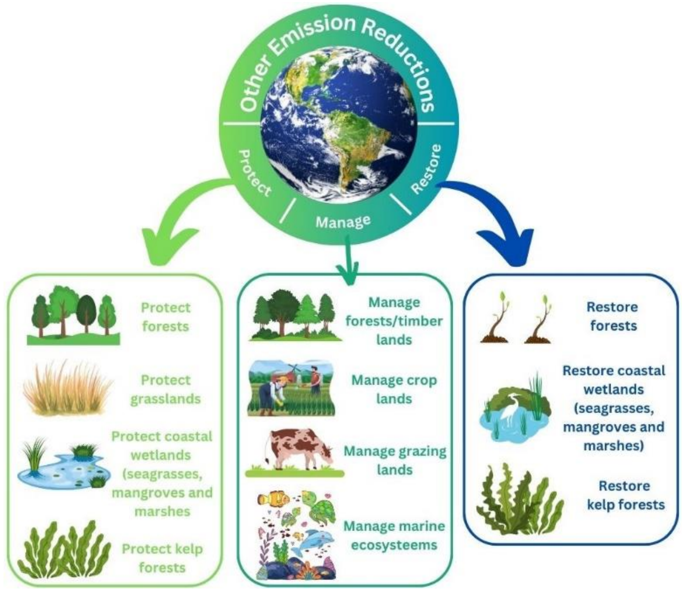

Figure 2: Natural Climate Solutions to assist in reducing the impacts of climate change.

Kelp as a Natural Climate Solution for Adaptation

Macroalgae, also known as seaweed, form the world's largest and most productive coastal ecosystems (Duarte et al., 2020) and subsequently contribute significantly to oceanic productivity (Howard et al., 2023). Kelp are large brown algae that usually form large forests in the ocean and provide various ecosystem services and benefits to humanity and nature (Rothman, 2015; Duarte, 2017). Kelp forests also support numerous ecological, social and economic benefits (Figure 3), including commercial fisheries, carbon storage and flux, mariculture, job creation, biodiversity conservation and shoreline protection (Blamey and Bolton, 2017).

Figure 3: Kelp provides many ecological, social, and economic benefits to ecosystems.

Biodiversity Benefits of Kelp

Kelp provides various biodiversity benefits that affect the overall species abundance, richness, biomass and functional diversity (e.g. ecological function and behavioural traits) of ecosystems (Smale et al., 2013; Steneck and Johnson, 2014; Forbes et al., 2022). Kelp also creates complex ecosystems by providing shelter, attachment sites, nursery sites, protection and nutrition to many organisms such as invertebrates, fish, mammals and seabirds (Anderson et al., 2006; Forbes et al., 2022). Kelp subsequently provides many direct and indirect benefits for humans through sustainable kelp harvesting (providing job opportunities), commercial and recreational fishing, and tourism activities (Blamey and Bolton, 2017; Forbes et al., 2022).

Figure 4: The De Winton's Golden Mole is an example of fauna that benefit of kelp.

Kelp Restoration

Macroalgae restoration initiatives are fewer than other coastal ecosystems (e.g. mangroves, seagrass meadows, oyster reefs) (Duarte et al., 2020; Eger et al., 2020; Morris et al., 2020). However, some of the restoration initiatives conducted thus far cannot match the scale of degradation or loss that occurs (Morris et al., 2020). Restoration efforts of macroalgal ecosystems have only gained momentum since the beginning of the 21st century (Duarte et al., 2020).

There are two main techniques used for kelp restoration:

1) Seeding - involves cultivating or spreading kelp seeds or gametophytes in the ocean. This method is beneficial because it requires fewer resources and can be grown in large quantities.

2) Transplanting - the introduction of mature kelp into the ocean. This approach is advantageous because kelp at older life stages is more resistant to stressors resulting in higher survival rates.

The primary reason for large-scale kelp forest restoration efforts is due to the high economic value associated with kelp-derived products and the fisheries industries that they support (Blamey and Bolton, 2017) and creates the opportunity potentially for carbon storage benefits.

Socio-Economic Benefits of Kelp

Kelp provides several socio-economic benefits to the local communities and the commercial market (Blamey and Bolton, 2017). The major social benefits that kelp farming has on local communities is creating various sustainable job opportunities and the inclusion of women in the workforce (social equality) (Sultana et al., 2023). Kelp is a commercially important seaweed with various applications in food, nutritional supplements, cosmetics, and agriculture (Morais et al., 2020; Zhang et al., 2022; Sultana et al., 2023). Kelp is abundant in minerals, vitamins and proteins, making it a highly nutritional food source (Morais et al., 2020; Zhang et al., 2022; Sultana et al., 2023). Seaweed aquaculture provides renewable and nutrient-rich food options that require minimal land, water, and fertilizer inputs, making it a sustainable food source (Sultana et al., 2023). It has been used to produce high value liquid fertilizers, used for plants and as abalone feed (dried pellets) (Msuya et al. 2022) and has uses for the pharmaceutical industry and biodegradable plastic production (Anderson et al., 2003; Troell et al., 2006; Blamey and Bolton, 2017; Sultana et al., 2023;).

Certain seaweeds (e.g. ground dried kelp) have also been used in livestock feed with potential benefits of reducing methane emissions (Kinely et al., 2020; Morais et al., 2020). One of the most harmful impacts to the ocean is plastic pollution which is particularly evident in ports and bays. Green production methods are more viable and sustainable in creating biodegradable plastics (Bioplastics). Seaweeds can form films that are either directly from the plant or the plant-derivatives (agar, carrageenan and alginate) which can be used in the development of bioplastics (Lim et al., 2021), however, further research on this needs to be conducted.

Kelp as a Natural Climate Solution for Mitigation and Blue Carbon

Recent studies have shown that NCS can potentially stabilize our climate by reducing global GHG emissions by one-third (Griscom et al., 2017) and storing carbon efficiently (Ellis et al., 2023). Carbon dioxide that is absorbed and stored by the ocean is referred to as 'blue carbon' (Macreadie et al., 2019). Coastal blue carbon is CO_2 that is mostly sequestrated and dissolved directly into the ocean and smaller amounts are stored in underwater sediments, vegetation and the soils of mangroves as well as salt marshes and seagrasses (Bertram et al., 2021; Pessarrodona et al., 2023). **Blue carbon ecosystems have the potential to store two to five times more carbon in their soils per unit area than terrestrial ecosystems** (Donato et al., 2011; Macreadie et al., 2021). Therefore, loss and degradation (e.g. deforestation, dredging, eutrophication) of coastal blue carbon ecosystems contribute substantially to the high amount of carbon dioxide emitted into the Earth's atmosphere (Pendleton et al., 2012; Adams et al., 2019; Hilmi et al., 2021). Blue carbon ecosystems play vital roles in the natural carbon cycle, therefore, it is important to include adaptation strategies to protect and restore these ecosystems as they have many other benefits for biodiversity conservation, water quality, storm surge protection and the livelihoods of local communities (Adams et al., 2019; Howard et al., 2023).

Blue carbon pathways assist in distinguishing the different ecosystems (Figure 5) and their potential to sequester and store carbon to mitigate the effects of climate change (Howard et al., 2023).

Five main criteria classify blue carbon pathways:
1) Potential for climate mitigation is quantifiable.
2) Impacts the actions have on overall human health and well-being.
3) Maintenance or enhancement of the ecosystem's natural state and function.
4) Potential for inclusion in the blue carbon policy frameworks.
5) If the prior criteria are unknown, find the knowledge gaps that require further research.

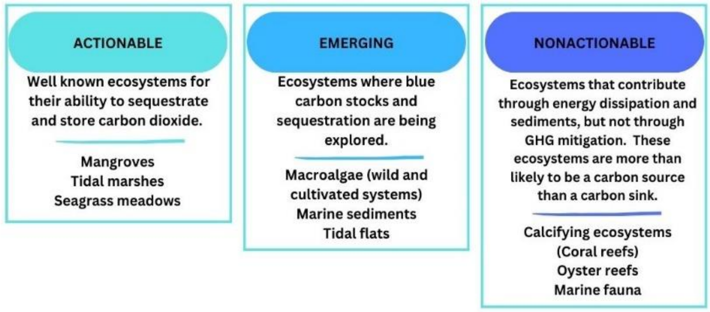

Figure 5: Blue carbon pathways categorized according to an ecosystems ability to sequester and store carbon.

Although coastal wetlands (mangroves, tidal marshes, sea meadow grasses) can sequester large amounts of carbon compared to the other ecosystems (Duarte et al., 2005; Howard et al., 2017; Lovelock and Duarte, 2019; Filbee-Dexter and Wernberg, 2020), there needs to be more focus placed on reforestation and afforestation solutions, as these have the largest potential to remove carbon dioxide from the atmosphere (Griscom et al., 2017; Troell et al., 2022).

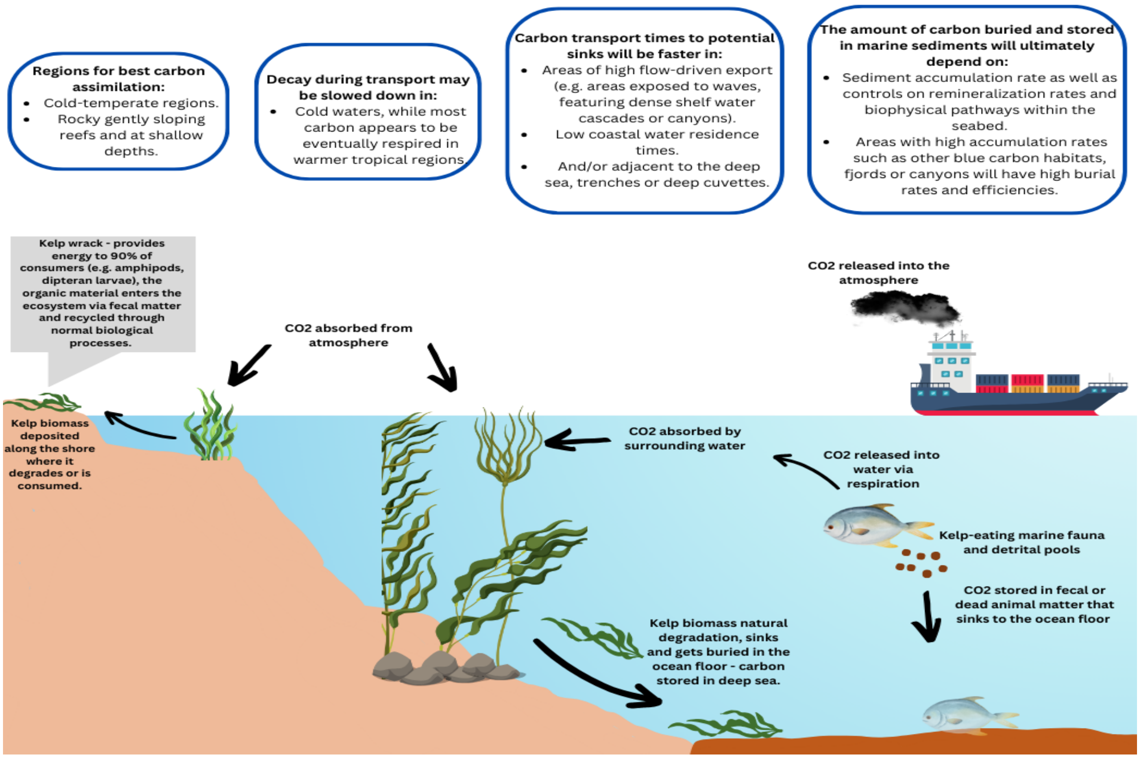

Figure 6: Carbon sequestration and storage pathways using kelp in marine ecosystems.

A recent study suggested that carbon export via macroalgae is widespread across all major oceanographic basins (Ortega et al., 2019). Macroalgae (especially kelp) can produce many 'useful' compounds and assist in carbon burial in sediments or transported to deep sea systems and stored long-term (Lovelock and Duarte, 2019). Macroalgae experience natural degradation throughout its lifecycle, therefore carbon stored in the plant biomass is then transported to other parts of the ocean (Figure 6).

Aquaculture and the Opportunity for Blue Carbon

To date, the kelp market in South Africa is focused on fresh kelp and beach-cast kelp harvesting. However, there is a growing interest in diversifying through methods such as kelp aquaculture with the total market value of kelp as abalone feed currently estimated at ZAR 9.8 million. Studies indicate there is potential for sea-based kelp farming, particularly in Saldanha Bay on the West Coast of South Africa. While large-scale commercial kelp farming has not been fully implemented yet in South Africa, ongoing experiments in Saldanha Bay may lead the way for its future development. In South Africa, relatively few other macroalgae species are harvested in the wild for commercial purposes, but establishing sustainable management guidelines in such cases is paramount to ensure the long-term viability of the resource (Adams et al., 2019).

Kelp Blue Namibia (Pty) Ltd has conducted a successful pilot test to grow giant kelp in Lüderitz, Namibia, achieving growth rates of 4-5 m in three months (Petrick, 2020). As of January 2024, Kelp Blue has ventured into establishing two large-scale (up to 9000 ha) offshore kelp farms (Petrick, 2020). The kelp canopy will be harvested regularly to produce various value-added products (e.g. agricultural growth biostimulants) (Petrick, 2020). The project has many other benefits (such as job creation, carbon sequestration, and potential boosts in marine biodiversity and commercial fish stocks) (Petrick, 2020), however, two of the major concerns of this project is 1) Kelp Blue is utilizing a non-native species, *Macrocystsis pyrifera* (Petrick, 2020). There are many risks to introducing a new species into the system (e.g. biosecurity risks) that can negatively impact the ecosystem. 2) There is also no verification yet of the blue carbon sequestered. Therefore, extensive environmental monitoring and management are important factors to implement (Petrick, 2020).

Aquaculture Development Policy Gaps in South Africa

In the Northern Cape, there is an opportunity for long-term development of the aquaculture sector, particularly in Port Nolloth's registered aquaculture zone, which is currently undeveloped. The challenge is that environmental authorizations must be renewed to develop new aquaculture activities within this zone. Several environmental policy challenges hinder an enabling environment include obtaining permits and licenses from the port authorities to conduct aquaculture-related activities as currently these activities can only be conducted within ports or bays. Policy adjustments are essential to support offshore aquaculture. However, a draft Aquaculture Development Bill was published for public comments, due January 2024, this proposed Bill aims to rectify historical imbalances in accessing aquaculture opportunities and create an enabling environment for the industry, to stimulate sector growth and development, boost investor confidence, and ultimately create employment opportunities. The Bill is currently in Parliament awaiting approval.

Challenges and Scientific Gaps in Considering Kelp as Natural Climate Solution

1) Carbon Sequestration

There is great variability in the transportation of the carbon to carbon sinks, this depends on local factors (e.g. seasonal variability) which requires extensive modelling and environmental data to estimate (Howard et al., 2023). Studying the kelp locations where carbon storage and sequestration occurs (e.g. open ocean, deep sea sediments and continental shelf) is often considered challenging and expensive, therefore, obtaining sequestration and storage estimates of these locations become limited and poorly quantified (Krause-Jensen and Duarte 2016; Howard et al., 2023). Future research needs to examine the export and burial rates of kelp stored in the seabed to better understand the total amount of carbon sequestered by kelp forests (Pessarrodona et al., 2023; Searle, 2024).

2) Marine species and Carbon

Investigating the influence that marine fauna has on carbon fluxes is a challenge as the exact amounts of carbon that these organisms contribute to the ecosystems is poorly quantified (Saba et al., 2021; Eger et al., 2022).

3) **South Africa Kelp and Carbon**

The lack of available data on the amount of carbon fixed by kelp species in South Africa. A recent study showed GIS biomass surveys of the three concession areas (15, 16 and 19) along the west coast of South Africa which were used to estimate the amount of carbon that can potentially be sequestered. The estimation demonstrated that the kelp forests in these concession areas have the potential of sequestrating carbon, however, the amount of carbon sequestered will vary between the areas (Searle, 2024). It is important to map the full extent of South Africa's kelp biomass including deepwater kelp ecosystems and understanding the restoration potential for areas that have experienced decline in kelp.

4) Monitoring and Verification

It is essential to set up a monitoring, reporting and verification (MRV) system particularly for carbon in deepwater and the seabed as this will assist in understanding carbon sequestration and storage potential. The MRVs will also assist in identifying blue carbon capacity areas that need protection and restoration (Searle, 2024).

5) Socio-Economic Benefits

Research in understanding the economic and social constructs of these coastal communities is important when initiating kelp restoration/mitigation projects. This can help unlock maximum utilization of kelp benefits within these communities. Promoting for human capacity and economic development can help these communities thrive.

6) Climate Change Impacts

Climate change can also directly or indirectly affect kelp ecosystems. Kelp is sensitive to changes in seawater temperature, this ultimately may cause redistribution of kelp (Smale, 2020), therefore, affecting not only the marine life but also the livelihoods of coastal communities. Increasing temperatures may also affect other factors such as nutrients, light availability, ocean currents, prevalence of pathogens and overgrowth of epiphytes (Smale, 2020) which are detrimental to the functioning of kelp ecosystems. Temperature has also shown to affect the strength and direction of ecological interactions such as competition and grazing (increased grazing pressure) which can affect overall population dynamics (Kordas et al., 2011; Smale, 2020).

References

Adams, J.B., Raw, J.L., Mbense, S.P., Bornman, T.G., Rajkaran, A., van Niekerk, L., 2019. Climate change and South Africa's blue carbon ecosystems. Report to Water Research Commission.

Anderson, R.J., Bolton, J.J., Molloy, F.J., Rotmann, K.W.G., 2003. Commercial seaweed production and research in southern Africa. In: Chapman, A.R.O., Anderson, R.J., Vreeland, V.J., Davison, I.R. (Eds.), *Proceedings of the 17th International Seaweed Symposium*. Oxford University Press, pp. 1–12.

Anderson, R.J., Rothman, M.D., Share, A., Drummond, H., 2006. Harvesting of the kelp Ecklonia maxima in South African affects its three obligate, red algal epiphytes. *Journal of Applied Phycology* 18, 343–349.

Aquaculture Development Bill Draft. 2023. Available: http://www.gov.za/sites/default/files/gcis_document/202311/4973gon4098.pdf. Accessed (29 April 2024)

Bertram, C., Quaas, M., Reusch, T. B. H., Vafeidis, A. T., Wolff, C., Rickels, W., 2021. The blue carbon wealth of nations. *Nature Climate Change* 11(8), 704–709.

Blamey, L.K., Bolton, J.J., 2017. The economic value of South African kelp forests and temperate reefs: Past, present and future. *Journal of Marine Systems* 188, 172-181.

Department of Forestry, Fisheries and the Environment (DFFE), 2020. Towards a South African Oceans Economy Master Plan (Draft V3.0). pp 1-34.

Department of Forestry, Fisheries and the Environment (DFFE), 2021. Scoping Study: A Blue Carbon Sinks Assessment for South Africa. Pretoria. South Africa.

Donato, D.C., Kauffman, J.B., Murdiyarso, D., Kurnianto, S., Stidaham, M., Kanninen, M., 2011. Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience* 4, 293-296.

Duarte, C.M., Middelburg, J.J., Caraco, N., 2005. Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences* 2(1), 1–8.

Duarte, C.M., 2017. Reviews and syntheses: hidden forests, therole of vegetated coastal habitats in the ocean carbon budget. *Biogeosciences* 14, 301-310.

Duarte, C.M., Agusti, S., Barbier, E., Britten, G.L., Castilla, J.C., Gattuso, J.P., Fulweiler, R.W., Hughes, T.P., Knowlton, N., Lovelock, C.E., Lotze, H.K., Predragovic, M., Poloczanska, E., Roberts, C., Worm, B., 2020. Rebuilding marine life. *Nature* 580, 39–51.

Duarte, C.M., Bruhn, A., and Krause-Jensen, D., 2021. A seaweed aquaculture imperative to meet global sustainability targets. *Nature Sustainability* (Springer Science and Business Media LLC), 1–9.

Eckert, I., Brown, A., Caron, D., Riva, F., Pollock, L.J., 2023. 30x30 biodiversity gains rely on national coordination. *Nature Communications* 14, 7113.

Eger, A.M., Vergés, A., Choi, C.G., Christie, H.C., Coleman, M.A., Fagerli, C.W., Fujita, D., Hasegawa, M., Kim, J.H., Mayer-Pinto, M., Reed, D.C., Steinberg, P.D., Marzinelli, E.M., 2020. Financial and institutional support are important for large-scale kelp forest restoration. *Frontiers in Marine Science* 7, 535277.

Eger, A.M., Marzinelli, E.M., Christie, H., Fagerli, C.W., Fujita, D., Gonzalez, A.P., Hong, S.W., Kim, J.H., Lee, L.C., Mchugh, T.A., Nishihara, G.N., Tatsumi, M., Steinberg, P.D., Vergés, A., 2022. Global kelp forest restoration: past lessons, present status, and future directions. *Biological Reviews* 97, 1449–1475.

Ellis, P.W., Page, A.M., Wood, S., Fargione, J., Masuda, Y.J., Denney, V.C, Moore, C., Kroeger, T., Griscom, B., Sanderman, J., Atleo, T., Cortez, R., Leavitt, S., Cook-Patton, S.C., 2024. The principles of natural climate solutions. *Nature Communications* 15, 547.

Evseeva, O., Evseeva, S., Dudarenko, T., 2021. The impact of human activity on the global warming. *E3S Web of Conferences* 284. 11017.

Filbee-Dexter, K., Wernberg, T., 2020. Substantial blue carbon in overlooked Australian kelp forests. *Scientific Reports* 10(1).

Findlay, K., Bohler-Muller, N., 2018. South Africa's Ocean economy and Operation Phakisa. In: Bohler-Muller N, Attri VN, editors. The blue economy handbook of the Indian Ocean region. Africa Institute of South Africa. p. 231–255.

Forbes, H., Shelamoff, V., Visch, W., Layton, C., 2022. Farms and forests: evaluating the biodiversity benefits of kelp aquaculture. *Journal of Applied Phycology* 34, 3059–3067.

Griscom, B.W., Adams, J, Ellis, P.W., Houghton, R.A., Lomax, G., Miteva, D.A., Schlesinger, W.H., Shoch, D., Siikamäki, J.V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R.T., Delgado, C., Elias, P., Gopalakrishna, T., Hamsik, M.R., Herrero, M., Kiesecker, J., Landis E., Laestadius, L., Leavitt, S.M., Minnemeyer, S., Polasky, S., Potapov, P., Putz, F.E., Sanderman, J., Silvius, M., Wollenberg, E., Fargione, J., 2017. Natural climate solutions. *Proceedings of the National Academy of Sciences 114*(44), 11645-11650.

Gurney, G.G., Adams, V.M., Alvarez-Romero, J.G., Claudet, J., 2023. Area-based conservation: Taking stock and looking ahead. *One Earth* 6(2), 98-104.

Hilmi, N., Chami, R., Sutherland, M.D., Hall-Spencer, J.M., Lebleu, L., Benitez, M.B., Levin, L.A., 2021. The role of blue carbon in climate change mitigation and carbon stock conservation. *Frontiers in Climate* 3.

Howard, J.L., Creed, J.C., Aguiar, M.V.P., Fouqurean, J.W., 2017. CO2 released by carbonate sediment production in some coastal areas may offset the benefits of seagrass "Blue Carbon" storage, *Limnology and Oceanography* 63(1), 160–172.

Howard, J., Sutton-Grier, A.E., Smart, L.S., Lopes, C.C., Hamilton, J., Kleypas, J., Simpson, S., McGowan, J., Pessarrodona, A., Alleway, H.K., Landis, E., 2023. Blue carbon pathways for climate mitigation: Known, emerging and unlikely. *Marine Policy* 156, 105788.

IPCC, 2023. Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Romero J.H.L., (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34.

Kinley, R., Martinez-Fernandez, G., Matthew, M., de Nys, R., Magnusson, M., Tomkins, W. 2020. Mitigating the carbon footprint and improving productivity of ruminant livestock agriculture using a red seaweed. *Journal of Cleaner Production* 259.

Kordas, R.L., Harley, C.D.G., O'Connor, M.I., 2011. Community ecology in a warming world: the influence of temperature on interspecific interactions in marine systems. *Journal of Experimental Marine Biology and Ecology* 400, 218–26.

Krause-Jensen, D., Duarte, C.M., 2016. Substantial role of macroalgae in marine carbon sequestration. *Nature Geoscience* 9(10), 737–742.

Lim, C., Yusoff, S., Ng, C., Lim, P., Ching, Y., 2021. Bioplastic made from seaweed polysaccharides with green production methods. *Journal of Environmental Chemical Engineering* 9(5), 105895.

Loureiro TG, Du Plessis N, Findlay K., 2019. Into the blue – The blue economy model in Operation Phakisa 'Unlocking the Ocean Economy' Programme. *South African Journal of Science* 118(11/12), 14664.

Lovelock, C.E., Duarte, C.M. (2019). Dimensions of blue carbon and emerging perspectives. *Biological Letters* 15, 20180781.

Macreadie, P. I., Anton, A., Raven, J. A., Beaumont, N., Connolly, R. M., Friess, D. A., Kelleway, J. J., Kennedy, H., Kuwae, T., Lavery, P. S., Lovelock, C. E., Smale, D. A., Apostolaki, E. T., Atwood, T. B., Baldock, J., Bianchi, T. S., Chmura, G. L., Eyre, B. D., Fourqurean, J. W., Hall-Spencer, J.M., Huxman, M., Hendriks, I.E., Krause-Jensen, D., Laffoley, D., Luisetti, T., Marba, N., Masque, P., McGlathery, K.J., Megonigal, J.P., Murdiyarso, D., Russell, B.D., Santos, R., Serranom, O., Silliman, B.R., Watanabe, K., Duarte, C. M. (2019). The future of Blue Carbon science. *Nature Communications* 10(1).

Msuya, F.E., Bolton, JJ., Pascal, F., Narrain, K., Nyonje, B., Cottier-Cook, E.J., 2022. Seaweed farming in Africa: current status and future potential. *Journal of Appl Phycology* 34, 985–1005.

Morais, T., Inácio, A., Coutinho, T., Ministro, M., Cotas, J., Pereira, L., Bahcevandziev, K., 2020. Seaweed Potential in the Animal Feed: A Review. *Journal of Marine Science and Engineering* 8(8), 559.

Morris, R.L., Graham, T.D.J., Kelvin, J., Ghisalberti, M., Swearer, S.E., 2020. Kelp beds as coastal protection: wave attenuation of Ecklonia radiata in a shallow coastal bay. *Annals of Botany* 125(2), 235-246.

NOAA National Centers for Environmental Information, Monthly Global Climate Report for Annual 2023, published online January 2024, retrieved on April 29, 2024. from https://www.ncei.noaa.gov/access/monitoring/monthly-report/global/202313.

Ortega, A., Geraldi, N. R., Alam, I., Kamau, A. A., Acinas, S. G., Logares, R., Gasol, J.M., Massana, R., Krause-Jensen, D., Duarte, C.M., 2019. Important contribution of macroalgae to oceanic

carbon sequestration. *Nature Geoscience* 12, 748–754.
Patel, S., Dey, A., Chaturvedi, A., Sharma, A., Singh, R., 2024. Adaptation and Mitigation Strategies Under Climate Change Scenario. In: Kumar, P., Aishwarya (eds). *Technological Approaches for Climate Smart Agriculture*.
Pendleton, L., Donato, D.C., Murray, B.C., Crooks, S., Jenkins, W.A., Sifleet, S., Craft, C., Fourqurean, J.W., Kauffman, J.B., Marba, N., Megonigal, P., Podgeon, E., Herr, D., Gordon, D., Baldera, A., 2012. Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. *PLoS One* 7, e43542.
Pessarrodona, A., Franco-Santos, R.M., Wright, L.S., Vanderklift, M.A., Howard, J., Pidgeon, E., Wernberg, T., Filbee-Dexter, K., 2023. Carbon sequestration and climate change mitigation using macroalgae: a state of knowledge review. *Biological Reviews* 98, 1945-1971.
Petrick, W., 2020. EIA scoping & impact assessment report for the proposed kelp cultivation pilot project near Lüderitz, Karas region. Kelp Blue Namibia (Pty) Ltd.
Rothman, M.D., 2015. The Phylogeny, Biology and Biogeography of the Southern African Kelps Ecklonia maxima and Laminaria pallida. PhD thesis. Department of Biological Sciences, University of Cape Town.
Saba, G.K., Burd, A.B., Dunne, J.P., Hernandez-Leon, S., Martin, A.H., Rose, K.A., Salisbury, J., Steinberg, D.K., Trueman, C.N., Wilson, R.W., Wilson, S.E., 2021, Toward a better understanding of fish-based contribution to ocean carbon flux. *Limnology and Oceanography* 66(5), 1639-1664.
Schulte, I., Eggers, J., O Nielsen, J., Fuss, S., 2022. What influences the implementation of natural climate solutions? A systematic map and review of the evidence. *Environmental Research Letters* 17, 013002.
Searle, L. 2024. The blue carbon potential of the kelp in Concession Area 15, 16 and 19. Deliverable 4. RFP No: Biomass-Survey. Unpublished Manuscript.
Smale, D.A., Burrows, M.T., Moore, P., O'Connor, N., Hawkinu, S.J., 2013. Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. *Ecology and Evolution,* 3: 4016–4038.
Smale, D.A., 2020. Impacts of ocean warming on kelp forest ecosystems*. New Phytologist Foundation*, 225: 1447-1454.
South African International Marine Institute (SAIMI), 2021. Partners in growing – Blue Economy. Brochure. pp. 1-13.
Steneck, R.S., Johnson, C.R., 2014. Kelp forests: dynamic patterns, processes, and feedbacks. In: Bertness, M.D., Bruno, J.F., Silliman, B.R., Stachowicz, J.J., (eds). Marine community ecology and conservation. Sinauer Associates, Inc., Massachusetts, pp 315–336.
Sultana, F., Wahab, M.A., Nahiduzzaman, M., Mohiuddin, M., Iqbal, M.Z., Shakil, A., Mamun, A., Khan, M.S.R., Wong, L., Asaduzzaman, M., 2023. Seaweed farming for food and nutritional security, climate change mitigation and adaptation, and women empowerment: A review. *Aquaculture and Fisheries* 8(5), 463-480.
Troell, M., Robertson-Andersson, D., Anderson, R.J., Bolton, J.J., Maneveldt, G., Halling, C., Probyn, T., 2006. Abalone farming in South Africa: an overview with perspectives on kelp resources, abalone feed, potential for on-farm seaweed production and socio-economic importance. *Aquaculture* 257(1), 266–281.
Troell, M., Henriksson, P. J., Buschmann, A., Chopin, T., Quahe, S., 2022. Farming the ocean–seaweeds as a quick fix for the climate? *Taylor & Francis*, 1–11.
Very, F., 2019. Operation Phakisa: Reflections upon an Ambitious Maritime-Led Government Initiative. *South African Journal of Military Studies* 72(2), 87-105.
Waring, B.G., Gurgel, A., Köberle, A.C., Paltsev, S., Rogelj J., 2023. Natural Climate Solutions must embrace multiple perspectives to ensure synergy with sustainable development. *Frontiers in Climate* 5, 1216175.
Yin, C., Pereira, P., Zhao, W., Barcelo, D., 2023. Natural climate solutions. The way forward. *Geography and sustainability* 4(2), 179-182.
Zhang, L., Liao, W., Huang, Y., Wen, Y., Chu, Y., Zhao, C., 2022. Global seaweed farming and processing in the past 20 years. *Food Production, Processing and Nutrition* 4, 23.