Labomar

Arquivos de Ciências do Mar

HOW CARBON IMMOBILIZATION FROM RESTORED MARINE FORESTS MAY HELP CLIMATE CHANGE MITIGATION PLANS?

Como a imobilização de carbono de florestas marinhas restauradas pode ajudar os planos de mitigação das mudanças climáticas?

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ABSTRACT

The ocean transformation due to the direct or indirect human influence is a fact. One of the most affected ecosystems are the benthic ones, where bottom trawling, urban/agricultural development and climate change (among other things) deeply transform the bottom communities. Among these threatened communities, the marine forest is the most complex. The marine forest is composed of benthic macroalgae, phanerogams and suspension feeders (sponges, corals, gorgonians, etc.) which conform three-dimensional living structures. Coral reefs, seaweeds, sponge grounds, seagrasses, oyster banks, cold water corals are some examples of this vast set of ecosystems dispersed all over the world. During the last two decades, the concept of Blue Carbon has been consolidated, describing the stocked carbon in vegetated coastal and marine habitats such as mangroves, salt marshes, seagrasses and seaweeds. There are also world-wide numbers about how much carbon is retained in the terrestrial forests, crops and soils. These systems act as carbon immobilizers from which we have proxies. Can we design and apply an ambitious shallow and deep marine forest restoration plan to help climate change mitigation? The aim of this paper is developing a simplified but realistic calculation of the role as carbon immobilizers of a restored marine forests in one area as a case study, setting up a huge restoration plan to help mitigating climate change, enhancing carbon retention. A shallow (10-30 meters depth) restoration plan of the marine animal forests with new technologies based on symbiotic artificial reefs, enhancing the role as carbon immobilizers and creating a protocol to help the climate change mitigation, is explained, using realistic numbers to calculate the real impact of such regenerative plan. Is time to have a much more applied and holistic view of what is in the ocean's floors in terms of habitat composition, complexity and biomass stocks, implementing new methods and technologies that are already in our

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Arq. Ciên. Mar, Fortaleza, 2022, 55 (Especial Labomar 60 anos): 202 - 218

hands. It is also time to give a chance to the oceans in helping in the climate change mitigation plans applying brave new restoration approaches that may change our relation with the sea.

Keywords: marine restoration, marine animal forests, artificial reefs, transplantation, forest ecology.

RESUMO

A transformação do oceano devido à influência humana direta ou indireta é um fato. Um dos ecossistemas mais afetados são os bentônicos, onde o arrasto de fundo, o desenvolvimento urbano/agrícola e as mudanças climáticas (entre outras coisas) transformam profundamente as comunidades de fundo. Entre essas comunidades ameaçadas, a floresta marinha é a mais extensa. A floresta marinha é composta por macroalgas bentônicas, fanerógamas e suspensívoros bentônicos (esponjas, corais, gorgônias, etc.) que conformam estruturas vivas tridimensionais. Recifes de coral, algas, campos de esponjas, ervas marinhas, bancos de ostras, corais de água fria são alguns exemplos desse vasto conjunto de ecossistemas dispersos por todo o mundo. Durante as duas últimas décadas, o conceito de carbono azul foi consolidado, descrevendo o carbono armazenado em habitats costeiros e marinhos com vegetação, como manguezais, sapais, ervas marinhas e algas marinhas. Existem também números mundiais sobre quanto carbono é retido nas florestas, plantações e nos solos terrestres. Esses sistemas atuam como imobilizadores de carbono dos quais temos proxies. Podemos projetar e aplicar um plano ambicioso de restauração de florestas marinhas rasas e profundas para ajudar na mitigação das mudanças climáticas? O objetivo deste artigo é desenvolver um cálculo realista simplificado do papel como imobilizadores de carbono de uma floresta marinha restaurada em uma área como um estudo de caso, estabelecendo um grande plano de restauração para ajudar a mitigar as mudanças climáticas, aumentando a retenção de carbono. Um plano de restauração raso (10-30 metros de profundidade) das florestas de animais marinhos com novas tecnologias baseadas em recifes artificiais simbióticos, reforçando o papel como imobilizadores de carbono e criando um protocolo para ajudar na mitigação das mudanças climáticas, é explicado, usando números realistas para calcular o impacto real de tal medida regenerativa. É hora de ter uma visão muito mais precisa e holística do que está no fundo do oceano em termos de composição de habitat, complexidade e estoques de biomassa, implementando novos métodos e tecnologias que já estão em nossas mãos. É também hora de dar uma chance aos oceanos para ajudar nos planos de mitigação das mudanças climáticas, aplicando novas e corajosas abordagens de restauração que podem mudar nossa relação com o mar.

Palabras-chave: restauração marinha, florestas de animais marinhos, recifes artificiais, transplante, ecologia florestal.

INTRODUCTION

Coastal and offshore areas are main providers of ecosystem services worldwide but rank also among those most affected by multiple synergistic perturbations. Such cumulative impacts require urgent and clear responses based on a solid understanding of the mechanisms affecting the functioning of key marine ecosystems, and the services they
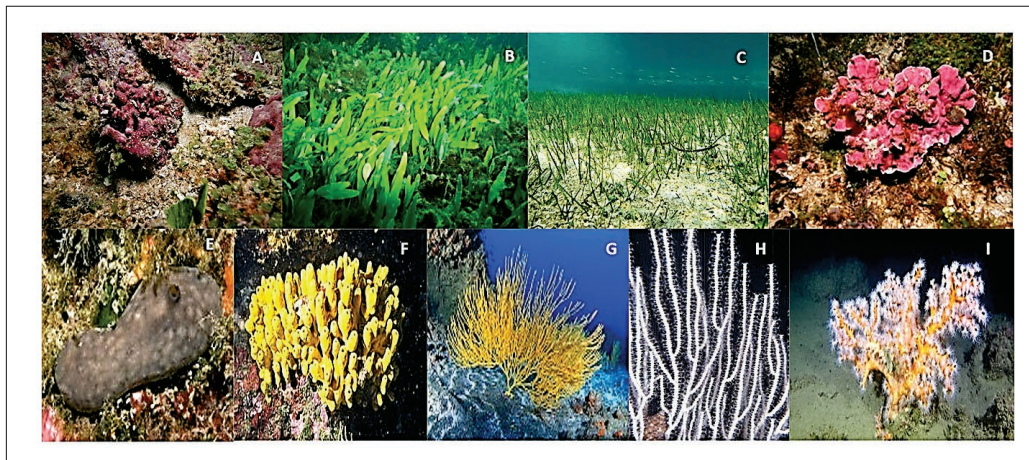
provide (Pörtner *et al.*, 2019; Rossi *et al.*, 2019). Ongoing ecosystem transformations and community shifts are so complex and synergistic that they may not always be perceived as dramatic changes but as part of our natural adaptation to current social and economic needs (Bearzi, 2009). Benthic communities are one of the most threatened and cover most of the seafloor, from shallow to deep waters, encompassing animals and plants as habitat builders (Thrush & Dayton, 2002; Rossi, 2013). Marine Forests (MFs) are, by far, the most prominent living three-dimensional benthic structures present in the oceans, spreading from tropical to polar latitudes and from shallow to deep waters. MAFs, which are functionally similar to terrestrial forests, are composed of seaweeds, seagrasses, and sessile benthic animals (Rossi *et al.*, 2017; Keith *et al.*, 2020). MFs builders are ecosystem engineers, altering local hydrodynamics, nutrient pathways, carbon cycling and influencing biodiversity patterns (Rossi *et al.*, 2017). MFs may adapt to changing environmental parameters, being to a certain extent also capable of overcoming occasional perturbations (Belwood *et al.*, 2004; Hoegh-Guldberg *et al.*, 2007; Rossi, 2013). However, more frequent and intense perturbations make recovery impossible for these complex structures (Belwood *et al.*, 2004; Falkenberg *et al.*, 2010; Pörtner *et al.*, 2019; Rossi *et al.*, 2019). The resulting regime shifts have serious consequences for the goods and services provided by these ecosystems (Conversi *et al.*, 2015) but, so far, we do not know how to ensure the sustainability of the marine resources associated with them. For example, the IPCC (2019), says "almost all coral reefs will degrade from their current state, even if global warming remains below 2° C (high confidence), and the remaining shallow coral reef communities will differ in species composition and diversity from present reefs (very high confidence). These declines in coral reef health will greatly diminish the services they provide to society, such as food provision (high confidence), coastal protection (high confidence) and tourism (medium confidence)" (Pörtner *et al.*, 2019). We are beginning to understand the role of MFs as biodiversity and biomass promoters and as carbon immobilizers (Doughty *et al.*, 2016; Rossi *et al.*, 2017; Gullström *et al.*, 2018; Rossi & Rizzo, 2020). The complexity of the three-dimensional structures that are at the base of MF functioning is due to the growth and accumulation of organic and inorganic carbon in their architecture and around them (Rossi & Rizzo, 2020). Carbon immobilization may be one of the more neglected ES in world's ocean (especially the carbon immobilized in Marine Animal Forests, Coppari; Zannela & Rossi, 2019). Even more, very few people have been thinking about what will happen in the next 30-40 years as a whole to the seascapes that are already suffering deep changes because of CC due to changes in ocean currents and to the primary and secondary productivity major transformations in a warmer and more acidic oceans (Smetacek & Cloern, 2008; Nixon *et al.*, 2009; Doney *et al.*, 2012). If we understand the importance of these ecosystem engineers at a global level, we can also use their capability to immobilize carbon to mitigate climate change effects with an ambitious but realistic plan.

Limited information is still available on how MFs will specifically respond to climate change and the extent of provision of climate change solutions through the protection and restoration of complex MF structures. By contrast, we have enough information to make serious and realistic restoration plans at large (regional and above) scales for these important habitats. What are the winning features for any successful marine restoration plan? 1) the restoration, protection and maintenance of the structural complexity, functionality and biodiversity of the systems, 2) identification of the best protocols to be applied in scaling-up scenarios, 3)

understanding the impacts of climate change and local stressors and how to ameliorate these and, 4) the successful integration of climate refugia. Considering large conservation and restoration programs aiming to protect and recover the marine forests, among other things, enhancing biodiversity and carbon immobilization should be put at the forefront of future ocean management plans. Moreno-Mateos *et al.* (2020) claimed that we have to "focus restoration science on the long-term (centuries to millennia) re-assembly of degraded ecosystem complexity integrating interaction network and evolutionary potential approaches". The marine restoration centred in MF has to be envisaged as a long-term plan that will help in climate change mitigation and the recovery of biodiversity (Rossi & Rizzo, 2020).

This paper trails the recent UN declaration for the decade 2021 to 2030 as the Decade on Ecosystem Restoration, an announcement responding to the devastating human-induced ecosystem degradation, biodiversity loss, and climate change. This implies a focus on restoring species compositions and ecosystem functioning and services, all guided by social responsibility that recognizes the interdependence between people and the biosphere. A rough calculation, based on present knowledge, will be made about how much carbon may be immobilized using key species in a softbottom and hardbottom restoration plan. I will also discuss about the possibility to create a system in which artificial reefs are designed to enhance a upscaled regeneration strategy.

Figure 1 - Marine forest species in the restoration plan simulated in Punta Blanca, Tenerife. (A) *Lithothamnion* sp. (B) *Caulerpa prolifera*; (C) *Cymodocea nodosa*; (D) *Mesophyllum* sp.; (E) *Chondrosia reniformis*; (F) *Aplysina aerophoba*; (G) *Leptogorgia viminalis*; (H) *Eunicella* sp.; (I) *Dendrophylia ramea*
Photos: marinespecies.org

Long-lived organisms and blue carbon

Due to the long-life cycles of the habitat-forming species in these ecosystem engineering dominated habitats, they might accumulate elevated quantities of C as biomass (Barnes, 2018; Rossi *et al.*, 2019; Rossi & Rizzo, 2020). This C might last for decades, centuries or millennia, accumulated in the body structures of these species (Roark *et al.*, 2006). An interesting paper by Howard *et al.* (2017) tries to clarify which ecosystems or communities are efficient Carbon sequesters or not. The conclusion is that only wetlands, mangroves and seagrasses in coastal areas are real carbon sinks. Here the question that we have to bear in our minds the time scale considered. Let us make an example. Phytoplankton may be considered a Carbon sink only for hours or weeks (Buitenhuis *et al.*, 2013). Once consumed

and respired, only a low fraction (but not negatable as a whole, 0.1%) reach the seafloor and remains unaltered for millennia (Falkowski, 2012). This phytoplankton is processed by upper trophic levels, including benthic suspension feeding organisms (Gili & Coma, 1998). The days or weeks in which the Carbon is processed in the phytoplankton may be partially transformed in decades or centuries or even millennia in these three-dimensional long-lived structures. Macroalgae like kelp also act as C immobilizers. The Carbon stored in kelp biomass ranges from 37-54 Mg C ha^{-1} (Muraoka, 2004), but the short life span of individual kelp plants (~1 year) and their lack of long-term Carbon storage mean that they cannot act as effective long-term Carbon sinks (Spalding; Foster & Heine, 2003; Muraoka, 2004). However, once the algae is fragmented and degraded, a non-neglectable part may be grazed by herbivores and detritivores. Some animals will have ephemeral life cycles, others may last for decades and accumulate part of the organic matter in their structures. Is the case of heterotrophic gorgonians, sponges or ascidians, which partly take this detritus, incorporating in their budget (and structures) the organic matter originated from the photosynthetic metabolism of microalgae or macroalgae (Coma *et al.*, 2001). The same calculation has to be made for microzooplankton, the whole seston is a source of material coming directly or indirectly from photosynthesis (Rossi & Gili, 2009) that will be partly fixed in the organic structures of benthic suspension feeders. In many cases, the elapsed time of sequestration will be short, like on the hydrozoans (Rossi *et al.*, 2012), but in other cases may last for very long periods of time (Rossi, 2013; Mallo *et al.*, 2019). Other systems should be considered, beside the previously studied C sink communities, like most of the marine animal forests. There are no broad scale studies for animal-dominated ecosystems calculating its importance as Carbon retainers, except possibly tropical coral reefs.

It is important thus to understand the life cycle and permanence of these organisms, and account how much CO_2 is produced (community respiration) and compare to the amount of carbon that is net buried for the Carbon sink equation. Immobilization and sink have to be clearly identified and studied in depth for each community. In addition, we cannot forget that CO_2 sink is not consistent with reef sediment geochemistry. The sink behaviour has been detected in studies carried out mostly on fringing reefs, which are more likely subject to anthropogenic stresses. There is increasing number of reefs shifting from coral-dominated to algal-dominated states (Done, 1992). This could lead to changes in coral reef metabolism, from net sources to net sinks. The effect of these changes on the ecosystem function are poorly known, and we have also to understand how effects of climate change will affect such balances. For example, there is the increasing effects of ocean acidification, which must be addressed to understand what the future of such balances will be (Comeau & Cornwall, 2017). Thus, when we make a restoration plan, we have to account on the elapsed time that the carbon will be fixed in the structures, and the related growth rates of the selected organisms.

Restoration plan

Selected area

The implementation area of Tenerife (Canary Islands) is in the South-West site of the island, at the Punta Blanca going from 0 m to 120 m depth. It is part of the RED-Natura 2000 network, specifically it falls in the ZEC area ES7020017 (Teno-Rasca Marine Zone). Within this selected implementation area, 3 habitats are specified (1110-Sandbanks,

1170-Reefs, 8330-Submerged or partially submerged sea caves) in addition to Maerl beds (EUNIS habitat type A5.51). This area shows different signals of habitat degradation such as fast growing-algae proliferation, biomass and biodiversity loss and overpopulation of the sea urchin *Diadema antillarium*.

Shallow reefs

The restoration plan will combine the natural (soft and hard bottom) and Symbiotic Enhanced Reefs (a SER specific set of artificial reefs designed to optimize the settlement and livelihood conditions for sessile and vagile organisms, SER®) substrates to optimize the gardening effect (Rossi & Rizzo, 2020). The SER® design has to be complemented with the seagrass and seweed restoration in soft bottoms to optimize both transplantation protocols.

Selected species

We require a complete picture to understand which organisms are most suitable for restoration, the level of connectivity among populations. We need to set up a protocol that spans and accounts for the autoecology of single species to the ecosystem services that MFs will promote in the restored area. We thus need to focus upon restoring at the system-scale, using all available knowledge to create a new gardening approach (Horoszowski-Fridman & Rinkevich, 2017). MF concepts (Rossi *et al.*, 2017) like patch density and orientation, population dynamics and structure, self-thinning role (Rossi *et al.*, 2012; Nelson & Bramanti, 2020), functional ecology related with species biodiversity (i.e. different morphologies, different effects on the community functioning), adaptation and acclimation to fast climate change impacts, selection of the more advantageous organisms for the carbon sequestration or the use of different methods to make an active gardening knowhow has to be used all together to optimize the restoration plan. We don't have the millennial experience of land silviculture, but during the last three decades we learned how to make an ecosystem-engineering approach in the sea in different kinds of MFs (Rinkevich, 2020). The evaluation process will also consider the best position for the SER® installations between 10 and 30 meters depth, in order to optimize the survivorship, growth and recruitment processes of the different organisms. It is also needed to explore the possibilities of the active restoration of seaweeds and seagrasses in hard and soft bottoms, as well as understanding where the metazoan recovery process would be more convenient inside those natural substrates.

The selected species are common in the southern part of Tenerife, also in Punta Blanca area (Espino-Rodriguez *et al.*, 2018). Soft bottoms: maërl is common in the soft bottoms of this zone, and I chose *Lithothamnion muelleri* as one of the species present that has also related literature of its biomass and growth; the seagrass *Cymodocea nodosa* (so called "sebadal") is also present in this southern part of the island and is a prone candidate for active seedling, having also numbers about its biomass and productivity; also in the soft bottoms, I made the simulation with *Caulerpa prolifera*, a common fleshy algae that may be found in this area and has biomass and productivity numbers. Hard bottom: representing the coralline algae, I chose *Mesophyllum* sp., present in the area and with cover and productivity numbers present in the literature; the two selected sponges were the slow growing *Chondrosia reniformis* and the photophilic, mixotrophic desmosponge *Aplysina aerophoba*; both have literature about its biomass and productivity per meter square; two gorgonians will be also selected to perform the three dimensional alive

structure of the marine animal forest, *Lophogorgia viminalis* and *Eunicella verrucosa*, both present in Tenerife and having density and productivity numbers; finally, an hexacorallia, *Dendrophyllia ramea*, has been selected to complete the species that have to represent the mosaic in the hard bottom places of our simulation surface (Espino-Rodriguez *et al.*, 2018). In this approach, the biomass increase (growth) will be considered as the contributor of carbon sequestration (Table I).

Table I – Immobilized carbon by species. The literature used has been used to transform growth into carbon retained by the three-dimensional alive structures. Here is not considered any loss by grazing, predation or fragmentation

Species	Type of substrate	Growth (gC m^{-2} day^{-1})	Sequestred Carbon (Tons C $hectare^{-1}$ $year^{-1}$)	Reference
Lithothamnion sp. (Rhodolith)	Soft bottom	0.36	0.19	Rivera; Riosmena-Rodrígues & Foster, 2004; Chimienti *et al.*, 2020
Caulerpa prolifera	Soft bottom	0.01	0.014	Malta *et al.*, 2005; Pérez-Ruzafa *et al.*, 2012
Cymodocea nodosa	Soft bottom	0.42	0.31	Cebriàn *et al.*, 2000; Agostini; Pergent & Marchant, 2003
			TOTAL TONS IN SOFT BOTTOMS	
			0.514 Tons Carbon $Hectare^{-1}$ $Year^{-1}$	
Mesophyllum sp.	Hard bottom & SER®	0.05	0.04	Littler; Littler & Hanisak, 1991; Garrabou & Ballesteros, 2000
Chondrosia reniformis	Hard bottom & SER®	0.02	0.012	Di Camillo *et al.*, 2012; Gökalp *et al.*, 2019
Aplysina aerophoba	Hard bottom & SER®	5.45	0.79	Hausman *et al.*, 2006; Schippers *et al.*, 2012
Leptogorgia viminalis	Hard bottom & SER®	0.01	0.001	Mistri & Ceccherelli, 1993; Rossi; Gili & Garrofé, 2011
Eunicella sp.	Hard bottom & SER®	0.03	0.025	Munari; Serafin & Mistri, 2013; Coppari; Zannela & Rossi, 2019
Dendrophyllia ramea	Hard bottom & SER®	0.02	0.011	Gori *et al.*, 2014; Orejas *et al.*, 2019
			TOTAL TONS IN HARD BOTTOMS	
			0.887 Tons Carbon $Hectare^{-1}$ $Year^{-1}$	
			TOTAL CARBON FIXED IN THE RESTORED AREA	
			1.407 Tons Carbon $Hectare^{-1}$ $Year^{-1}$	

Numbers for carbon immobilization in shallow SER

The first think that we have to do is imagine one determinate surface, one hectare (10000 m^2). In this area, 40% of the space (4000 m^2) are occupied by the SER®, whilst 60% (6000 m^2) are soft bottoms. The SER® have a particular three-dimensional structure (Figure 3), and they offer (only outside faces of the structure) 4.2 m^2 per each m^2 occupied (i.e. 16800 m^2). However, we have to consider that 25% of this space are holes that facilitate to pass the water currents (and may be used as refugees for vagile fauna such as fishes, lobsters, cephalopods, etc.). This means that the surface available for transplantation is 12600 m^2.
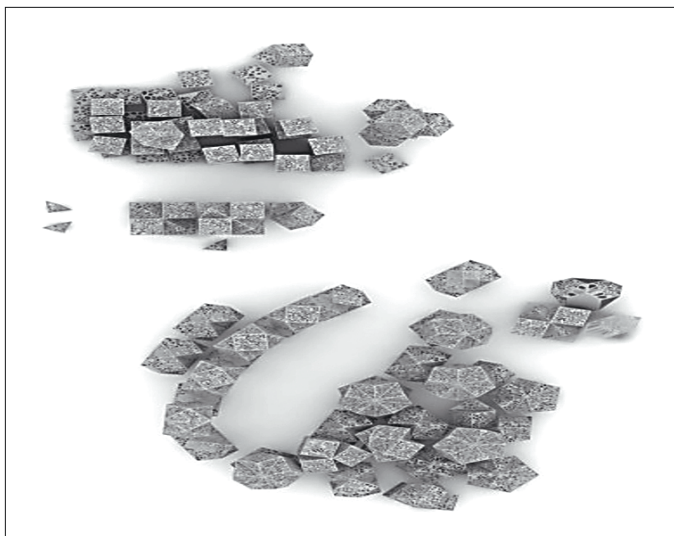
Figure 2 - Simulation of SER distribution in the space to create different regeneration areas, combining soft and hard bottom zones

Both substrates (soft and hard bottoms) will be gardened. In both zones, organisms with different growth rate (and carbon immobilization capabilities) have been chosen (see above) to make this simulation. In Table I the numbers are specified for each species.

To simplify the process, we made proportions for the distribution of the potential areas in which we will actively transplant the organisms. For example, in soft bottoms, for the 6000 m^2 that potentially can be colonized with the three different species, only 5000 m^2 have been considered (leaving 1000 m^2 for the areas around the SER® to let the divers garden the hard bottom structures without damaging the soft bottom transplants). The 5000 m^2 have been divided in 1500 m^2 for *Lithothamnion sp.*, 1500 m^2 for *Caulerpa prolifera* and 2000 m^2 for *Cymodocea nodosa*. For the soft bottoms, a similar procedure applies (see Table I).

The upscaling process

In Table I we can see the simulation of different gardened species in Punta Blanca. There are huge differences between species in terms of sequestered carbon, being the sponge *Aplysina aerophoba* the faster growing species and the gorgonians the ones fixing less carbon during a whole year. In general, compared with other habitats, the restored ecosystem of Punta Blanca in Tenerife is on the order of magnitude of the Amazonian forest or the mangroves (Table II, Rossi & Rizzo, 2020). Coppari, Zannela and Rossi (2019) showed that, in natural conditions, three different gorgonians (*Paramuricea clavata*, *Leptogorgia sarmentosa* and *Eunicella singularis*), with different distribution, density and life cycles-growth, had a low capability to retain carbon. In this simulation, the gorgonians were potentially transplanted in denser patches, but they still had no significant role in the overall carbon sequestration. This may suggest that the selection of the species in the gardening process is essential when you want to enhance the blue carbon in restoration plans.

Table II – Comparison of different ecosystems and three octocorals of the Mediterranean sea, in terms of carbon immobilized (transformed from Rossi and Rizzo, 2020)
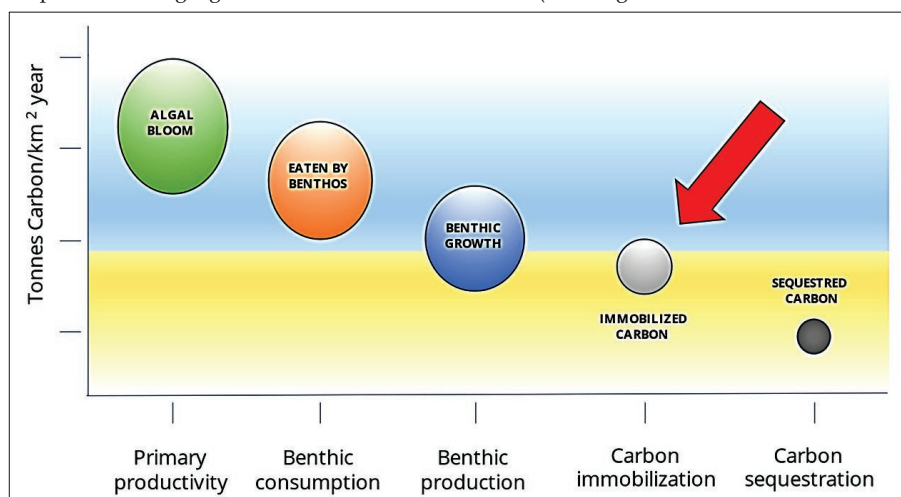
Habitat or group of species	T C ha^{-1} year^{-1}
Punta Blanca simulation	1.41
Wetlands	0.19
Amazonian forest	1.02
Seagrass	6.7
Mangrove	1.5
Three Mediterranean gorgonians (Coralligene)	0.014

However, gorgonians are very important as habitat builders, they may help trapping particles as they interfere with the near bottom currents (Nelson & Bramanti, 2020). The same may be applied to the soft bottom species chosen here (Table I), their complexity as ecosystem engineers is essential to trap particles (organic and inorganic) that will be buried around the patch. The choice of the combined species is thus an essential factor to optimize biogeochemical cycles and carbon sequestration (Horozowski-Fridman & Rinkevich, 2017; Rinkevich, 2020).

We do have to consider the real benefit of such restoration plan: the upscaling process. If we have one hectare of a gardened area in which both soft bottom and hard bottom (mostly artificial, the SER, but that can me mixed with the natural one such as walls and boulders), the mitigation plan, that will be combined with many other mitigation and adaptation plans to climate change, do work. The present manuscript is only a simulation, it can be easily perfectioned. For example, another thing that is not considered here is optimization of CO_2 immobilization. One of the possibilities is increase the growth (and thus the carbon immobilized) in suspension feeding organisms (Rossi & Rizzo, 2020; Giangrande *et al.*, 2021). Do to the fact that suspension feeders have mixotrophic and heterotrophic inputs, the enhancement of carbon inputs may be explored to foster their capability of sequester carbon in their structures. For example, suspension feeding organisms have an asymmetrical energy inputs due to food pulses that may be essential to understand carbon balances of the species (Rossi & Rizzo, 2020). This means that, through the time, there are punctual moments in which the suspension feeding organisms activate their food capture strategies (Rossi *et al.*, 2019) to accumulate food that will be also dedicated to the structural expansion (growth) of these species (Coma *et al.*, 1998). This is also observed in the optimization of the photosynthetic performance through annual cycles (Rossi *et al.*, 2020) or even during in daily feeding cycles (Orejas *et al.*, 2013). Now we may for example imagine a situation in which we can feed our organisms. If we consider an Integrated Multitrophic Aquaculture (IMTA) in which we create biomass through the presence of bioremediatory organisms (e.g. bivalves, macroalgae, ascidians, etc.) that take advantage of the nutrients and particles produced from the main targeted species (e.g. maricultured fishes), we may use part of this biomass produced (which may be very abundant and also trap carbon, Moore; Heilweck & Petros, 2021a) to feed our transplanted organisms in situ (Giangrande *et al.*, 2021) (Figure 3). The growth may be enhanced, using this IMTA products to immobilize carbon in these three-dimensional alive structures. In fact, this may be envisaged as part of the gardening, in which you accelerate the carbon immobilization process. In this optimization, as we have discussed before, the density, population structure and diversity of organisms has to be also considered to enhance the particle capture (Nelson

& Bramanti, 2020). A Life Cycle Assessment will be necessary, in terms of carbon, to understand if our restoration plan is a carbon sink or source but, in any case, we will not have to think in short-term balances, we might think that the blue carbon and biodiversity enhancement in this regenerated area will last for the future generations.

Figure 3 - Benthic suspension feeders will benefit from a stimulus of organic matter production. Increasing the primary productivity or the detritus will speed up the carbon immobilization by suspension feeding organisms in the restoration area SERs (Drawing transformed from Barnes, 2018)

CONCLUSIONS

With such an active regeneration plan, we will create a replicable protocol of underwater coastal restoration in which a new generation of gardeners of the sea in an economically self-sustained program will enhance local economies, ecosystem engineering species and serve as a key notion for new 'people and oceans harmony' (Rossi & Rizzo, 2020). The potential to create a new generation of engaged citizens and gardeners of the Ocean is a key aspect to create a win-win situation, where biodiversity, complexity and biomass increases are directly related to societal and economic gains. The local fisheries, spillover effect, larval export, nutrient cycling, nursery grounds, sediment retention, enhancing productivity in general or microplastic trapping, and also, social, cultural and spiritual ecosystem services will be ensured through an integrative remit in which people will learn about and love the sea.

In this restoration plan, both animal and vegetated forest in coastal areas will be combined improving the normal carbon sequestration through a precise mapping and evaluation protocol. We can enhance the capture of organic particles or the light harvesting of mixotrophic species increasing substantially the carbon immobilization, with new methods based on the ecology of suspension feeding organisms. The combination of autotrophic (seagrasses and seaweeds), mixotrophic (symbiotic metazoans) and heterotrophic species is the key to create the perfect "carbon stocking" in coastal areas at a large scale. Once settled up, the growing species will contribute to regenerate (with larvae, propagules, seeds, etc.) the restored and neighboring areas with new individuals that will be essential to increase biodiversity and complexity.

Climate change mitigation is also high on the agenda of the EU and the UN. The possibility to alleviate or stop the almost exponential growth in carbon emissions is of

great concern (Pörtner *et al.*, 2019; Balzan *et al.*, 2020). The chemical and physical geo-engineering solutions proposed during the last two decades (Marshall, 2017; Lawrence *et al.*, 2018; Trisos *et al.*, 2018) are not viable options to mitigate climate change: they have too many uncertainties in terms of unknown collateral impacts on the Earth's global matter and energy cycles, while the artificial proposition seems to satisfy nobody (Möller, 2020). Mitigation through biological geo-engineering has been claimed as a natural based solution, like land forest expansion (Seddon *et al.*, 2020), but, following climate change, land forests are suffering from increasingly intense and frequent wildfires, droughts and heat waves. Hence there are many places in which recovery seems impossible under present trends (Sun *et al.*, 2019; Vicente-Serrano *et al.*, 2020). It seems also that Carbon sequestration may be saturated or even declining in terrestrial forests (Hubau *et al.*, 2020). In contrast, submersed coastal areas are immobilizing carbon even at a higher rate than their terrestrial counterparts, in some cases (Kraus-Jensen *et al.*, 2018). The UNEP report underlines the importance of the blue carbon ecosystem, in term of macrophytes and sediments (Macreadie *et al.*, 2019; Lovelock, 2020) and it also highlighted the contribution of benthic organisms on rock substrates to carbon sequestration (Duarte & Krause-Jensen, 2017). We are losing control of Carbon sequestering because we are rapidly degrading ecosystem engineered habitats, with their complex three-dimensional (3D) structure, and these organic-calcifying organisms may be the key to help climate change mitigation (Moore; Heilweck & Petros, 2021b). Most of these complex structures are found just below water surface and are known as marine forests (MFs) (Rossi & Rizzo, 2020). These marine ecosystems, including the carbon sequestering organisms, also host most of the biodiversity in benthic ecosystems, altogether presenting 3D structures essential for good ecosystem functioning in which different species interact (Pessarrodona; Foggo & Smale, 2019). Is thus time to consider realistic but brave alternatives that will give us a chance to mitigate climate change. Combined with deep societal changes, they could be part of our salvation plan as a species in this fast changing world.

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