BUCKMINSTER FULLER INSTITUTE

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ACCELERATING BLUE CARBON

Illuminating a path on where and how to fund the promise of blue carbon, igniting mass mobilization

Co-Operating Manual for Spaceship Earth

Special thanks to **LIFT Economy** for its contribution to the blue carbon research and report content.

PHOTOS: MOHAMED SAMEEH (cover); ANNA UTOCHKINA (this page)

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Executive Summary

OUR OCEAN DEEPLY INFLUENCES THE GLOBAL CARBON CYCLE through **coastal blue carbon** (mangroves, seagrasses, macroalgae and salt marshes) and **oceanic blue carbon** (phytoplankton, marine animals, and other open ocean biota) mechanisms. It has been 10 years since the term "blue carbon" was coined (2009) and although the importance of these ecosystems and mechanisms is not yet entirely understood, many of the conclusions posited in the first blue carbon published research have been continually affirmed and refined including the following:

- Whereas open ocean surface phytoplankton capture carbon from the atmosphere via photosynthesis, only a relatively small but important fraction of that carbon sinks all the way to the deep sea floor without being respired back to the atmosphere. Geoengineering schemes to stimulate phytoplankton growth and carbon burial are still burdened with controversy, uncertain outcomes and efficacy.
- Key coastal ecosystems (mangroves, seagrass meadows and salt marshes) have outsized carbon burial rates compared to terrestrial ecosystems with important long-term carbon storage potential.
- These coastal ecosystems also provide significant co-benefits to coastal communities including mitigating impacts of sea level rise and extreme storms while providing diverse goods and services.
- These key ecosystems are endangered and urgently threatened by pollution run-off from land, urban development, aquaculture and overfishing. When disturbed these ecosystems emit stored carbon and lose their capacity to sequester carbon.
- Despite being critically important to biodiversity and coastal community food security, coral reefs do not act as carbon sinks, but in fact are modest carbon sources due to the chemistry of their growth.

Over the last decade research published in hundreds of papers has revealed some new key insights relevant to our collective understanding of and partnership with blue carbon ecosystems including the following:

- Emergent techniques of local community-led conservation and restoration of the key blue carbon ecosystems (especially mangroves) can preserve and enhance coastal community food security and material economy while creating or maintaining carbon capture and coastal protection benefits.
- Formerly thought of as modest stores of labile carbon (easily consumed by other organisms and thus respired back to the atmosphere), macroalgae (kelp bed) ecosystems are increasingly recognized as critical contributors to long term blue carbon capture.
- Ocean farming techniques to create or reforest macroalgae ecosystems have emerged with carbon mitigation and sequestration potential.
- The mechanisms by which marine vertebrates (fish, whales, etc.) impact oceanic blue carbon capture and deposition have been identified and begun to be measured. Whales, in particular, appear to play an outsized role in stimulating the productivity and sink capacity of open ocean phytoplankton.
- While still not totally known, the extent of existing and potential seagrass meadow ecosystems has been assessed as much larger than earlier thought pointing to significant carbon capture potential as emergent lower cost techniques for establishment and restoration are tested and developed.
- While potentially controversial, novel blue carbon ecosystems can be created in certain places where drawing in seawater to arid inland regions can create significant carbon capture processes and food security benefits or in the open ocean where artificial macroalgae 'reefs' are proposed.

KEY ABBREVIATIONS

t	=	ton
Mg	=	Megagram; 1 Mg = 1 Metric ton
Mt	=	Metric ton; 1 Mt = 1 Megagram
Gt	=	Gigaton; 1 Gt = 1 Petagram
Pg	=	Petagram; 1 Pg = 1 Gigaton
Tg	=	Teragram; 1 Tg = 1,000,000 Mg
1 Pg	=	1000 Tg = 1,000,000,000 Mg
1 Gt	=	1,000,000,000 Mt = 1,000,000,000 Mg = 1Pg
C	=	carbon
CO_2	=	carbon dioxide
CO_2e	=	carbon dioxide equivalent
1Mt C	=	3.667t CO_2e
km^2	=	square kilometer
ha	=	hectare: unit of area measurement; 1 hectare = 10,000 m^2; 100 hectare = 1 km^2
Mha	=	Million hectares

PHOTO: JOHN WESTROCK

There still exists a "charisma" gap for blue carbon. Whereas the loss of terrestrial rain forests has captured popular attention, the world is losing its coastal habitats four times faster.[1] Action is being taken, but needs to be scaled to match the magnitude of the crisis.

Best practices for developing and funding blue carbon projects have begun to emerge. Key strategies focus on emulating and restoring cultural practices that result in beneficial human impact and interaction with our oceans. The Japanese concept of Satoumi, which describes coastal landscapes positively impacted through human-oceanic interactions for long timescales, like many other indigenous philosophies, can act as guidelines. Best practices are primarily focusing on mangroves, seagrasses, macroalgae (kelp) and oceanic blue carbon (including whale pump and biomixing). These also make up the most "actionable" blue carbon ecosystem initiatives, based on an analysis by Lovelock, et al., and are self-evidently ready to enhance carbon capture and ecosystem health[2] now.

Indigenous Ocean Philosophies and Mariculture Practices

Hawaiian Ahupua'a System of organizing land stewardship for the benefit of all

Japanese Satoumi Coastal landscapes that have been positively impacted by human interactions for millenia

Sri-Lankan Cascading Tank System Ancient method of paddy farming, or aquaculture

Indonesian Empang Parit Traditional ecological system of shrimp farming in tandem with mangroves

MANGROVES

The world's mangrove ecosystems (around 140,000 km²) alone could store the equivalent of more than two years of global carbon emissions in their soils, much of which would be released into the atmosphere if mangroves were destroyed.[3] Globally, 8,120 km², or six percent of former mangrove areas are considered restorable. Of the land lost, 81.7% of that area is considered highly restorable, making these locations prime spots for successful blue carbon initiatives.

Both mangrove restoration and conservation are critical. Some research indicates that mangroves can sequester more carbon yearly than any other aquatic or terrestrial ecosystem on the globe.[4] Key players in mangrove conservation and restoration include practices such as Silvoaquaculture, Silviculture, and projects such as the Mangrove Action Project and Blue Ventures.

Mangrove replanting after tsunami. https://wle.cgiar.org PHOTO: ECOSIA.ORG

An example of community-based ecological mangrove restoration (CBEMR), Tanakeke Islanders hand digging 1.5 km of tidal creeks in disused shrimp ponds to restore natural hydrology. PHOTO: YUSRAN NURDIN

Indonesians process seaweed in Nusa Tenggara Timur (NTT) province. PHOTO: ILO ASIA-PACIFIC

SEAGRASSES

Global seagrass carbon pools range from 4.2 petagrams (Pg) to 19.9 Pg organic carbon[5]; seagrass soils have the potential to sequester 1.38 Mg C/ha per year and to export some carbon material out to deep sea sinks.[6] 30% of seagrass ecosystems has been lost over the last 50 years. Recent estimates suggest seagrass meadows support the productivity of 20% of the world's biggest fisheries,[7] making them important to human livelihoods and well-being while also providing key habitats for keystone species such as sea turtles. Fishing community-led efforts are best positioned to restore seagrass ecosystems for optimal cover, lowest cost and greatest co-benefits.

MACROALGAE

A polyculture vertical farming system, developed and open sourced by GreenWave, grows a mix of seaweed and shellfish in near-shore ocean environments, with research indicating that as much as 30% of net primary production from growth of macroalgae is exported to deeper marine sediments where the carbon in seaweed becomes sequestered over long timeframes.[8] The World Bank estimates that increasing seaweed farming from 9 to 14% growth per year would generate 500 million tons dry weight by 2050.[9] Market development of potential uses for seaweed is critical to increase adoption of ocean farming. Macroalgae's biggest carbon cycle contribution may be via mitigating the emissions from other agricultural activity, for instance by replacing carbon-intensive fertilizers and food products.

INTEGRATED SEAWATER AGRICULTURE SYSTEMS (ISAS)

ISAS is a method of cultivating halophytes (salt-tolerant flowering plants) in inland areas by bringing saline irrigation techniques into inland soils. ISAS systems can produce a host of products including proteins (shrimp, tilapia), oils, fuel, habitat, building materials, medicines and more. Dense groundcover enabled by the salt water cools local climates and builds soil carbon.[10] Although still in research and development, projects have been piloted in Eritrea, Mexico and Egypt, and are especially suitable to those regions where salinization has already occurred due to industrialized agricultural practices, areas which are increasing at a rate of two million hectares annually. A key player for this strategy is Seawater Works.

BIOMIXING WHALE PUMP

Whereas the majority of attention on blue carbon tends to be toward coastal blue carbon, the open ocean has significant influence on the global carbon cycle. Complex exchanges of carbon with the atmosphere[11] in open ocean plays a role in the global carbon sequestration cycle. When great whales carry nutrients from deep ocean by defecating at the surface, their liquid faeces, rich in iron and nitrogen, feed phytoplankton which contribute to carbon capture. The total potential impact of increasing the population and activity of whales is an active area of research, but whales are charismatic animals and linking them with carbon sequestration in popular discourse could benefit all marine life and global carbon ecosystems. Reduction in plastic debris and chemical, oil and sonic pollution all are effective means for increasing whale populations and have beneficial impacts on fisheries and cascading impacts on the carbon cycle.

FUNDING GAPS

Blue carbon projects (conservation, restoration or other) appear to receive a minority of global philanthropic funding associated with ocean and ocean environments. FundingtheOcean.org (Foundation Maps by Candid)[12] lists $8.3billion total dollar value from 51,412 grants given globally for oceans and ocean environments from 2009–2019. Using query terms common to blue carbon ecosystems, the number of global grants for blue carbon related initiatives from 2009–2019 totaled 175 less than 1% of total giving for oceans. For comparison, over the same period, "coral" received 2,004 grants for $206,100,000.

ADDITIONAL RESEARCH NEEDED

1. Coastal blue carbon in the face of climate change: More research on the adaptability of coastal blue carbon ecosystems in the face of sea level rise and extreme events is needed.
2. Global importance of macroalgae as blue carbon sinks/donors. How much of macroalgae production becomes long term carbon storage as sediment on the seafloor? How to stimulate market demand for kelp and kelp derived products should also be researched.
3. What factors influence blue carbon burial rates and what management actions best maintain and promote blue carbon sequestration?
4. Oceanic Blue Carbon. In general, a greater understanding of the mechanisms for increasing oceanic blue carbon capture is needed, including developing our understanding of marine vertebrate carbon, marine viruses and fertilization and alkalinization.
5. Conduct research on how to reduce costs to implement coastal blue carbon restoration projects at larger scales.
6. Conduct interviews with funders to discover barriers.
7. Pilot projects that help mainstream the notion of geographic and community-informed suitability.

A note about key players: Research for this report sought to identify key players that could advance blue carbon initiatives in alignment with humanitarian principles such as the Blue Forests Project's Blue Carbon Code of Conduct that encourages" 1) Fair conservation governance and decision-making processes 2) Socially-just conservation actions and outcomes and 3) Accountable conservation initiatives and organizations."[13] Key players featured in sidebars throughout the report embody these principles in scaleable ways and could be catalytic models for new initiatives.

PART 1
SCIENCE

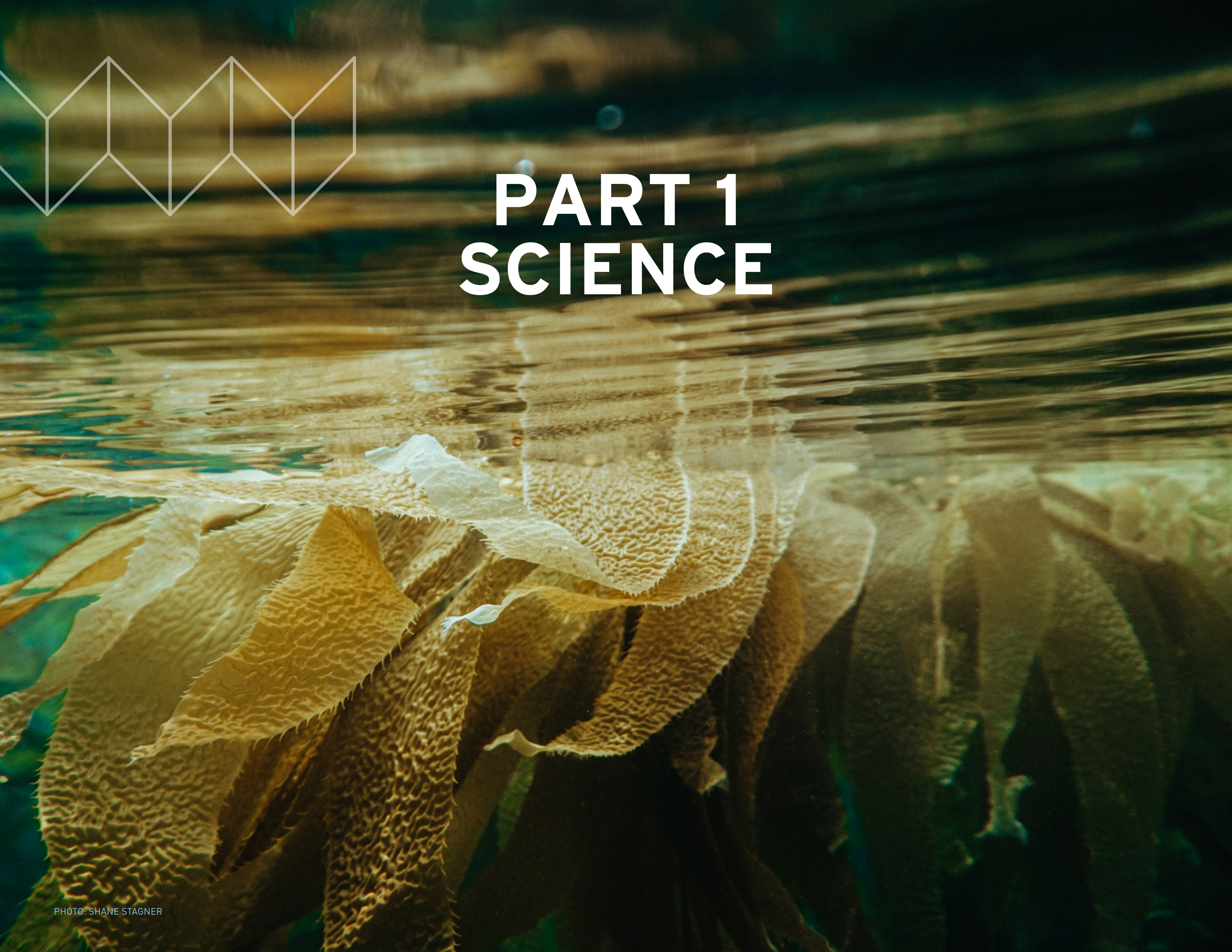

PHOTO: SHANE STAGNER

SECTION 1

Blue Carbon Defined, Its Impact and Importance to Funders

BLUE CARBON REFERS TO CARBON stored and sequestered in marine environments and includes the carbon fixed in **coastal blue carbon** (mangroves, seagrasses, macroalgae and salt marshes) and **oceanic blue carbon** (phytoplankton, marine animals, and other open ocean biota). The relationship of the ocean to the carbon cycle involves a series of complex interactions that result in carbon being taken out of the atmosphere, respired back to the atmosphere, stored in the water as dissolved carbon and sometimes stored for thousands (or many more) years in coastal and deep sea sediments.

Marine phytoplankton and other marine microorganisms perform half of all photosynthesis on Earth (about 50 Pg C per year[14]). Through gravity, food web interactions and mixing of water, this carbon slowly descends out of the range of sunlight; however the majority of this sinking carbon is consumed, respired (or remineralized) back to the atmosphere in short order. Only about 1%, a still significant 0.2–0.5 Pg C per yr, of the surface production finally reaches the seafloor for long term storage.[15] Mechanisms to stimulate greater primary production of phytoplankton or increase marine vertebrate populations to capture, store and sink more of the photosynthetic production of marine phytoplankton are the key to deep sea sequestration and make up the majority of oceanic blue carbon solutions.

Coastal blue carbon ecosystems capture and store carbon through primary photosynthesis (storing carbon in soil and above ground biomass), capturing carbon in runoff from the land and, the most important part of the process, 'exporting') carbon to deep sea sediments when, for instance, certain biomass gets cut off or removed from the primary ecosystem. Remarkably, the carbon storage capacity of coastal blue carbon ecosystems is exceptional compared with the open ocean or terrestrial forests. Despite tidal marsh, mangrove, and seagrass ecosystems occupying less than 0.2% of the seabed area, they contribute nearly 50% of the CO_2 sequestration in marine sediments, and their carbon sequestration rates exceed by 30 to 50 times those in the soils of many terrestrial ecosystems.[16, 17, 18] At a global scale, coastal blue carbon ecosystems sequester 130–490 Tg C/yr, equivalent to 1%–5% of current CO_2 emissions from fossil fuel combustion.[19] It is estimated that 41–278 Tg C/yr of the anthropogenic carbon released into the atmosphere comes from the degradation and disturbance of blue carbon environments and ecosystems, leaving humanity with the pressing opportunity to regenerate blue carbon ecosystem health while sequestering carbon dioxide.[20]

CARBON POTENTIAL: CARBON CYCLE AND GLOBAL WARMING

i. Coastal Blue Carbon Sequestration:
While there are many ecosystemic and regional nuances that influence the rate of carbon sequestration, according to the Atlas of Ocean Wealth coastal wetlands sequester enough CO_2 to offset the burning of over one billion barrels of oil.[21] The analysis of burial rates, carbon stocks, carbon export to deep-sea sediment from coasts and responses of coastal ecosystems to a warming planet is an active field with frequent new research being published. The key players elements in this process are:

1. **Mangroves:** These tropical forests found at the edge of land and sea are estimated to have an average annual carbon sequestration between 1.6 and 2.2 Mg C/ha (metric tons of Carbon per hectare). The world's mangrove ecosystems (around 140,000 km^2) alone could store as much as 20 Pg of carbon — equivalent to more than two years of global carbon emissions — in their soils, much of which would be released into the atmosphere if mangroves were destroyed.[22]

2. **Seagrasses:** These submerged coastal marine "grasses" living in shallow waters affect soil carbon via an underground network of roots and rhizomes. While there are high error bars of uncertainty as to

actual carbon stocks of seagrass soil, one report estimates that global seagrass carbon pools could range from 4.2 Pg to 19.9 Pg of organic carbon (Fourqurean, 2012)[23]. When healthy and not over-grazed, seagrass soils have the potential to sequester 1.38 Mg C/ha per year. Recent analysis suggests seagrass may play a greater role in exporting (during storm events, for example) carbon material out to deep sea sinks than has previously been established.[24]

3. **Salt marshes:** These saline tidal marshes store carbon in marsh soil sometimes many meters in depth, representing a significant stock of carbon. The average annual carbon sequestration rate for tidal marshes is between 1.6 and 2.2 Mg C/ha, about two to four times greater than that observed in mature tropical forests.

4. **Kelp or macroalgae:** Coastal macroalgae stands sequester carbon when they grow. Until recently, it was believed that when macroalgae material is shed it is consumed and respired back to the atmosphere. New research in the last couple of years suggests that up to 30% of net primary productivity of kelp growth is exported to the deep sea for deposition and long term sequestration. These findings put this ecosystem and methods such as regenerative ocean farming to kelp reforesting more squarely in the blue carbon field.[25]

ii. Oceanic Blue Carbon Sequestration:

1. Whereas the majority of the focus of the literature, projects, funding and organizations identified as blue carbon is associated with coastal blue carbon, the open ocean and the full water column to the seafloor have significant influence on the global carbon cycle. Ocean dynamics, known as the solubility pump and the biological pump, exchange carbon with the atmosphere through complex systems of interaction. The biological pump takes photosynthetically-produced organic matter and moves it (exports it) from the surface layer to depths that sequester the carbon in deep-sea material for millenia by a combination of processes: sinking particles, vertical mixing of dissolved organic matter, and transport by animals.[26]

2. Planktonic algae in the open ocean also plays a role in the global carbon sequestration cycle, sequestering 9.9 Pg C/yr via photosynthesis, of which 0.14Pg C/yr ends up in deep ocean sediment carbon stocks.[27]

3. A number of mechanisms influence the efficient functioning of the biological pump that humans may potentially in turn influence through our behavior and disturbance.

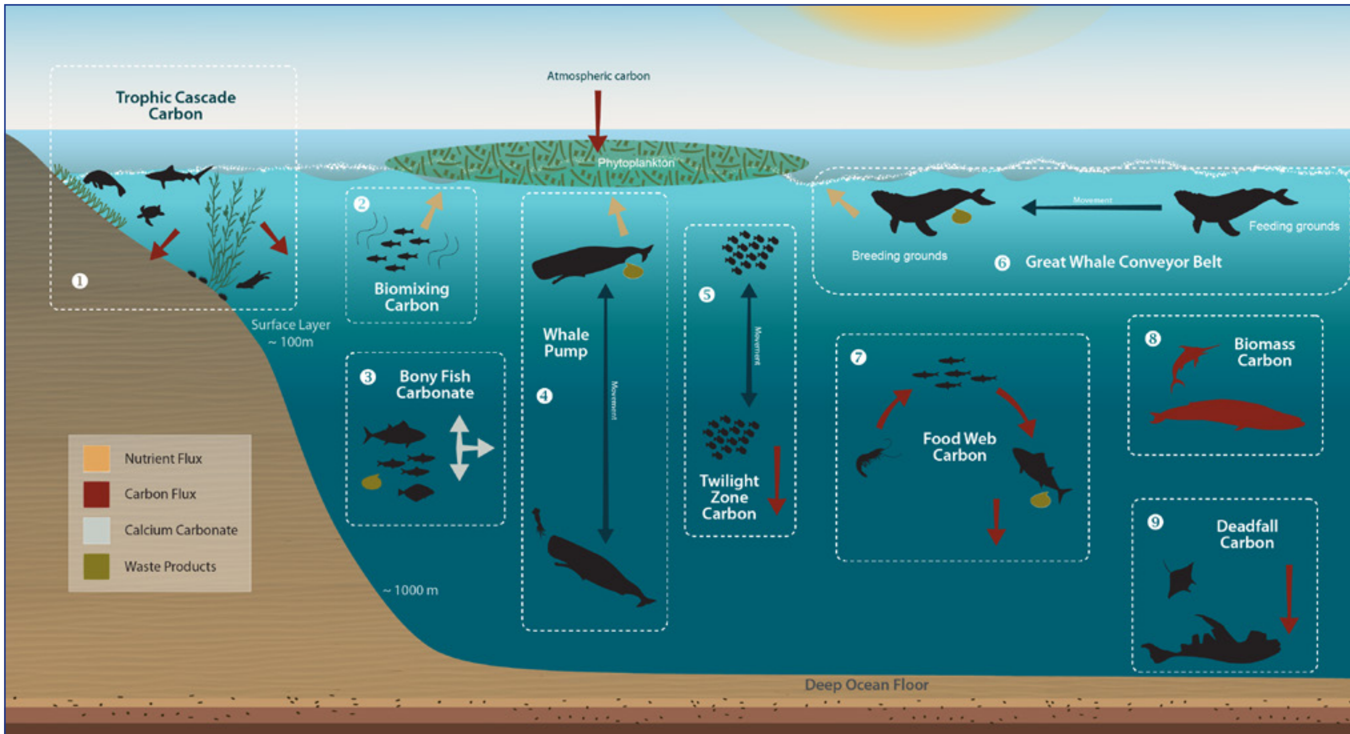

FIGURE 1. Visual of the nine oceanic blue carbon mechanisms.

Visit this interactive story map for specifics on each mechanism. NOTE: Data for carbon sequestration and storage extrapolated from Lutz SJ, Pearson H, Vatter J, Bhakta D. 2018. Oceanic Blue Carbon. Story Map, GRID-Arendal.

TABLE 1: Carbon Sequestration Rate and Carbon Storage of Oceanic Blue Carbon Mechanisms

MECHANISM	SEQUESTRATION RATE (TG C/YR)	50 YEARS — TOTAL STORED AT RATE (PG C)	UNCERTAINTY / NOTES
Trophic Cascade Carbon	0.18	0.00900	Overlap with macroalgae, seagrass, other? Median rate (range = 0.13–0.23 Tg/y) was used
Biomixing Carbon	19.21	0.96052	600 metric tons per 80 whales, extrapolated to pre-whaling population of 2,561,380 whales globally. Different whales in different regions would likely have different mixing and sequestration rates.
Whale Pump	42.69	2.13450	Pre-whaling population of 120,000 sperm whales considered for metrics of 2Tg/yr — extrapolated to pre-whaling population of 2,561,380 whales globally. Different whales would likely account for rates different from sperm whales.
Twilight Zone Carbon	27.7	1.38500	No clear mechanism for increasing (e.g., lantern fish populations)
Great Whale Conveyor Belt	0.14	0.00700	Carbon estimates were based on the pre-whaling population of 340,208 blue whales that inhabited the Southern Ocean
Biomass Carbon	0.0625	0.00313	Unclear if this rate increases if fish stocks increase beyond pre-commercial fishery levels
Deadfall Carbon	0.1927	0.00964	Estimated from a pre-whaling population of 2,561,380 whales globally
Total Oceanic Carbon	**90.17555**	**4.50878**	**This calculation is meant to characterize potential scale of sequestration. Uncertainty exists for every extrapolated value and whale population used for estimation is counterfactual. Further calculations could be developed that assume certain whale population growth rates given certain accelerators (such as Marine Protected Areas — MPAs).**

A simplified analysis to measure the relative reportive impact of these mechanisms. NOTE: Data for carbon sequestration and storage extrapolated from Lutz SJ, Pearson H, Vatter J, Bhakta D. 2018. Oceanic Blue Carbon. Story Map, GRID-Arendal.

When our current understanding, **coastal blue carbon ecosystems and associated mechanisms are the priority focus over the less understood oceanic blue carbon ecosystems**. Coastal blue carbon ecosystems influence oceanic blue carbon mechanisms by stimulating the biological pump as a critical breeding habitat for marine vertebrates (fish, turtles, etc.) who play a role in the biological pump (see for example this article on impact of fish stocks).

CO-BENEFITS OF COASTAL BLUE CARBON

Similar to the way tree-planting campaigns can have unintended adverse impacts when conducted without local community control and skillful ecological oversight, so too can blue carbon initiatives. A global coalition, the Blue Forests Project, has developed a Blue Carbon Code of Conduct which prioritizes community decision making, indigenous community engagement and protection of human rights, among other things. The code recommends adopting a lean, cost-effective and iterative approach that prioritizes learning from on-the-ground results and pilot projects rather than engaging in drawn-out and costly planning processes prior to implementation. The total potential co-benefits of food security, local coastal economic activation, sea level rise adaptation, pollution mitigation along with carbon capture and storage are sometimes referred to as blue carbon's ecosystem services. The global monetary value of these services from coastal blue carbon ecosystems was estimated at $23 billion per year between 1980 and 2008.[28] When blue carbon projects are executed effectively, co-benefits can include:

Coastal protection from extreme weather events: As the quantity and severity of extreme weather events increases, coastal blue carbon ecosystems may be a more effective method for protecting coastline than hard infrastructure as they require less maintenance and address adaptation and mitigation simultaneously.[29]

Improved sea level rise adaptation: Coastal blue carbon ecosystems also have the capacity to adapt to sea level rise whereas hard infrastructure like seawalls and levees do not.[30] Planning is required to allow for this intrinsic characteristic of natural ecosystems to be realized. For example, mangroves can only adapt to sea level rise if there is room for mangroves to retreat and no physical infrastructure impedes their migration.

Pollution mitigation/ nitrogen cycling: Coastal blue carbon ecosystems have an added benefit of mitigating pollution runoff from upstream agriculture that often has detrimental effects on ocean ecosystems. Atlas of Ocean Wealth points out that mangroves and salt marshes utilize 50% or more of nitrogen passing through these coastal buffers,[31] thus reducing the risk of eutrophication and dead zones caused by agricultural amendments and other pollutants.

Jobs, co-products and fish stocks: According to Atlas of Ocean Wealth, "a single hectare of **seagrass** in southern Australia will generate an additional 30,000 fish into a bay or estuary every year, with a commercial fishery enhancement value of some US$24,000 and a hectare of **salt marsh** will generate 235 kilograms of shrimp and 170 kilograms of blue crab in the Gulf of Mexico. **Oyster habitats** are among the most threatened habitats globally, and 85% have been lost, but we now know that a single hectare of oyster reef adds 3,200 adult blue crabs to the fishery each year in the Gulf of Mexico and, further, that across the 31 major bays and estuaries of the US for which we have data, remaining oyster habitat is still generating an additional 185,000 Mg of fish annually."[32] Increasing fish stocks near the coast has beneficial feedback on increasing open ocean (high seas) fish stocks due to migration and feeding patterns of pelagic fish. Lalao Aigrette, Deputy National Blue Forests Programme Lead for Blue Ventures (BV) describes diverse regional enterprises within BV's mangrove restoration efforts. For example, sea cucumbers, seaweed farming and honey from beekeeping are diverse co-products that can be grown within mangrove forests, providing viable revenue and jobs for coastal communities while incentivising the preservation and protection of ecosystems.

An examination and application of these co-benefits of halting the decline of and active restoration of coastal blue carbon ecosystems would greatly improve ocean health and global environmental and social health. Conserved and restored blue carbon ecosystems have the capacity to oxygenate coastal waters, serve as nurseries, help restore world fish stocks, and shelter the shoreline from storms and extreme weather events.[33, 34]

SECTION 2

Strategies for Rapid Acceleration

NOT ALL POTENTIAL BLUE CARBON ECOSYSTEM IMPROVEMENTS are self-evidently ready for action for enhancing carbon capture and ecosystem health. This is not to say that all potential blue carbon ecosystem improvement initiatives are not worthy of attention and action, but not all share the same degree of readiness for acceleration of carbon capture and storage.

Lovelock, et al., provide the best and most up to date analysis of readiness to be considered "actionable" blue carbon ecosystem initiatives. The analysis demonstrates a bias for action in coastal environments—seagrass, mangrove, tidal marsh, and macroalgae ecosystems.[35]

Despite the importance of blue carbon ecosystems and their outsized impact on the global carbon cycle, until recently they have received little popular attention or focus from the philanthropic and investment community. While terrestrial rain forests are receiving ever higher levels of attention, the world is losing its coastal habitats at four times as fast a rate.[36] This differential in attention is sometimes referred to as a "charisma" gap. Despite the losses, action is being taken to conserve, protect and restore these coastal ecosystems. For example, worldwide there are some 2500 protected areas which include mangrove forests within their boundaries. These include some 54,000 km^2, or over 39% of the world's remaining mangroves.[37, 38] Ecosystem loss in these protected areas is dramatically lower than in those areas not protected.

The literature predominantly puts an emphasis on the priority of conservation and protection of remaining coastal blue carbon ecosystems and these conservation mechanisms are often erroneously conflated with mechanisms for restoration and/or creation.

	scale of GHG removals or emissions are significant	long-term storage of fixed CO_2	undesirable anthropogenic impacts on the ecosystem	management is practical/possible to maintain/ enhance C stocks and reduce GHG emissions	interventions have no social or environmental harm	alignment with other policies: mitigation and adaptation
mangrove	yes[1,2]	yes[3]	yes[4,5]	yes[6,7]	?	yes[8]
tidal marsh	yes[1,9]	yes[9]	yes[10]	yes[11,12]	?	yes[13]
seagrass	yes[1,14]	yes[15]	yes[16]	yes[17]	yes	yes[18]
salt flats (sabkhas)	?	?	yes[19]	?	?	?
freshwater tidal forest	?	yes[20]	yes[21]	yes[22]	?	?
macroalgae	yes[23]	?[23]	yes[24]	yes[25]	?	yes[26]
phytoplankton	yes[27]	?[28]	?	?	?	no
coral reef	no[29]	no	yes[30]	no	?	yes[31]
marine fauna (fish)	no[29]	no	yes[32]	no	?	no
oyster reefs	no[29]	?	yes[33]	no	yes	yes[34]
mud flats	?[35]	?	yes[36]	?	yes	yes[36]

FIGURE 2. Criteria for Inclusion as Actionable Blue Carbon Ecosystems

NOTE: Data from Lovelock CE, Duarte CM. 2019 Dimensions of Blue Carbon and emerging perspectives.

TABLE 2: High Level Table of Blue Carbon Strategies

BLUE CARBON TYPE	ECOSYSTEM	MECHANISM
Coastal Blue Carbon	Seagrass Meadows	Restoration Activities
		Conservation Activities
	Estuarine and Coastal Mangroves	Restoration Activities
		Conservation Activities
	Macroalgae	Restoration Activities
		Conservation Activities
	Tidal / Salt Marshes	Restoration Activities
		Conservation Activities
Oceanic Blue Carbon	Marine Life Activities phytoplankton, krill, fish, seabirds, sea turtles, and marine mammals	Restoration Activities
		Conservation Activities

The series of interviews accompanying this report as well as the literature point towards specific key blue carbon **ecosystems** and specific **mechanisms** and **techniques** as potentially providing the highest leverage for rapid acceleration and greatest beneficial impact. These include:

TABLE 3: Highest Leverage Potential for Rapid Acceleration and Greatest Beneficial Impact

ECOSYSTEM	MECHANISM	TECHNIQUE
Mangroves	Mangrove Restoration	Community Based Ecological Mangrove Restoration (CBEMR)
Mangroves	Mangrove Conservation	Mangrove concessions with silvoaquaculture
Seagrass	Seagrass Restoration	Transplanting in scale with novel plug substrates et al.
Macroalgae	Ocean Farming	Multitrophic polyculture ocean farming; Regenerative ocean farming
Mangroves; Salt Marsh	Mangrove Creation	Integrated Seawater Agriculture Systems
Oceanic Blue Carbon	Biomixing and Whale Pump	Strategic MPAs to protect whale breeding habitat
	KEY	Proven, Ready to Scale
		Proof of Concept, Initial Scaling
		Feasibility, Initial Proof and Metrics Established

MANGROVES

A mangrove is "a woody tree or shrub that lives along sheltered coastlines within the tropic or subtropic latitudes."[39] The term is also used to refer to mangrove forests, where foliage on land provides a habitat for other plants and animals, and under water their complex branching root system provides shelter and nesting grounds for many fish. Mangroves are an extremely effective ecosystem for carbon capture and storage, due to their ability to sequester atmospheric CO_2 and store it in organic soils and biomass for thousands of years, stable and undisturbed.[40]

MECHANISM: RESTORATION

Globally, 8,120 km^2, or 6% of former mangrove areas are considered restorable according to the Mangrove Restoration Potential Report, supported by The Nature Conservancy, IUCN, and the University of Cambridge[41]. Of the land lost, 81.7% is considered highly restorable, making these locations prime locations for successful blue carbon initiatives.

PRIORITY AREAS

The level of restorability is based upon the restoration potential score, an expert-derived model for 'restorability' determined by key environmental components that influence the ease of restoration[24]. Areas with a restoration potential score of 60 or higher, based on a scale from 0–100, are considered highly restorable. Notable factors taken into consideration include sea level rise, tidal range, time since loss, and the average size of loss. The analysis makes clear that the restoration potential score is only a starting point and is unable to account for localized activity such as political, social and economic drivers, along with localized ecological and geological factors.

TABLE 4: Mangroves and Carbon — The Stats

DIMENSION	AMOUNT
Total Soil Carbon Held in Mangroves	6 Pg/C
Carbon Sequestered (estimated) by mangroves from 1990 to 2016	0.42 Pg/C
Total Storage Loss 1996–2016	0.436 Pg/C
Mangrove soil carbon stores lost from 1996–2016	**0.354 Pg/C**
Mangrove aboveground biomass stores lost since 1996–2016	0.082 Pg/C
Total Restorable Aboveground Biomass & Soil Carbon	0.365 Pg/C
Restorable Aboveground Biomass (AGB) through mangrove restoration (Equivalence: annual emissions from 25 million US homes in sequestration)	0.069 Pg/C
Restorable Soil Carbon through mangrove restoration (Equivalence: annual emissions from 117 million US homes in avoided emissions)	**0.296 Pg/C**

NOTE: Data for mangrove carbon stats from Worthington, T., & Spalding, M. (2018). Mangrove Restoration Potential: A global map highlighting a critical opportunity.

TABLE 5: Mangrove Restoration Areas

TOTAL RESTORABLE MANGROVE AREA (KM^2)	TOTAL HIGHLY RESTORABLE MANGROVE AREAS	REGION WITH HIGHEST OVERALL RESTORATION POTENTIAL
8,120 (6%)	6,630 (81.7%)	Southeast Asia: 3,037 km^2 6.4% of Global Mangroves

NOTE: Data for mangrove carbon stats from Worthington, T., & Spalding, M. (2018). Mangrove Restoration Potential: A global map highlighting a critical opportunity.

>> Key Player: Mangrove Action Project (MAP)

is a 25-year old nonprofit organization that supports and advocates for a technique of mangrove restoration called community-based ecological mangrove restoration (CBEMR) or ecological mangrove restoration (EMR). CBEMR is a comprehensive planning and implementation tool that facilitates community-driven restoration projects that solve the root causes of mangrove degradation so that mangroves can naturally regenerate, resulting in better survival rates and faster growth and ultimately producing a more resilient, self-sustaining mangrove ecosystem. CBEMR's focus on restoration projects that are community-driven and governed, socially just, and accountable to the specific conditions that will allow mangroves to thrive places MAP squarely within the three pillars of the Blue Carbon Code of Conduct. A report by Wetlands International and MAP's Asia Offices entitled, "To Plant or Not to Plant" outlines the case for CBEMR. The report warns that many well-intentioned restoration efforts that focus solely on outcomes such as the number of trees planted do not holistically integrate the local community or adequately consider the drivers of mangrove habitat disruption; these projects may be producing initially high survival rates but not creating long-term systems change or carbon storage.

PHOTO: SILAS BAISCH

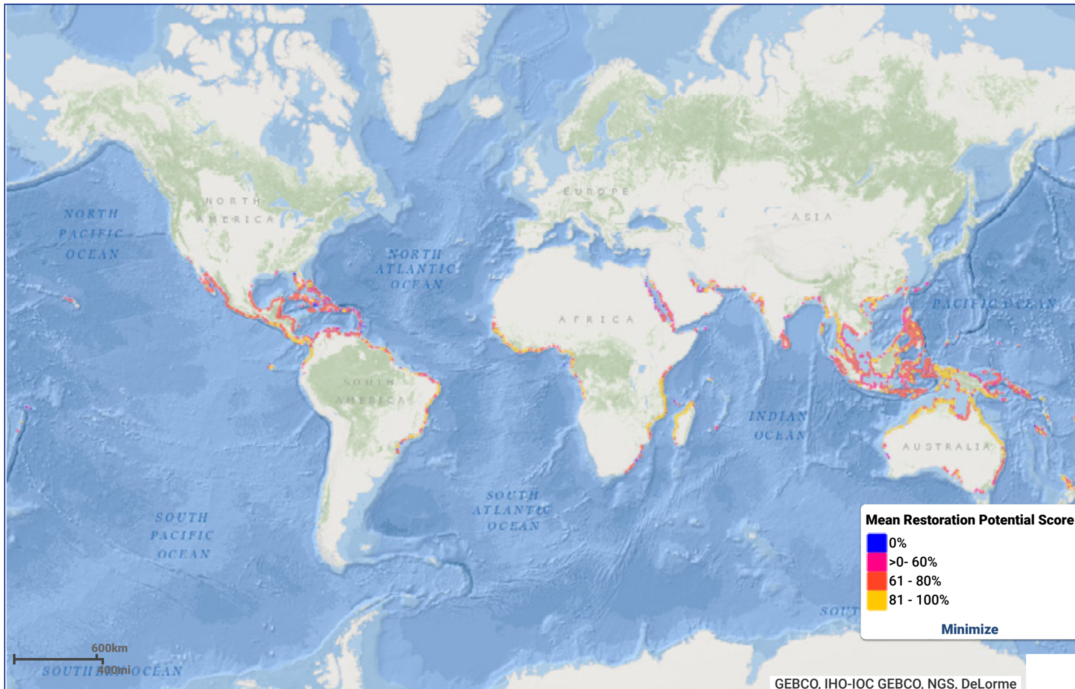

FIGURE 3. Map of Total Restorable Area of Mangroves Colored by Restoration Potential Score.

NOTE: To view an interactive version of this map and see more in-depth statistics by country, visit Mapping Ocean Wealth Explorer, an interactive mapping tool of marine and coastal ecosystems provided by the Nature Conservancy.

Not all mangrove typologies have the same restoration capacity or priority for ecosystem improvement initiatives. Some research indicates that overall, mangroves in deltaic coasts such as the Mississippi River delta, the Amazon in Brazil and the Sundarbans in India and Bangladesh can sequester more carbon yearly than any other aquatic or terrestrial ecosystem on the globe. These can be considered the world's blue carbon hot spots.[42]

That said, others have assessed, in detail, particular regions in the world where mangrove restoration is most feasible for greatest carbon impact over the greatest area.[43] The most recently provided estimate of total global area of mangroves is 136,714 km^2, based on 2016 data. Almost 90% of the world's restorable mangroves are located in 24 countries. Addressing the top five countries alone would include 56.5% of mangroves that can be restored.

TABLE 6: Restorable Areas Ranked by Largest Extents or High Proportion of Restorable Mangrove Area

COUNTRY (AREA IN KM^2)	RESTORABLE AREA	% TO TOTAL GLOBAL RESTORATION AREA	AVERAGE RESTORABILITY SCORE	EXTENT OF HIGHLY RESTORABLE MANGROVE AREAS	AREA OF DEGRADED MANGROVES
Indonesia	1,866	23.00%	0.64	1,616	419
Mexico	1,455	17.90%	0.65	993	33
Brazil	491	6.00%	0.73	476	58
Myanmar	436	5.40%	0.75	431	295
Australia	336	4.10%	0.74	314	54

NOTE: Data for mangrove carbon statistics from Worthington, T., & Spalding, M. (2018). Mangrove Restoration Potential: A global map highlighting a critical opportunity.

TABLE 7: Countries with the Highest Total Potential in Terms of Restorable Above-ground Biomass and Soil Carbon

TOP RANKED COUNTRIES	HIGHEST SUM OF RESTORABLE SOIL CARBON	HIGHEST AVERAGE SOIL CARBON PER RESTORABLE AREA	HIGHEST SUM OF RESTORABLE ABOVE GROUND BIOMASS	HIGHEST AVERAGE ABOVE GROUND BIOMASS PER RESTORABLE AREA
1	Indonesia 0.97 Pg	Indonesia 521 Mg/ha	Indonesia 0.21 Pg	Malaysia 120 Mg/ha
2	Mexico 0.42 Pg	United States 507 Mg/ha	Mexico 0.09 Pg	Indonesia 114 Mg/ha
3	Brazil 0.15 Pg	Malaysia 481 Mg/ha	Brazil 0.03 Pg	Papua New Guinea 114 Mg/ha
4	United States 0.11 Pg	Cuba 465 Mg/ha	Myanmar 0.03 Pg	Philippines 101 Mg/ha
5	Myanmar 0.10 Pg	Columbia 416 Mg/ha	Australia 0.02 Pg	Nigeria 91 Mg/ha

NOTE: Data for mangrove carbon statistics from Worthington, T., & Spalding, M. (2018). Mangrove Restoration Potential: A global map highlighting a critical opportunity.

BEST PRACTICES FOR SUCCESSFUL MANGROVE RESTORATION PROJECTS[44]

1. Understand the ecology and hydrology of the land.
2. Have local community engagement and support.
3. Establish clear responsibility and management of the project site.
4. Incorporate policy to ensure long-term success and prevent relapse.
5. Address causes of degradation and natural impediments to mangrove settlement and growth to allow for natural regeneration.
6. Improve land-use practices to decrease nutrient and sediment run-off.
7. If propagules are limited, plant mangrove seedlings and propagules to accelerate recovery.
8. Hydrological restoration is recognized as the most successful and cost-effective restoration approach and includes:
   - Restoring tidal hydrology through excavation or back-filling.
   - Reconnecting blocked areas to normal tidal influences.
   - Restoring hydrological regimes and sediment flow to ensure access to freshwater and sediments which help mangroves keep up with changes in sea level and support carbon sequestration.

MECHANISM: CONSERVATION

If mangroves are not conserved and are cleared from the land, we further propel global warming as soil carbon begins to decompose and living biomass carbon is swiftly converted to CO_2 and released into the atmosphere.

Protected Areas: Assign Responsibility: About 60% or 82,714 km^2 of the world's remaining mangroves are not under protected areas according to the World Database on protected areas (Worthington & Spalding).

Minimize Threats from External Environment: Within protected areas, degradation can be minimized but activities occurring outside and adjacent to protected areas can still potentially harm protected mangroves and thus should also be monitored and minimized. Threats to look out for include:

- Upstream water abstraction
- Sediment supply changes
- Coastal erosion
- Remote coastal engineering
- Sea level rise

>> Key Player: Silvoaquaculture

Silvoaquaculture, silvofisheries, Ecological Aquaculture[45] or the Indonesian "Empang Parit" aims to produce edible proteins and other saleable goods in mangrove forests while minimizing the disruption of the ecosystem itself. In response to the destruction caused by shrimp aquaculture, which cleared roughly 66,250 hectares of mangrove forests of the Ca Mau province of Vietnam between the years 1980–1995, the region adopted silvoaquaculture at scale and has certified roughly 10,000 hectares of shrimp aquaculture as organic (organic certification verifies that mangrove forests comprise 50% or more of the total farming area) as of 2015. Plans exist to expand that coverage to 20,000 hectares by 2020 and 118,000 hectares by 2030.[46]

>> Key Player: Silviculture

Silviculture is the practice of controlling the biomass production of forests, in this case mangrove forests, in order to harvest it for meeting human needs including fuel, forage, timber and food products.

Matang Mangrove Forest Reserve in Malaysia is the longest-running managed mangrove forest in the world, with systematic management beginning in 1904. The 40,288 hectares of this riverine mangrove forest is managed primarily for the production of pole timber and charcoal production from silviculture. Mangrove wood is harvested sustainably at 17.4 t/ha per year over a 30-year cycle.[47] Preserves like Matang can fulfill critical research and development roles for mangrove management. When the community is carefully engaged, a culture of silviculture can preserve forest extents over long timescales.

SEAGRASS

Seagrasses are common and form meadows in coastal environments, typically in very shallow waters down to 60 m depth. They occur in many areas of the world, but mainly in tropical Atlantic and tropical Indo–Pacific waters.

TABLE 8: Seagrass Area by Global Regions

REGION	COUNTRIES	DOCUMENTED SEAGRASS AREA (KM²)
1. Temperate North Atlantic	25	3,430
2. Tropical Atlantic	64	109,146
3. Mediterranean	30	25,260
4. Temperate North Pacific	6	1,675
5. Tropical Indo-Pacific	74	168,488
6. Temperate Southern Oceans	9	17,179
GLOBAL	**208**	**325,178**

NOTE: Data from Unsworth, Richard KF, Len J. McKenzie, Catherine J. Collier, Leanne C. Cullen-Unsworth, Carlos M. Duarte, Johan S. Eklöf, Jessie C. Jarvis, Benjamin L. Jones, and Lina M. Nordlund. "Global challenges for seagrass conservation." Ambio 48, no. 8 (2019): 801–815.

Some 30% of seagrass ecosystems have been lost globally over the last 50 years.

SEAGRASS AND CARBON – THE STATS

- Globally, seagrass ecosystems could store as much as 19.9 Pg/C
- The current seagrass carbon pool lies between 4.2 and 8.4 Pg/C[48]
- When healthy and not overgrazed, seagrass soils have the potential to sequester 1.38 Mg C/ha per year

PRIORITY LOCATIONS

For seagrasses, factors that affect carbon sequestration include water depth, turbidity, and other habitat variables. Priority for conservation and restoration should be given to large persistent species in shallow/low turbidity areas. Areas where coastal fishing communities can perform the active restoration and/or engage in co-managed conservation should be prioritized. Countries with active efforts include Madagascar, Malaysia, Indonesia, Mozambique, Solomon Islands, Sri Lanka, Vanuatu and Abu Dhabi.

It should be noted that in the case of restoration, a time lag of 10–20 years might be required to achieve carbon accumulation rates comparable with natural seagrass meadows.

BENEFITS

In addition to being a carbon sink, seagrasses provide a number of additional co-benefits. When not overwhelmed by eutrophication or coastal pollution, seagrass can utilize coastal runoff nutrient and mitigate eutrophication. Recent estimates suggest seagrass meadows support the productivity of
20% of the world's biggest fisheries through nursery habitat provision.[49] Wherever they are present in proximity to human populations they form a targeted fishing ground of significant importance to human livelihoods and well-being.[50] Seagrasses also provide key habitats for keystone species such as sea turtles.

MECHANISM: CONSERVATION, RESTORATION AND CREATION

Although there remains uncertainty on the total extent of global seagrass ecosystems, modeling has been developed that estimates the following potential for interventions:

- 35 Mha of existing seagrass can be protected through seagrass conservation
- 14.2 Mha of seagrass ecosystem, lost to degradation in the last 100 years, can be restored through seagrass restoration
- 143 Mha of potential habitat that could be suitable for seagrass can be planted through seagrass creation

The priority focus is seagrass conservation and restoration.

TECHNIQUES

Seagrass conservation practices are similar to the practices utilized in mangrove settings. Examples of notable successful conservation sites include small community led marine protected areas (MPA) (e.g., in Tolitoli and Baru Baru) and MPAs focused on protecting keystone species such as dugong (e.g., in Bintan). Conservation incentive schemes (e.g., community-led efforts to reforest degraded riparian vegetation such as in Wakatobi NP) are also indicated in certain regions.

Seagrass restoration presents certain challenges and opportunities regarding cost and survival rates. According to the most widely cited resources for costs of blue carbon ecosystem restoration, seagrass ecosystem total restoration costs average $383,672/ha (2010 USD). This is likely a high estimate, especially given a median survival rate of 38%. Recent exercises using volunteer manual planting are far cheaper at $16,000–$34,000/ha, depending on plant unit spacing. The same planting using paid labor ranges from $84,000 to $168,000/ha.[51]

Specific techniques and practices have been tested to reduce costs and increase survival rates, but their application is not yet a widespread practice. Best practices for seagrass restoration include:[52]

- Plant enough plants or seeds (between 1000 and 10,000 shoots/seeds at a minimum) for effective survival and population growth rate.
- Carefully select sites and species,for instance, a sheltered location with adequate light. Priority areas include shallow neritic zone areas that are less affected by pollution and/or areas where a complementary pollution mitigation strategy is being applied, such as a pollution biofiltration technique.
- Remove existing threats prior to replanting, e.g., controlling pollution, dredging.
- Prioritize water quality in restoration plans. Poor water quality is a leading cause of restoration failure.

One particular study of importance used biodegradable hessian bags (burlap sacks) partially filled with sand as a means of distributing seagrass plugs. Economically, hessian bags appear to be a sound option for large-scale rehabilitation. Materials are inexpensive and sites can be established by simply throwing bags off a boat as opposed to transplanting which is slow and costly to establish, requiring expensive divers and specialist expertise to cover a much smaller area per unit time. Cost-benefit analyses for large-scale rehabilitation indicate that a sowing density of 1000 hessian bags/ha would cost $16,737 (includes cost of materials, construction, and deployment), whilst covering the same area using transplants would cost at least $27,593.[53] The authors also estimate an ecosystem services value of $27,039/ha/y. So, payback on capital investment is 1 year.

Another paper identified clear increased survival rates (doubled) associated with a critical mass (minimum of between 1000 and 10,000 shoots/seeds) of planting.[54] The larger initial number of transplants were more resistant in the long term.

Fishing community-led efforts, using some form of hessian bag methodology, clustered for resilience, and observing the aforementioned best practices are best positioned to restore seagrass ecosystems for optimal cover, lowest cost and greatest co-benefits.

OCEAN FARMING

Recent analysis shows that as much as 30% of net primary production from growth of macroalgae is exported to deeper marine sediments where the carbon in these seaweeds becomes sequestered over long timeframes.[55]

Many coastal regions have the potential for extensive macroalgae reforestation and ocean farming. Those areas with economically depressed coastal fishing communities would be the highest priority locations.

FIGURE 4. High likelihood areas for natural seaweed production, brown for brown seaweeds, red for reds. Greens will generally grow in the same areas as browns. It should be noted that this method of identifying high likelihood areas is not exhaustive. Seaweeds are grown in many areas outside of those indicated and many sites within identified high likelihood areas will not be suitable.56 See map below for certain highly suitable areas.[56]

NOTE: Data from Yarish, C., Brummett, R., (Eds.) (2016). Seaweed Aquaculture for Food Security, Income Generation and Environmental Health in Tropical Developing Countries. Technical Report.

See map below for certain highly suitable areas.

OCEAN FARMING AND CARBON – THE STATS

The World Bank estimates the following impact from expanded seaweed farming over the next thirty years. While global seaweed production in 2012 was three million tons dry weight and growing at a rate of nine percent per year, increasing seaweed farming to 14% growth per year would generate 500 million tons dry weight by 2050.[57] Market development for potential uses for seaweed is critical to increase adoption of ocean farming.[58]

According to Project Drawdown, the food sector's potential to mitigate current contributions to global warming comprises one third of the plausible scenario for reversing global warming.[59] Thus, macroalgae's biggest contribution to rebalancing the carbon cycle may be via mitigating the emissions from other terrestrial agriculture activity, for instance by replacing carbon-intensive fertilizers and food products. Apart from mitigation, macroalgae, when not fully harvested, contribute to carbon burial when portions of the biomass is sequestered in long-term sediment storage[60] and foster soil carbon increases in terrestrial soil when used as an agricultural amendment with other soil-building practices (for instance, reduced tillage).

Ocean area required	500,000 km^2	Based on average annual yield of 1,000 dry tons/km^2 undert current best practice. Equals 0.03% of the ocean surface area.
Protein for people and animals	50,000,000 tons	Assumes average protein content of 10% dry weight. Estimated value $28 billion. Could completely replace fishmeal in animal feeds.
Algal oil for people and animals	15,000,000 tons	Assumes average lipid content of 3% dry weight. Estimated value $23 billion. Could completely replace fish oil in animal feeds.
Nitrogen removal	10,000,000 tons	Assumes nitrogen content 2% of dry weight. Equals 18% of the nitrogen added to oceans through fertilizer.
Phosphorous removal	1,000,000 tons	Assumes phosphorous content 0.2% of dry weight. Represents 61% of the phosphorous input as fertilizer.
Carbon assimilation	135,000,000 tons	Assumes carbon content 27% of dry weight. Equals 6% of the carbon added annually to oceans from greenhouse gas emissions.
Bioenergy potential	1,250,000,000 MWH	Assumes 50% carbohydrate content, converted to energy. Equals 1% of annual global energy use.
Land sparing	1,000,000 km^2	Assumes 5 tons/ha average farm yield. Equals 6% of global cropland.
Freshwater sparing	500 km^3	Assumes agricultural use averages 1 m^3 water/kg biomass. Equals 14% of annual global freshwater withdrawals.

FIGURE 5. Extrapolated ecosystem services from 500 million tons (dry weight) of seaweeds.

NOTE: Data from Yarish, C., Brummett, R., (Eds.) (2016). Seaweed Aquaculture for Food Security, Income Generation and Environmental Health in Tropical Developing Countries. Technical Report.

INTEGRATED SEAWATER AGRICULTURE SYSTEMS (ISAS)

ISAS is a method of selecting halophytes (salt-tolerant flowering plants) and intentionally cultivating them in desertified, degraded or desert soils by introducing saline irrigation, for instance "ocean rivers", to inland soils. This method of *creating* blue carbon habitats might be considered controversial due to the appearance of large-scale ecosystem manipulation.

ISAS methods have been piloted in Eritrea, Mexico and Egypt. Globally, the range of ecosystems suitable for ISAS include coastal deserts, inland salt deserts and regions where salinization has occurred due to industrialized agricultural practices otherwise known as "secondary salinization." According to a 2006 report, secondary salinization has spread to one billion hectares globally and is increasing at a rate of two million hectares annually. An estimated 130 million hectares may be immediately available for halophyte cultivation.[61]

>> Key Player: Greenwave

is a nonprofit that has developed a model for farms that sit just below the surface and leverage the entire water column. The coastal farming system they have developed and open-sourced grows 100,000 shellfish and 10 tons of kelp per acre. The archetypal Greenwave model farm requires 20 ocean acres, a boat, and $20,000 to get started. Greenwave's rapidly scaleable vision is to create 500 restorative ocean farms in 10 regions in the next 5 years to feed people with zero-input food. Each region would consist of small-scale ocean farms, a land-based hatchery and processing hub, and a ring of large-scale institutional buyers and entrepreneurs developing value-added products. These reefs are then replicated in strategic locations. In adherence to the Blue Carbon Code of Conduct, Greenwave prioritizes partnerships with indigenous-lead initiatives around the globe and the majority of their ocean farms are lead by women.

Ocean farming as a blue carbon strategy has been initiated in Korea. Critical locations for further development include China and North America.

ISAS AND CARBON – THE STATS

According to the same report, halophyte production in a potential 130 Mha area has the capacity to assimilate 0.6–1.2 Pg of carbon per year, sequestering 30–50% of this carbon in long-term soil carbon. Coupling with nitrogen-fixing salt-tolerant plants such as *Prosopis* or *Acacia* spp. could increase sequestration in soil carbon even further by two T/ha and grasses such as *Panicum vergatum* (or switchgrass) grown on degraded soil has been shown to increase soil carbon by 12% over 10 years.[62]

Carl Hodges and Arthur Gensler of Seawater Works have explored partnerships with the Cucapah Indians of Mexico to apply this technology by bringing seawater through the Salton Sea of California, travelling through Mexicali and the Imperial Valley along the way. Other priority locations include India, Morocco, Pakistan, and the countries of the Middle East and North Africa.

ISAS systems can be utilized for production of shrimp, tilapia, salicornia (pickleweed) and mangroves. These species produce a host of products including proteins, oils, fuel, habitat and improve soil carbon. Salicornia, being a dense carbohydrate, can also be turned into sturdy building materials. The dense groundcover cools local climates and builds soil carbon. Other uses include medicines (for such ailments as digestive troubles and heart disease), fuel wood and timber, forage/fiber, chemicals (such as soda for soap-making and glass) and landscaping.[63]

>> Key Player: **Blue Ventures (BV)**

is a social enterprise hybrid comprised of a for-profit excursion/education arm combined with a philanthropic arm which develops and tests new models for conservation and restoration. Their work has ambitions to reach 3M people in the world's tropical regions by 2020 and the organization has garnered respect for employing the necessary nuanced and grassroots-oriented understanding of the complexities of actualizing blue carbon for carbon sequestration and overall community health.

"We work in places where the ocean is vital to local cultures and economies, and are committed to protecting marine biodiversity in ways that benefit coastal people. By demonstrating that effective marine conservation is in everyone's interest, we're striving for impact at scale."

While this technique is still in a research and development phase, the potential boon to food security in very specific regions (i.e., coastal areas that are desertified and/or food insecure like California), makes this an attractive and potentially cost-effective strategy to explore. The blue carbon literature and funding sources largely overlook this mechanism.

BIOMIXING WHALE PUMP

Whales are creatures of the open ocean and although whales are found widely throughout the world's oceans, most species prefer the colder waters of the northern and southern hemispheres, and migrate to areas closer to the equator to give birth. Once relentlessly hunted, whales are now protected by international law which is not always enforced or enforceable.

Whales carry nutrients such as nitrogen from the ocean depths back to the surface. When whales (and other mammals with similar depth feeding and surface defecation patterns) defecate at the surface their liquid faeces, rich in iron and nitrogen, feed phytoplankton. The southern ocean is an example of a high nitrate low chlorophyll (HNLC) region. In these regions of the ocean, the limiting factor to the growth of phytoplankton and other micro-life is nutrients such as iron. Increasing the population and activity of whales in these regions could stimulate phytoplankton growth, some of which would be exported to the deep sea as sequestered carbon.The total potential impact of this nutrient provision is not well understood. The factors that need to be understood to develop an accurate estimate of their impact would include total current whale population (estimated at 10% of pre-commercial whaling population), growth of population, identification of defecation patterns and regional residence time for each species, the iron content of the diet of each type of whale and the export rate of phytoplankton to the deep ocean in each region.

The map in Figure 6 on the next page visualizes a number of areas of the ocean that are known as HNLC regions, where increasing the population and activity of whales could stimulate phytoplankton growth.

Whales are charismatic animals and linking them with carbon sequestration in popular discourse could stimulate increased emotional connection to blue carbon. Restoring whale populations implies protecting whales and whale habitat which would have co-benefits of increased fisheries and other cascading impacts on the carbon cycle.

Whales continue to be threatened by killings, captures, bombings, plastic ingestion, and pollution. Creating more MPAs, reducing plastic debris and reducing chemical, oil and sonic pollution all are effective means for increasing whale population and health.

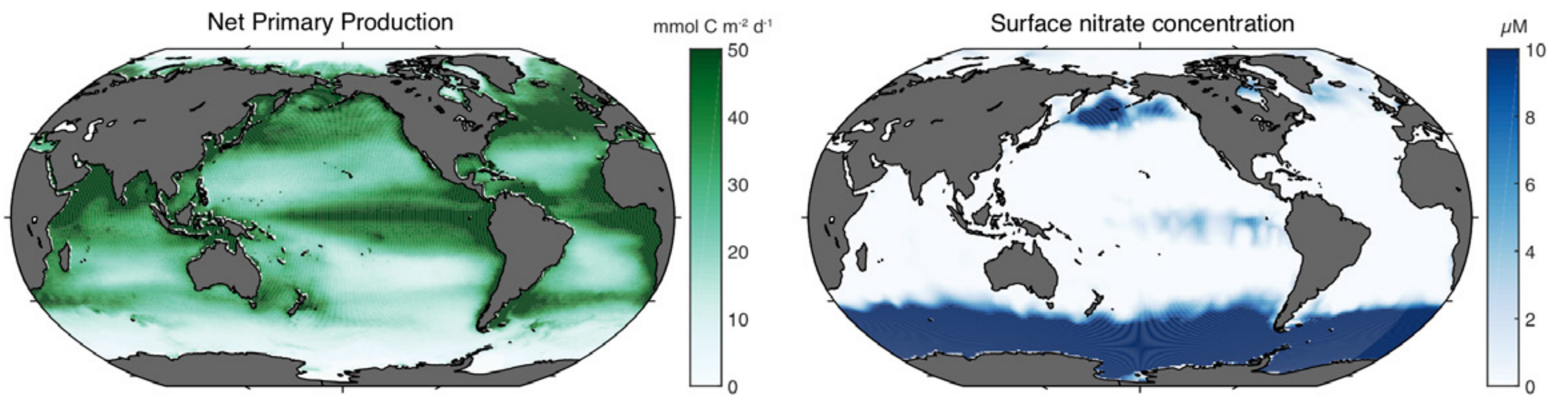

FIGURE 6. This map visualizes a number of areas of the ocean that are known as HNLC regions, where increasing the population and activity of whales could stimulate phytoplankton growth.[64]

NOTE: From Galbraith, E. D., Le Mézo, P., Bianchi, D., & Kroodsma, D. (2019). Growth limitation of marine fish by low iron availability in the open ocean. Frontiers in Marine Science, 6, 509.

A NOTE ABOUT "GEO-ENGINEERING" AND OTHER STRATEGIES

Based on actionable criteria referenced above by Lovelock, et al., this report focuses on potent and sometimes novel approaches within mostly conventional blue carbon mechanisms. Additionally, the report considers and assesses mechanisms for climate change mitigation known as geo-engineering.

The spider chart in Figure 7 from Gattuso, et al.[65] explains the readiness and durability of other, ocean-based strategies being examined and developed.

Similarly, the chart in Figure 8 on the next page from Gattuso, et al, affirms the conclusions regarding readiness (actionability) arrived at by Lovelock, et al. while providing additional detail regarding some of the strategies assessed in the section of this report entitled Additional Research Needed.

Of particular note are strategies to increase net primary productivity of phytoplankton. Due to the charisma of marine megafauna like whales and significant co-benefits associated with their preservation, this report has featured the biological mechanism of whale pump and biomixing, with noted potential limitations of carbon effect.

Ocean fertilization, the use of iron or other mineral nutrients to stimulate net primary productivity, has received much attention. Adding material to the ocean is potentially considered pollution and ocean fertilization is prohibited

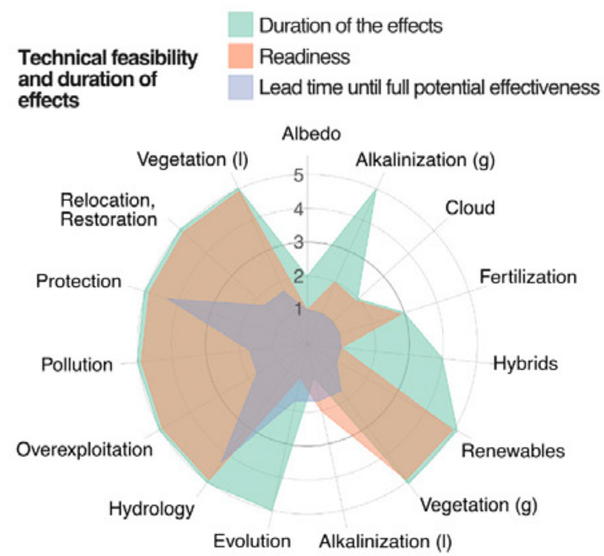

FIGURE 7. Assessment of ocean-based measures to address key ocean drivers. Scores 1 to 5: very low, low, moderate (thicker circle), high, and very high.

NOTE: Figure from Gattuso, J. P., Magnan, A.(Eds). (2018). Ocean solutions to address climate change and its effects on marine ecosystems. Frontiers in Marine Science, 5, 337.

(except for research purposes by the London Convention and the London Protocol). The main arguments against fertilization include ecological risks (uncertain and unintended effects on biological life and food webs other than phytoplankton) and the scale and duration of fertilization activity. An assessment framework has been developed for future research.[66]

Alkalinization also receives considerable attention. This mechanism involves adding carbonate material (examples include limestone and olivine) to the ocean to reduce acidity, which would enable the ocean to absorb additional carbon from the atmosphere. Critics have expressed concern about the emissions footprint of mining and transporting alkalizing land material to the ocean weighed against its carbon capture potential. This mechanism is particularly interesting because of the co-benefits of reducing acidification of the ocean. As of yet, there is no reasonable scale testing and measurement of the net benefits from this mechanism. Of particular note is Project Vesta—focused on olivine weathering.

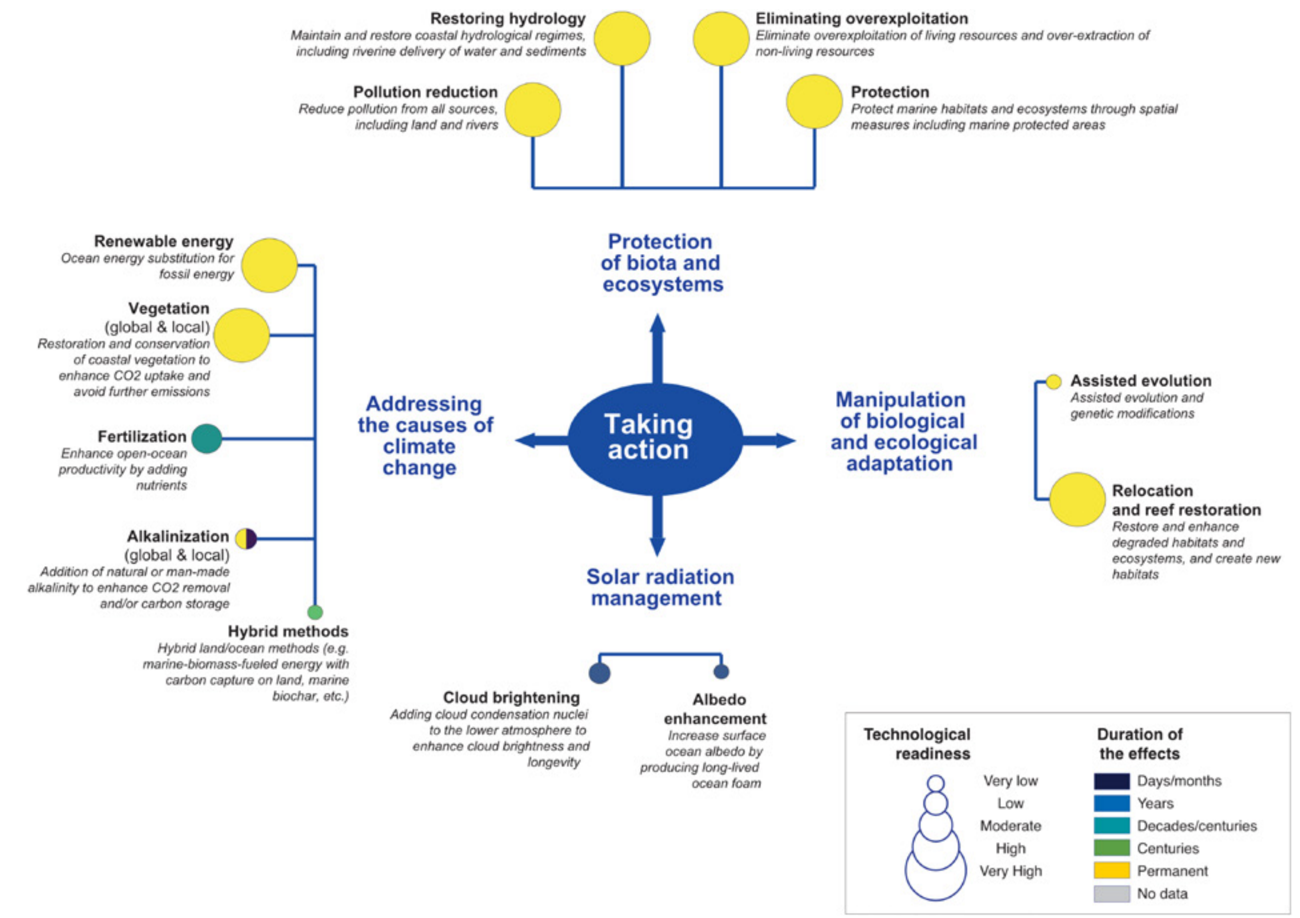

FIGURE 8. Potential ocean solutions. Four main groups are considered: addressing the causes of climate change (i.e., reducing anthropogenic greenhouse gas emissions or increasing the long-term removal of greenhouse gases, primarily CO_2), solar radiation management, protection of biota and ecosystems (habitats, species, resources, etc.), and manipulation of biological and ecological adaptation.

NOTE: Figure from Gattuso, J. P., Magnan, A.(Eds). (2018). Ocean solutions to address climate change and its effects on marine ecosystems. Frontiers in Marine Science, 5, 337.

SECTION 3

Blue Carbon Projects

MAP IMAGES CAROUSEL

There are a variety of maps that exist that geolocate a diversity of aspects of the Blue Carbon universe. Here are a number of maps you can click through to enhance your understanding.

WHERE ARE COASTAL BLUE CARBON ECOSYSTEMS?

Region	Mangrove		Seagrass		Salt marsh	
	Hectares	% of total	Hectares	% of total	Hectares	% of total
Africa	2,631,069	22.9%	6247	2.8%	1565	0.4%
Asia	3,276,758	28.6%	23,690	10.8%	22,008	6.3%
Australia and South Pacific	1,578,385	13.8%	2622	1.2%	16,644	4.7%
Central and South America	2,991,043	26.1%	10,368	4.7%	5315	1.5%
Europe	0	0%	23,614	10.7%	162,039	46.2%
Middle East	23,995	0.2%	351	0.2%	174	0.0%
North America	965,678	8.4%	153,266	69.6%	143,239	40.8%
Global total	**11,466,928**		**220,158**		**350,984**	

FIGURE 9. Known global extent and distribution of blue carbon ecosystems.[67]

SOURCE: Giri et al., 2011; Mcowen et al., 2017; UNEP-WCMC, 2016.

KUMU MAPS

A collaborative mapping project for cooperative input of identified blue carbon projects has been created as a by-product of the current report. We expect the following map to be updated regularly and provide a reference source for general use and distribution to projects around the globe.

Please visit the online and interactive version of this report at spaceshipearth.live/blue-carbon to explore three maps- geographic, resources, and research.

While blue carbon funding has been steadily increasing (and the known dataset has likely not captured the entirety of these increases), based on the CEA data reviewed comprising an analysis of 317 grants from 2009 through full-year 2016, and partial years 2017 and 2018, the following geographical focus of funding was identified:

Table 9: Funding by Location

TIER 1 LOCATION	TOTAL GRANTS
Asia	$3,105,467
North America	$11,493,232
South America	$2,825,942
Unspecified	$18,211,288
Europe	$3,496,271
Global	$6,408,296
Oceania	$4,395,857
Africa	$3,160,382
Science	$3,852,963
Central America and Caribbean	$195,500
Arctic	$250,000
TOTAL	**$57,395,198**

PART 2
ACTION

PHOTO: ABIGAIL LYNN

GUIDING NATURE-INSPIRED PRINCIPLES

Grow New Biomass
— as the source of most rapid carbon gains, biomass can be used to immediately benefit communities via food, fiber and fuel production.

Stack In Benefits
— include political regulation, community engagement, local restorative food, fuel and income generation, ecosystem restoration, conservation, etc. with each project. Ecosystems whether existing or restored are best managed when they are integral to the health of local communities.

Stakeholder Engagement At Every Level
— beyond mere financial involvement, can we learn from nature in inviting diverse voices to increase the resiliency of projects?

HOW TO ACTIVATE A BLUE CARBON MASS MOBILIZATION

1. DEMONSTRATE VIABILITY AND SCALABILITY OF BLUE CARBON PROJECTS THROUGH A NETWORK OF PROJECTS.

2. FULLY INTEGRATE BLUE CARBON INITIATIVES INTO EXISTING AND NEW POLICY.

3. ENSURE PROJECTS HAVE EXCELLENT MANAGEMENT PROTOCOLS THAT ARE CLEAR AND IMPLEMENTABLE.

4. DEFINE CLEAR PROJECT METHODOLOGY.

SECTION 4

Funding Gaps

BLUE CARBON PROJECTS (conservation, restoration or other) appear to receive less than a quarter of one percent of global philanthropic funding associated with ocean and ocean environments. FundingtheOcean.org (Foundation Maps by Candid)[68] lists $8.3 billion total dollar value from 51,412 grants given globally for oceans and ocean environments from 2009–2019. Using query terms common to blue carbon ecosystems, the number of global grants to blue carbon related initiatives from 2009–2019 totaled 175 and $20,000,000 (0.24% of total giving for oceans). For comparison "coral" totals 2,004 grants for $206,100,000.

A separate analysis of Funding The Ocean data analyzed by CEA Consulting has identified those grants that had been previously tagged by CEA staff during review as relating to blue carbon and those grant descriptions which contained "blue carbon," "mangrove," "seagrass" or "coastal wetland." This analysis showed 317 grants from 2004–2017 broadly classifiable as blue carbon initiative support for a total of $57,395,198.

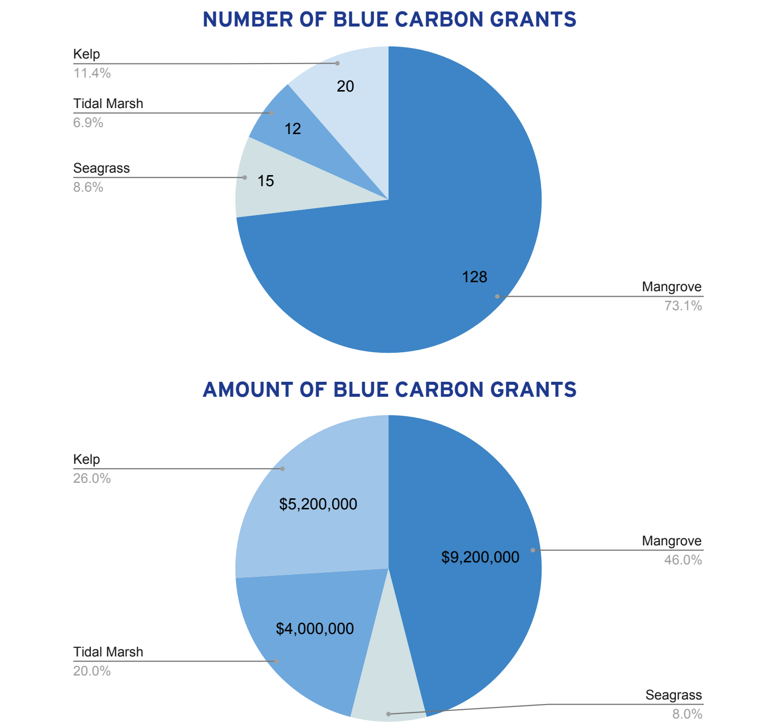

FIGURE 10. Blue Carbon Grants on FundtheOcean.org 2009–2019

SOURCE: FundtheOcean.org.

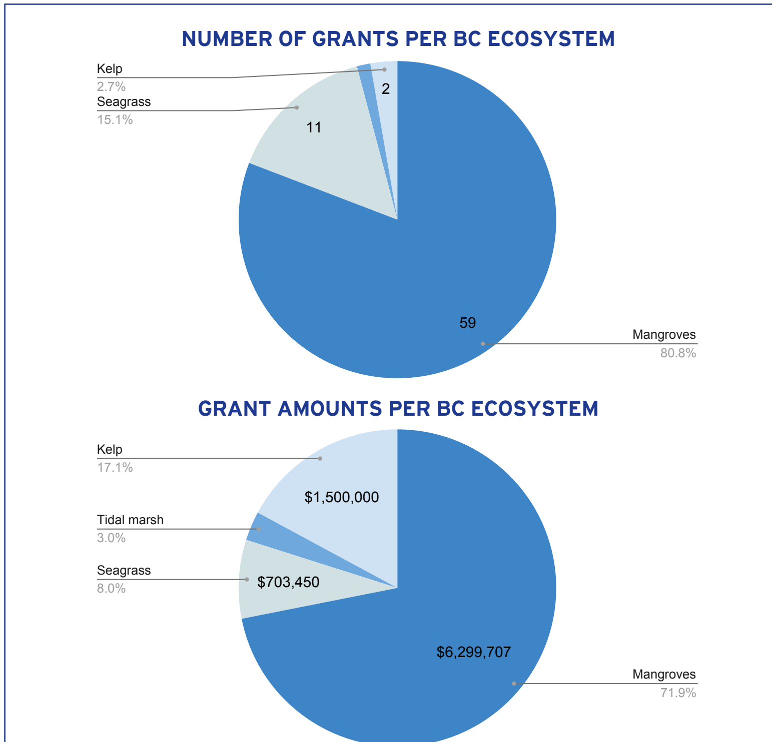

FIGURE 11. Blue Carbon Grants on FundtheOcean.org analyzed by CEA 2004–2017

SOURCE: FundtheOcean.org.

Some patterns clearly appear:

- Only a small percentage of philanthropic funding for oceans and ocean health has been allocated to blue carbon initiatives or projects identified as blue carbon related
- Mangroves receive the majority of blue carbon funding

In order to gauge the amount of resources potentially needed to significantly scale up blue carbon a simplified analysis was done looking at a few key blue carbon ecosystems, their potential for restoration and creation (does not include protection and conservation of existing extent) and the average cost (and average low cost) for acting on **restorable** extent.

Not including conservation costs (creating MPAs, etc.) but only considering active restoration and creation of certain blue carbon ecosystems, there is a need for between US$425 billion to US$60 trillion to achieve total potential impact. This cursory analysis also points to some critical funding needs to reduce the cost of restoration and creation and to better understand how natural (i.e., not active) revegetation might occur from protection and conservation and reduce the overall cost. Current philanthropic giving needs to be catalytic to larger pools of resources (e.g., government and multilateral funds) as the total philanthropic giving to oceans is a couple of orders of magnitude too little to fully resource blue carbon ecosystem restoration and protection. Challenges and constraints identified by government funders and the investment community include the need for more reliable estimate of blue carbon offset metrics and co-benefit yields developed through more (measured) pilot projects. Additionally, uncertainty of financial costs and returns, lack of government policy and legal frameworks have been named as barriers.[72]

FUNDING MECHANISMS

Financing blue carbon project implementation at scale remains the most difficult task for achieving conservation and restoration objectives[73] and the investment mechanisms and desire to finance projects remain inadequate.[74]

There are a diversity of multilateral and national funds that could possibly finance blue carbon strategies. Philanthropy and debt purchasing or conversion are non-market, non-multilateral or national fund mechanisms that play a critical role in developing pilot projects that prove the funding hypothesis for the investment of larger pools of capital and the use of market-based mechanisms. Carbon markets (voluntary and regulated) are still at an emergent stage, but are showing promise (e.g., see Seagrass Grow as of Sept. 2019—335,222 sq ft of seagrass planted).

Figure 12 on the next page describes current potential funding sources.

Interviews conducted for this report and the current literature recommend leveraging private funding to develop a network of demonstration projects needed to show the viability of blue carbon projects in order to garner funding, sequester carbon and build community resilience simultaneously. Demonstration projects can help build investor confidence,expedite development of regulatory frameworks and policy, act as incubators to develop tools to reduce project costs, expose unforeseen risks, and calibrate estimates of carbon

TABLE 10: Blue Carbon Ecosystems by Restoration Potential and Average Cost [69, 70, 71]

ECO-SYSTEM TYPE	TOTAL ESTIMATED ECOSYSTEM AREA (2019)	EST. HISTORICAL RANGE (1850+)	EST. RECENT LOSS (1850+)	EST. POTENTIAL RANGE	POTENTIAL RESTORATION	POTENTIAL RESTORATION & EXPANSION	AVG. COST RESTORATION PER HA	TOTAL POTENTIAL AVERAGE COST FOR TOTAL RESTORATION AND CREATION (EXPANSION)	LOW COST RESTORATION PER HA	POTENTIAL LOW COST (FOR MANGROVE AND SEAGRASS RESTORATION ONLY)
Mangrove	13,671,400	27,342,800	13,671,400		812,000	812,000	$2,508	$2,036,496,000	$786	$638,232,000
Seagrass	35,000,000	49,295,775	14,295,775	164,678,800	14,295,775	143,974,575	$383,672	$55,239,013,004,304	$29,749	$425,285,000,000
Tidal Marsh	38,000,000	50,000,000	12,000,000		12,000,000	12,000,000	$151,129	$1,813,548,000,000		
Kelp	350,000,000			571,000,000		221,000,000	$15,000	$3,315,000,000,000		
							TOTAL	$60,369,597,500,304	**TOTAL**	$425,923,232,000

NOTE: Data for mangrove carbon statistics from Worthington, T., & Spalding, M. (2018). Mangrove Restoration Potential: A global map highlighting a critical opportunity.

offset yields and co-benefits.[76] These demonstration projects should be designed to harvest key outcomes and ways to overcome problems and pitfalls of project implementation. Blue carbon as a vehicle for ecosystem conservation, sustainable use and restoration also needs to be fully integrated into existing national and regional policy frameworks as a mechanism for climate change mitigation. Most projects have suffered from poor management protocols, such as not having proper success or failure criteria, and from poor or uncertain methodology. The Abu Dhabi Global Environmental Data Initiative provides an introductory guide to building blue carbon projects, created in collaboration with over 10 notable organizations[77]. The United Nations Environment Programme (UNEP) has developed Guiding Principles for delivering wetland carbon projects[78].

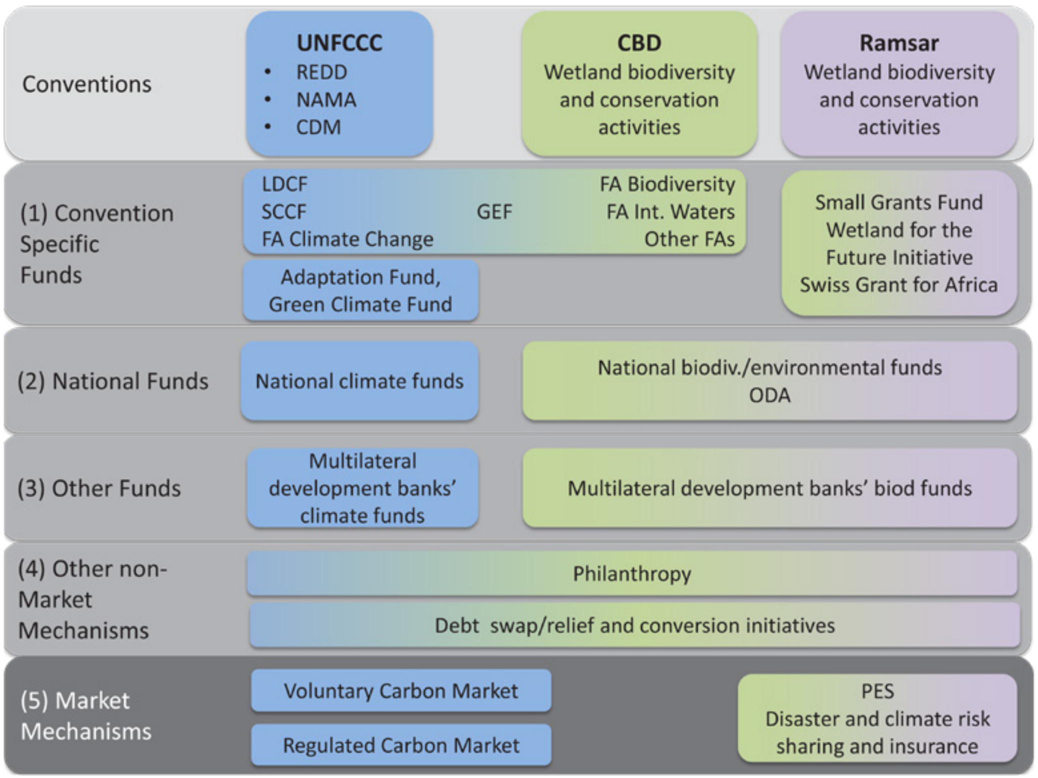

FIGURE 12. Overview of the main climate (blue) and biodiversity-related (green and purple) finance mechanisms relevant for coastal (wetland) carbon projects and programs.

NOTE: Figure from Herr, D. T. Agardy, D. Benzaken, F. Hicks, J. Howard, E. Landis, A. Soles and T. Vegh (2015). Coastal "blue" carbon. A revised guide to supporting coastal wetland programs and projects using climate finance and other financial mechanisms. Gland, Switzerland: IUCN[75]

During the interview process informing this report, interviewees were asked to identify some of the "key players" that are currently contributing to the space. Of the thirteen interviewees, coastal communities (referenced by nine interviewees) and fishermen (referenced by six) were the most commonly referenced key players, yet foundations appear to be neglecting them. Upon entering the search term "fishermen or fisherman" in the Funding the Ocean database (which describes funding from 2009 to September 2019)[80] global funding for initiatives focused on supporting fishermen was $32.3 million compared to "fishing," which received $1.8 billion globally. Coastal communities appear to have received more funding than fishermen advocacy groups at $125.7 million and coastal restoration received even more at $207.2 million. Key players that were mentioned by a subset of two or three interviewees include "indigenous communities" which received just $27.8 million of global giving and "youth" which received $17.6 million globally. Community-based ecological mangrove restoration (CBEMR) appeared grossly under-funded, receiving only $38,058 of global oceans giving, according to Funding the Ocean.

Based on our interviews, the following key players are optimal candidates for increased philanthropic funding:

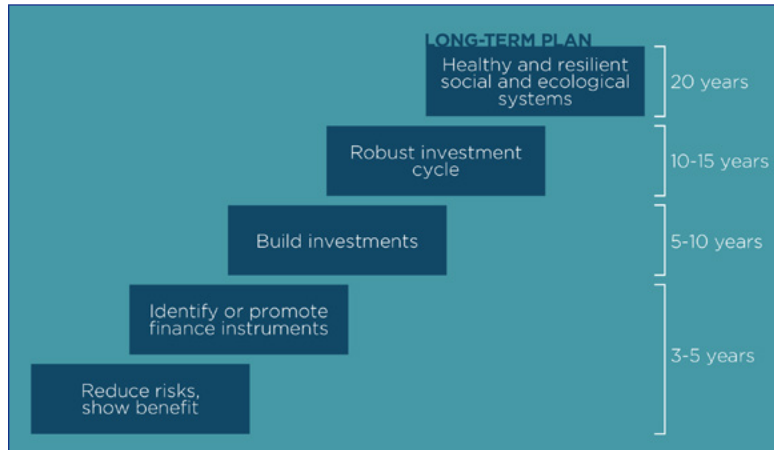

FIGURE 13. Graphical representation of the steps needed to develop investments that will support healthy and resilient socialecological blue carbon systems.

NOTE: Figure from Vanderklift, Mat & Marcos-Martinez, Raymundo & Butler, James & Coleman, Michael & Lawrence, Anissa & Steven, Andy & Thomas, Sebastian. (2017). Blue Carbon Finance Workshop Summary. 10.13140/RG.2.2.18649.21609.[79]

1. Community-based ecological mangrove restoration (CBEMR)
2. Indigenous-lead initiatives
3. Youth-centered restoration and conservation
4. Coastal fishing communities
5. Non-charismatic habitats and species such as seagrasses and species inhabiting salt marshes (such as salicornica)

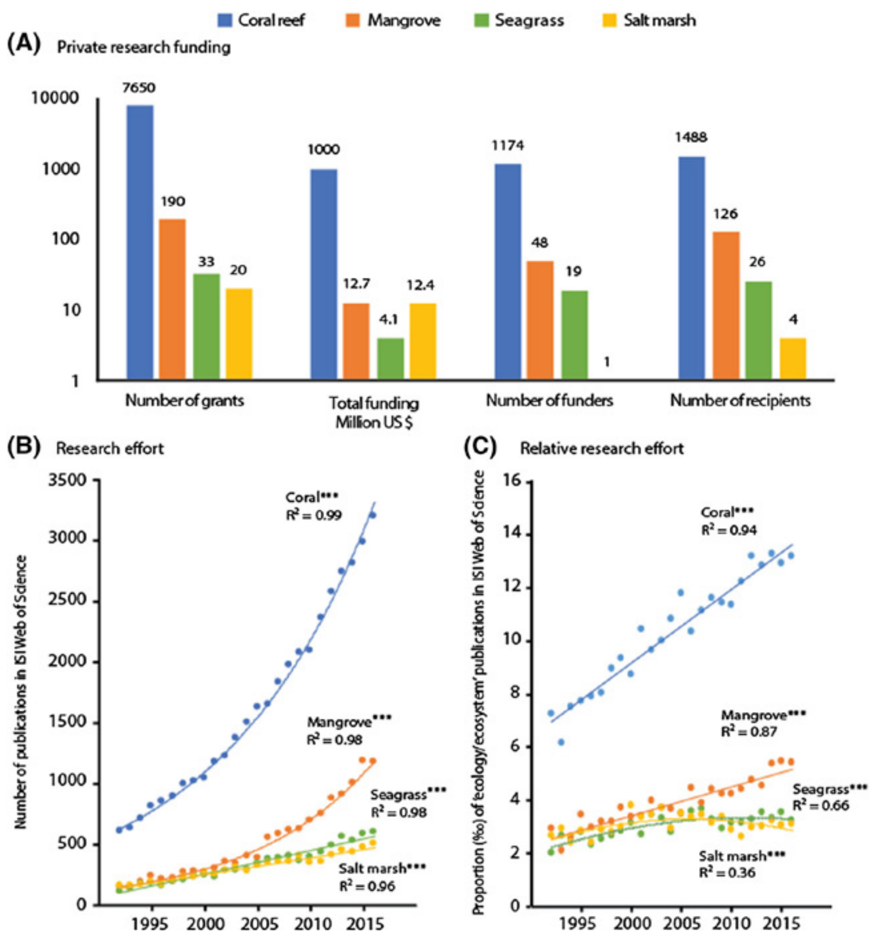

FIGURE 14. Private Research Funding, Research Efforts & Relative Research Effort by Blue Carbon Ecosystem.[81]

Ocean conservation and funding typically focus on charismatic habitats and species (such as coral), while ignoring many less familiar habitats, such as seagrass, and species that are of major significance to responding to the challenges of climate and food security such as whales. The chart below shows the "imbalance in funding to, and effort in, research and conservation on four coastal ecosystems: coral reefs, seagrass meadows, mangroves and salt marshes. Graphs show differences in a) private foundation funding (summarised over the period 2006–2016), and increasing temporal differences, b) research effort (number of publications per year during 1992–2016) and c) the proportion of general ecology/ecosystem research effort (number of publications) allocated to each of the four ecosystems." The lack of conservation attention toward lesser known habitats remains problematic in light of limited and finite conservation and restoration resources.

TABLE 11: Key Organizations to Feature

BLUE CARBON ORGANIZATIONS	BLUE CARBON ECOSYSTEM	SPECIALTY/NOTES
Grid Arendal	Coastal, Oceanic	Global
Ocean Foundation	Coastal	Global
King Abdullah University of Science and Technology	Coastal, Oceanic	Global
Blue Carbon Initiative / Ocean Forests Foundation	Oceanic	Global
International Scientific Working Group on Blue Carbon	Coastal	Global
Chesapeake Bay Foundation	Coastal	Chesapeake Bay, US
Worldview International Foundation's Mangrove Restoration Project	Coastal	Global
GCEEF.org	Coastal	Jamaica, Philippines, Thailand, Indonesia, Singapore, Malaysia, India, USA

SECTION 5

Additional Research Needed

MACREADIE, PETER I., ET AL. HAVE IDENTIFIED A TEN-POINT ROADMAP for continued research in blue carbon.[82] Of these ten research areas, four align with the highest potential for actionable carbon sequestration covered in this report.

1. **How does climate change impact carbon accumulation in mature blue carbon ecosystems and during their restoration?**
2. **What is the global importance of macroalgae, including calcifying algae, as blue carbon sinks/donors (i.e., does macroalgae carbon biomass become respired back to the atmosphere or how much of the production becomes long term carbon storage as sediment on the seafloor)?**
3. **What factors influence blue carbon burial rates?**
4. **What management actions best maintain and promote blue carbon sequestration?**

How does climate change impact carbon accumulation in mature blue carbon ecosystems and during their restoration?

Some hyperbolic claims are made that, due to sea level rise, all coastal blue carbon projects and initiatives will be for naught. The argument is that the rate of sea level rise will soon be greater than the rate of material deposition and therefore all coastal blue carbon ecosystems will become open ocean/water ecosystems. Research indicates the story is much more nuanced and this outcome is not inevitable. Historically, observations of widespread wetland drowning are infrequent due its ability to actively engineer its own positioning and self-stabilize based on changing conditions[83]. Whether they continue to survive ever faster rates of sea level rise is unclear and vulnerability may even be overestimated[84]; yet modifiable human behavior is a key determinant of how effectively and quickly wetlands can continue to adapt[85].

- People
- Fish
- Carbon fertilization

What is the global importance of macroalgae, including calcifying algae, as blue carbon sinks/donors?

Macroalgae are highly productive and occupy the largest global area of any vegetated coastal ecosystem, yet only in relatively few cases have they been included in blue carbon assessments. A recent meta-analysis has estimated that macroalgae growing in soft sediments have a global carbon burial rate of 6.2 Tg C per year. This carbon burial rate occurs through as much as 30% of the primary production of kelp being naturally trimmed and exported via powerful ocean currents, which then deposit this excess biomass in deep ocean sediments and trenches. Krause-Jensen and Duarte's synthesis of multiple studies shows that macroalgae currents control this deposition of excess biomass in carbon sinks well beyond macroalgae habitats.[86] Determining specific mechanisms to enhance and increase carbon export from macroalgae stands to deep sea sediment should be an active area of research while simultaneously restoring macroalgae stocks through adoption of ocean farming.

- A sub-theme of this research question should include how to catalyze increased macroalgae stocks by creating market demand for macroalgae via research on potential uses for seaweed and current opportunities for expansion. The Nature Conservancy and Encourage Capital have begun to address this by quantifying, for example, the growth of the food thickeners market, which increased by 342% from 2006 to 2016.[87] Of course, this would require expanding macroalgae stocks sufficiently to both feed the market for seaweed consumption and increase deep sea carbon sequestration.

What factors influence blue carbon burial rates?

Specific project sites and regions show significant diversity in carbon burial rates within the same ecosystem type. Additional research on biogeochemical processes, temperature, hydrodynamics, biological actions and other factors that drive burial rates will help with carbon storage modeling and possibly prioritization of sites for restoration and conservation. This might involve researching specific species of seagrass or salt marsh vegetation or even mechanisms to modify or stimulate wave action or the location of high burial rate sites relative to other ecosystem features.

What management actions best maintain and promote blue carbon sequestration?

Developing and researching additional projects aligned with community-centered development that model practices of community inclusion and determination is critical. Technical, financial and policy barriers remain to be addressed before local initiatives can be scaled up to make large impacts—such as through national REDD+initiatives. This should also include research on how to reduce the costs and increase the co-benefits of restoration. A report reviewing the biophysical and institutional failures of mangrove restoration in the Philippines found that planting costs of mangrove rehabilitation escalated over the 20th century, with added costs attributed to management, supervision and project management and that survival rates were found to be just 10–20% despite this significant investment and increase in costs.[88]

Additional areas of further research identified in the development of this report include:

Oceanic Blue Carbon: In general a greater understanding of the mechanisms for increasing oceanic blue carbon capture is needed. Scientific understanding of marine vertebrate carbon is still in its infancy. Most of the carbon-trapping mechanisms that we have identified are based on limited studies, and can be refined with further research. So far, researchers have examined the carbon-trapping abilities of less than one percent of all marine vertebrate species. (Sea creatures and their carbon sequestration potential.) There is still a critical question as to whether viruses hinder or stimulate biological production[89]. Fertilization and alkalinization of the ocean are interesting potential mechanisms. Additional research and action are recommended with caution regarding fertilization in order to avoid unintentional negative consequences by, for instance, measuring life cycle costs and emissions.

1. **Conduct research on how to reduce costs to implement coastal blue carbon restoration projects at larger scales**
2. **Conduct interviews with funders to discover barriers**
3. **Pilot projects that help mainstream the notion of geographic and community-informed suitability:** In a changing climate, with a rapidly shifting research landscape, rather than spending philanthropic dollars mapping and modeling the “most ideal” areas for restoration, funds should be deployed to “put on the map” “optimal archetypal restoration pilot projects” and monitor their success in a manner that mainstreams and open-sources learnings, budgets and business models to promote project viability, which could entice larger pools of capital investment such as impact capital and multilateral funding.

SECTION 6

Big Picture Strategies

A MIX OF OFFENSIVE AND DEFENSIVE, restoration and conservation actions addressing the threats to blue carbon ecosystems at every level, from local to global, is required. Nature shows it thrives in diversity and this is no exception for approaches to blue carbon. We need an intersectoral and inclusive approach to craft long-term systemic impacts.

Strategies to catalyze blue carbon solutions:

1. **Conserve** – Coastal ecosystems must be conserved before full restoration can take place or they will emit and continue to emit high amounts of carbon from degraded areas and drained soils. These emissions will continue even if external threats to these ecosystems are addressed. Tactics include: expanding protected areas, limiting external threats (including ecosystem conversion for development/ logging/aquaculture, pollution and industrial contamination, desalinization, unsustainable/ destructive fishing and upland drainage).
2. **Involve community** – Enforce land-use laws by increasing community capacity for commons management.
3. **Restore** – Restore coastal blue carbon ecosystems for optimal co-benefits.
4. **End the exploitation** – Expand protected areas for marine mammals and end whaling.
5. **Reduce demand** – Transform global protein demand from fish stocks and climate-intensive land-based proteins to proteins produced with restorative methods (e.g., macroalgae production, whose dry weight matter can be 10–30% protein,[90] in tandem with bivalve/shellfish mariculture, ecological aquaculture farming[91], integrated seawater agriculture systems).
6. **Feed people, not profit** – Industrial fishing today is dominated by high income countries with "97% of the trackable industrial fishing on the high seas and 78% of such effort within the national waters of lower-income countries."[92] Additionally, 90% of the fish used for purposes other than for direct human consumption (DHC) (e.g., fish feed for aquaculture systems) comes from food grade fish.[93] We should transition from a mindset of fueling optimal profit to one of producing enough food for everyone, with an emphasis on the world's poor first.
7. **Fund Additional Research** – Fund additional research to clarify carbon storage and carbon burial rates for seagrass ecosystems that will reduce the costs of restoration and thereby realize the full impact of coastal and oceanic blue carbon.

Endnotes

1. Waycott, M., Duarte, C. M., Carruthers, T. J., Orth, R. J., Dennison, W. C., Olyarnik, S., ... & Kendrick, G. A. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the national academy of sciences, 106*(30), 12377–12381. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2707273/

2. Lovelock CE, Duarte CM. 2019 Dimensions of Blue Carbon and emerging perspectives. Biol. Lett. 15: 20180781. http://dx.doi.org/10.1098/rsbl.2018.0781

3. Siikamäki, J., Sanchirico, J. N., & Jardine, S. L. (2012). Global economic potential for reducing carbon dioxide emissions from mangrove loss. *Proceedings of the National Academy of Sciences of the United States of America, 109*(36), 14369–14374. doi:10.1073/pnas.1200519109

4. https://news.gefblueforests.org/mapping-blue-carbon-in-coastal-mangrove-forests

5. Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M. A., ... Serrano, O. (2012). Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience, 5*(7), 505–509. doi:10.1038/ngeo1477

6. Duarte CM and Krause-Jensen D (2017) Export from Seagrass Meadows Contributes to Marine Carbon Sequestration. *Front. Mar. Sci.* 4:13. doi: 10.3389/fmars.2017.00013

7. Unsworth, R. K., McKenzie, L. J., Collier, C. J., Cullen-Unsworth, L. C., Duarte, C. M., Eklöf, J. S., ... & Nordlund, L. M. (2019). Global challenges for seagrass conservation. Ambio, 48(8), 801–815.

8. Ortega, A., Geraldi, N. R., Alam, I., Kamau, A. A., Acinas, S. G., Logares, R., ... Duarte, C. M. (2019). Important contribution of macroalgae to oceanic carbon sequestration. *Nature Geoscience.* doi:10.1038/s41561-019-0421-8

9. Bjerregaard, Rasmus; Valderrama, Diego; Radulovich, Ricardo; Diana, James; Capron, Mark; Mckinnie, Cedric Amir; Cedric, Michael; Hopkins, Kevin; Yarish, Charles; Goudey, Clifford; Forster, John. 2016. *Seaweed aquaculture for food security, income generation and environmental health in Tropical Developing Countries (English).* Washington, D.C. : World Bank Group.

10. Khan, M. (2006). Crop diversification through halophyte production on salt-prone land resources. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 1*(048). doi:10.1079/pavsnnr20061048

11. Turner, J. T. (2015). Zooplankton fecal pellets, marine snow, phytodetritus and the ocean's biological pump. *Progress in Oceanography,* 130, 205–248.

12. http://alturl.com/w6i7w Accessed September 2019

13. Blue Forests Project. "Blue Carbon Code of Conduct" https://news.gefblueforests.org https://news.gefblueforests.org/blue-carbon-code-of-conduct#! (Accessed September 25, 2019)

14. Baumert, H.Z.; Petzoldt, T. The role of temperature, cellular quota and nutrient concentrations for photosynthesis, growth and light-dark acclimation in phytoplankton. Limnologica 2008, 38, 313–326.

15. Bopp, L., Bowler, C., Guidi, L., Karsenti, E., & de Vargas, C. (2015). The ocean: a carbon pump. *See http://www. ocean-climate.org.*

16. Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., & Lynch, J. C. (2003). Global carbon sequestration in tidal, saline wetland soils. *Global biogeochemical cycles,* 17(4).

17. Duarte, C. M., Kennedy, H., Marbà, N., & Hendriks, I. (2013). Assessing the capacity of seagrass meadows for carbon burial: current limitations and future strategies. *Ocean & coastal management, 83,* 32–38.

18. Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., ... & Silliman, B. R. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Frontiers in Ecology and the Environment, 9*(10), 552–560.

19. Serrano, O., Kelleway, J. J., Lovelock, C., & Lavery, P. S. (2019). Conservation of Blue Carbon Ecosystems for Climate Change Mitigation and Adaptation. In *Coastal Wetlands* (pp. 965–996). Elsevier.

20. Pendleton, L., Donato, D. C., Murray, B. C., Crooks, S., Jenkins, W. A., Sifleet, S., ... & Megonigal, P. (2012). Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. *PloS one, 7*(9), e43542.

21. Spalding, MD; Brumbaugh RD; and Landis, E (2016). Atlas of Ocean Wealth. The Nature Conservancy. Arlington, VA.

22. Siikamäki, J., Sanchirico, J. N., & Jardine, S. L. (2012). Global economic potential for reducing carbon dioxide emissions from mangrove loss. *Proceedings of the National Academy of Sciences of the United States of America, 109*(36), 14369–14374. doi:10.1073/pnas.1200519109

23. Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M. A., ... Serrano, O. (2012). Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience, 5*(7), 505–509. doi:10.1038/ngeo1477

24. Duarte CM and Krause-Jensen D (2017) Export from Seagrass Meadows Contributes to Marine Carbon Sequestration. *Front. Mar. Sci.* 4:13. doi: 10.3389/fmars.2017.00013

25. Ortega, A., Geraldi, N. R., Alam, I., Kamau, A. A., Acinas, S. G., Logares, R., ... Duarte, C. M. (2019). Important contribution of macroalgae to oceanic carbon sequestration. *Nature Geoscience.* doi:10.1038/s41561-019-0421-8

26. Turner, J. T. (2015). Zooplankton fecal pellets, marine snow, phytodetritus and the ocean's biological pump. *Progress in Oceanography, 130,* 205–248.

27. Spalding, M., Brumbaugh, R., & Landis, E. (2016). Fact box 3. The role of ocean viruses and bacteria in the carbon cycle

28. Pendleton, L., Donato, D. C., Murray, B. C., Crooks, S., Jenkins, W. A., Sifleet, S., ... & Megonigal, P. (2012). Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. *PloS one, 7*(9), e43542.

29. D. Herr, E. Landis, Coastal blue carbon ecosystems: Opportunities for Nationally Determined Contributions.Policy brief, http://bluecsolutions.org/dev/wp-content/uploads/BC-NDCs_FINAL.pdf

30. D. Herr, E. Landis, Coastal blue carbon ecosystems: Opportunities for Nationally Determined Contributions.Policy brief, http://bluecsolutions.org/dev/wp-content/uploads/BC-NDCs_FINAL.pdf

31. Spalding, MD; Brumbaugh RD; and Landis, E (2016). Atlas of Ocean Wealth. The Nature Conservancy. Arlington, VA. p. 47

32. Spalding, MD; Brumbaugh RD; and Landis, E (2016). Atlas of Ocean Wealth. The Nature Conservancy. Arlington, VA.

33. Hemminga, Marten A., and Carlos M. Duarte. *Seagrass ecology.* Cambridge University Press, 2000.

34. Danielsen, Finn, Mikael K. Sørensen, Mette F. Olwig, Vaithilingam Selvam, Faizal Parish, Neil D. Burgess, Tetsuya Hiraishi et al. "The Asian tsunami: a protective role for coastal vegetation." *Science* 310, no. 5748 (2005): 643–643.

35. Lovelock CE, Duarte CM. 2019 Dimensions of Blue Carbon and emerging perspectives. Biol. Lett. 15: 20180781. http://dx.doi.org/10.1098/rsbl.2018.0781

36. Waycott, M., Duarte, C. M., Carruthers, T. J., Orth, R. J., Dennison, W. C., Olyarnik, S., ... & Kendrick, G. A. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the national academy of sciences, 106*(30), 12377–12381.

37. Worthington, T., & Spalding, M. (2018). Mangrove Restoration Potential: A global map highlighting a critical opportunity.

38. Miteva, D. A., Murray, B. C., & Pattanayak, S. K. (2015). Do protected areas reduce blue carbon emissions? A quasi-experimental evaluation of mangroves in Indonesia. Ecological Economics, 119, 127–135.

39. "Mangroves | Smithsonian Ocean." 30 Apr. 2018, http://ocean.si.edu/ocean-life/plants-algae/mangroves.

40. Spalding, MD; Brumbaugh RD; and Landis, E (2016). Atlas of Ocean Wealth. The Nature Conservancy. Arlington, VA.

41. Worthington, T., & Spalding, M. (2018). Mangrove Restoration Potential: A global map highlighting a critical opportunity

42. https://news.gefblueforests.org/mapping-blue-carbon-in-coastal-mangrove-forests

43. Worthington, T., & Spalding, M. (2018). Mangrove Restoration Potential: A global map highlighting a critical opportunity

44. Ellison, A. M., 2000; Lewis, 2005; Lewis, Streever, & Theriot, 2000; McLeod et al., 2009

45. Costa-Pierce, B.A. 2015. Seven Principles of Ecological Aquaculture: A Guide for the Blue Revolution. Ecological Aquaculture Foundation, Biddeford, Maine, USA. ©2015 Ecological Aquaculture Foundation

46. Retrieved from https://www.greatermekong.org/how-mangrove-friendly-shrimp-farming-protecting-mekong-delta

47. Bosire, J. O., Dahdouh-Guebas, F., Walton, M., Crona, B. I., Lewis, R. R., Field, C., ... Koedam, N. (2008). Functionality of restored mangroves: A review. Aquatic Botany, 89(2), 251–259. doi:10.1016/j.aquabot.2008.03.010

48. Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M. A., ... & Serrano, O. (2012). Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience, 5*(7), 505.

49. Unsworth, R. K., McKenzie, L. J., Collier, C. J., Cullen-Unsworth, L. C., Duarte, C. M., Eklöf, J. S., ... & Nordlund, L. M. (2019). Global challenges for seagrass conservation. Ambio, 48(8), 801–815.

50. Nordlund, Lina M., Richard KF Unsworth, Martin Gullström, and Leanne C. Cullen-Unsworth. "Global significance of seagrass fishery activity." Fish and Fisheries 19, no. 3 (2018): 399–412.

51. Paling, & Fonseca, Mark & Katwijk, Marieke & van Keulen, Mike. (2009). Seagrass restoration.

52. Matheson, F. E., Reed, J., Dos Santos, V. M., Mackay, G., & Cummings, V. J. (2017). Seagrass rehabilitation: successful transplants and evaluation of methods at different spatial scales. *New Zealand journal of marine and freshwater research, 51*(1), 96–109.

53. Irving, Andrew D., Jason E. Tanner, Stephanie Seddon, David Miller, Greg J. Collings, Rachel J. Wear, Sonja L. Hoare, and Mandee J. Theil. "Testing alternate ecological approaches to seagrass rehabilitation: links to life-history traits." *Journal of Applied Ecology 47,* no. 5 (2010): 1119–1127.

54. van Katwijk, M. M., Thorhaug, A., Marbà, N., Orth, R. J., Duarte, C. M., Kendrick, G. A., ... & Cunha, A. (2016). Global analysis of seagrass restoration: the importance of large-scale planting. *Journal of Applied Ecology, 53*(2), 567–578.

55. Ortega, A., Geraldi, N. R., Alam, I., Kamau, A. A., Acinas, S. G., Logares, R., ... Duarte, C. M. (2019). Important contribution of macroalgae to oceanic carbon sequestration. *Nature Geoscience.* doi:10.1038/s41561-019-0421-8

56. Yarish, C., Brummett, R., Hansen, S., Bjerregaard, R., Valderrama, D., & Sims, N. (2016). *Seaweed Aquaculture for Food Security, Income Generation and Environmental Health in Tropical Developing Countries.* Technical Report.

57. Bjerregaard, Rasmus; Valderrama, Diego; Radulovich, Ricardo; Diana, James; Capron, Mark; Mckinnie, Cedric Amir; Cedric, Michael; Hopkins, Kevin; Yarish, Charles; Goudey, Clifford; Forster, John. 2016. *Seaweed aquaculture for food security, income generation and environmental health in Tropical Developing Countries (English).* Washington, D.C. : World Bank Group.

58. Duarte, C. M., Wu, J., Xiao, X., Bruhn, A., & Krause-Jensen, D. (2017). Can seaweed farming play a role in climate change mitigation and adaptation?. Frontiers in Marine Science, 4, 100.

59. Project Drawdown: Sector: Food. (2019, January 17). Retrieved from https://www.drawdown.org/solutions/food

60. Ortega, A., Geraldi, N. R., Alam, I., Kamau, A. A., Acinas, S. G., Logares, R., ... Duarte, C. M. (2019). Important contribution of macroalgae to oceanic carbon sequestration. *Nature Geoscience.* doi:10.1038/s41561-019-0421-8

61. Khan, M. (2006). Crop diversification through halophyte production on salt-prone land resources. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 1*(048). doi:10.1079/pavsnnr20061048

62. Khan, M. (2006). Crop diversification through halophyte production on salt-prone land resources. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 1*(048). doi:10.1079/pavsnnr20061048

63. Khan, M. (2006). Crop diversification through halophyte production on salt-prone land resources. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 1*(048). doi:10.1079/pavsnnr20061048

64. Galbraith, E. D., Le Mézo, P., Bianchi, D., & Kroodsma, D. (2019). Growth limitation of marine fish by low iron availability in the open ocean. *Frontiers in Marine Science, 6,* 509.

65. Gattuso, J. P., Magnan, A. K., Bopp, L., Cheung, W. W., Duarte, C. M., Hinkel, J., ... & Billé, R. (2018). Ocean solutions to address climate change and its effects on marine ecosystems. *Frontiers in Marine Science, 5,* 337.

66. http://www.imo.org/en/MediaCentre/PressBriefings/Pages/Assess-ment-Framework-for-scientific-research-involving-ocean-fertiliza-tion-agreed.aspx

67. Himes-Cornell, A., Pendleton, L., & Atiyah, P. (2018). Valuing ecosystem services from blue forests: A systematic review of the valuation of salt marshes, seagrass beds and mangrove forests. Ecosystem Services, 30, 36–48. doi:10.1016/j.ecoser.2018.01.006

68. http://alturl.com/w6i7w Accessed September 2019

69. Macreadie, P. I., Anton, A., Raven, J. A., Beaumont, N., Connolly, R. M., Friess, D. A., ... & Lovelock, C. E. (2019). The future of Blue Carbon science. *Nature communications, 10*(1), 1–13.

70. Bayraktarov, E., Saunders, M. I., Abdullah, S., Mills, M., Beher, J., Possingham, H. P., ... & Lovelock, C. E. (2016). The cost and feasibility of marine coastal restoration. *Ecological Applications, 26*(4), 1055–1074.

71. Duarte, C. M., Wu, J., Xiao, X., Bruhn, A., & Krause-Jensen, D. (2017). Can seaweed farming play a role in climate change mitigation and adaptation?. *Frontiers in Marine Science, 4,* 100.

72. Vanderklift, Mat & Marcos-Martinez, Raymundo & Butler, James & Coleman, Michael & Lawrence, Anissa & Steven, Andy & Thomas, Sebastian. (2017). Blue Carbon Finance Workshop Summary. 10.13140/RG.2.2.18649.21609.

73. Vanderklift, Mathew A., Raymundo Marcos-Martinez, James RA Butler, Michael Coleman, Anissa Lawrence, Heidi Prislan, Andrew DL Steven, and Sebastian Thomas. "Constraints and opportunities for market-based finance for the restoration and protection of blue carbon ecosystems." Marine Policy (2019).

74. Bos, Melissa, Robert L. Pressey, and Natalie Stoeckl. "Marine conservation finance: The need for and scope of an emerging field." Ocean & Coastal Management 114 (2015): 116–128.

75. Herr, D. T. Agardy, D. Benzaken, F. Hicks, J. Howard, E. Landis, A. Soles and T. Vegh (2015). Coastal "blue" carbon. A revised guide to supporting coastal wetland programs and projects using climate finance and other financial mechanisms. Gland, Switzerland: IUCN.

76. Vanderklift, Mat & Marcos-Martinez, Raymundo & Butler, James & Coleman, Michael & Lawrence, Anissa & Steven, Andy & Thomas, Sebastian. (2017). Blue Carbon Finance Workshop Summary. 10.13140/RG.2.2.18649.21609.

77. Building Blue Carbon Projects—An Introductory Guide. AGEDI/EAD. Published by AGEDI. Produced by GRID-Arendal, A Centre Collaborating with UNEP, Norway. 2014

78. UNEP and CIFOR 2014. Guiding principles for delivering coastal wetland carbon projects. United Nations Environment Programme, Nairobi, Kenya and Center for International Forestry Research, Bogor, Indonesia, 57pp.

79. Vanderklift, Mat & Marcos-Martinez, Raymundo & Butler, James & Coleman, Michael & Lawrence, Anissa & Steven, Andy & Thomas, Sebastian. (2017). Blue Carbon Finance Workshop Summary. 10.13140/RG.2.2.18649.21609.

80. The Funding the Ocean database focuses on foundation giving only and may not be a complete picture of the funding landscape (due to the time lag in data, reporting limited to foundations, etc.)

81. Unsworth, R. K., McKenzie, L. J., Collier, C. J., Cullen-Unsworth, L. C., Duarte, C. M., Eklöf, J. S., ... & Nordlund, L. M. (2019). Global challenges for seagrass conservation. Ambio, 48(8), 801–815.

82. Macreadie, P. I., Anton, A., Raven, J. A., Beaumont, N., Connolly, R. M., Friess, D. A., ... & Lovelock, C. E. (2019). The future of Blue Carbon science. Nature Communications, 10(1), 1–13.

83. Kirwan, M. L., & Megonigal, J. P. (2013). Tidal wetland stability in the face of human impacts and sea-level rise. Nature, 504(7478), 53–60. doi:10.1038/nature12856

84. Kirwan, M. L., Temmerman, S., Skeehan, E. E., Guntenspergen, G. R., & Fagherazzi, S. (2016). Overestimation of marsh vulnerability to sea level rise. Nature Climate Change, 6(3), 253–260. doi:10.1038/nclimate2909

85. "Investing in Blue Carbon for a Resilient Future—The Nature Conservancy" (2018). https://www.nature.org/en-us/what-we-do/our-insights/perspectives/investing-in-blue-carbon-for-a-resilient-future/.

86. Krause-Jensen, D., & Duarte, C. M. (2016). Substantial role of macroalgae in marine carbon sequestration. *Nature Geoscience, 9*(10), 737–742. doi:10.1038/ngeo2790, Retrieved from https://www.nature.com/articles/ngeo2790

87. O'Shea, T., Jones, R., Markham, A., Norell, E., Scott, J., Theuerkauf, S., and T. Waters. 2019. Towards a Blue Revolution: Catalyzing Private Investment in Sustainable Aquaculture Production Systems. The Nature Conservancy and Encourage Capital, Arlington, Virginia, USA. (p. 127)

88. Primavera, J. H., & Esteban, J. M. (2008). A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects. Wetlands Ecology and Management, 16(5), 345–358. doi:10.1007/s11273-008-9101-y https://link.springer.com/article/10.1007/s11273-008-9101-y

89. Gobler, Christopher J., David A. Hutchins, Nicholas S. Fisher, Elizabeth M. Cosper, and Sergio A. Sañudo-Wilhelmy. "Release and bioavailability of C, N, P Se, and Fe following viral lysis of a marine chrysophyte." Limnology and Oceanography 42, no. 7 (1997): 1492–1504.

90. Seaweed Aquaculture for Food Security, Income Generation and Environmental Health in Tropical Developing Countries. (2016). doi:10.1596/24919

91. https://thewickedproblemofclimatechange.weebly.com/uploads/9/3/2/4/93241378/costa-pierce_2015.pdf

92. McCauley, Douglas J., Caroline Jablonicky, Edward H. Allison, Christopher D. Golden, Francis H. Joyce, Juan Mayorga, and David Kroodsma. "Wealthy countries dominate industrial fishing." *Science advances* 4, no. 8 (2018): eaau2161.

93. Cashion, Tim, Frédéric Le Manach, Dirk Zeller, and Daniel Pauly. "Most fish destined for fishmeal production are food-grade fish." *Fish and Fisheries* 18, no. 5 (2017): 837–844.

APPENDIX: Links to BFI's Blue Carbon Interviews

INTERVIEWEE (click hyperlink to view recorded interview)	AFFILIATION	BIO
Bren Smith	Greenwave	Founder of Greenwave, former commercial fisherman turned ocean farmer
Gabriel Grimsditch	United Nations Environment Program (UNEP)	Program Management Officer with UNEP working to address the impacts of climate change on oceans
James Kairo	Kenya Marine and Fisheries Research Institute (KMFRI)	Pew Fellow 2019 and coordinator of Blue Carbon Unit at KMFRI to advise Kenyan government on the wise use of aquatic resources, including mangroves
Katie Lebling & Colin McCormick	World Resources Institute (WRI)	Researchers for WRI on the policy, cost and funding of bringing blue carbon to scale
Lalao Aigrette	Blue Ventures	Deputy National Blue Forests Programme Lead who oversees the mangrove conservation, carbon projects, testing and viability of mangrove projects at a large scale
Murray Fisher	Billion Oyster Project	Founder of Billion Oyster Project & NY Harbor School
Ben Scheelk	Ocean Foundation	Senior Program Manager lead providing critical infrastructure and operational expertise to coastal and marine conservation projects
Priya Shukla	PhD Student at UC Davis	PhD Student studying climate change, ocean science, and food security
Sarah Myhre, PhD	Independent Oceanographer	Paleoceanographer and Kavli Fellow with expertise in social and ecological decision-making and climate
Sergio Ruiz, PhD	Save the Med	Marine Biologist focusing on carbon exchange between the atmosphere and the water table
Steven Lutz	GRID Ardenal	Blue Carbon Programme Leader in support of UN Environment including Abu Dhabi Blue Carbon Demonstration Project and the GEF/UN Environment Blue Forests Project
Tim Flannery	Blue Carbon Initiative | Ocean Forest Foundation	Professor and chair and founder of the ocean forest foundation
Tom Goreau	Global Coral Reef Alliance	Biochemist, founder of Global Coral Reef Alliance and author of many books including *Geotherapy & Marine Ecosystem Restoration*

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