Can Sustainable Development Save Mangroves?

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Review

Can Sustainable Development Save Mangroves?

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Abstract: The Earth is warming, ecosystems are being overexploited, oceans are being polluted, and thousands of species are going extinct—all fueled by the need for a permanent increase in production for more consumerism and development. "Business as usual" continues untouched, while increasing attention has been given to the "sustainable development" concept. Despite their importance as life supporting ecosystems, forests, oceans, and wetlands are being destroyed at an accelerating rate. The conservation and restoration of mangroves, for example, are also vital for the planet to face catastrophic global warming. Based on a non-systematic literature review, we address how true mangrove conservation is incompatible with so-called "sustainable development". We turn to the urgent changes needed to avoid environmental and societal collapse, promoted by the Western economic development paradigm, and address why the sustainable development approach has failed to stop environmental degradation and protect resources for next generations. Proposed solutions involve the rejection of the capital-oriented, nature-predatory systems, degrowth, a deep transformation of our energy matrix, and a shift in our nutrition to lower levels of the food chain. These are based on a profound sense of responsibility over the planet, respecting all life forms, ecosystem dynamics, and life sustaining properties of the biosphere.

Keywords: conservation; sustainable development; economic development; developmentalism; life support ecosystems; environmental inequity; ecosystem collapse

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1. Introduction

Since their popularization by the Our Common Future Report in 1987 [1], "sustainable development", "sustainability", and other similar terms meaning an economic development without depletion of natural resources and their ecosystem services, have been used as mantras. This approach assumes that "green" consumption and the development of economies and technology could be solutions to the ecological dilemma that humanity faces [2]. Hence, the increase in industrial production and economic growth would be assisted by "green" technologies. Natural resources would be able to support economic growth, consumption, and accumulation standards of the richest countries (and people). Large-scale "sustainable" agriculture and factory farming would warrant food for all present and future generations.

Today, the Earth is going through a critical moment of social–ecological challenges [3–7]. Centuries of society growth, industrial development, and natural resources overexploitation are turning out to be a heavy burden for the planet [8–10]. Impacts shift from local to global; the climate is being altered and life supporting ecosystems (LSEs) continue to collapse (oceans and forests among the most important), causing countless species that are vital for ecosystem functionality to go extinct. Cattle breeding and harmful agricultural practices are destroying soils and increasing greenhouse gas (GHG) emissions, bringing the biosphere close to the threshold of a state shift of adverse conditions, or even of collapse [11–13]. As early as 2011, Biello [14] estimated that the world's richest 500 million

people were producing half of the world's GHG emissions, whereas the poorest three billion were emitting just 7%. Additionally, while the richest one fifth of the human population earns 74% of the world's income, having far more than their basic needs in terms of food security and welfare, another one fifth earns just 2% of the global income and lack basic necessities [15]. Around one billion people suffer from chronic hunger [15–17], despite global food production being already sufficient for all, but is unevenly distributed [18–20]. Using evermore limited natural resources, the human-made mass of inanimate objects equals the biomass of the overall global mass of all living taxa, including humans and their livestock [21]. The "Sustainable Development Goals" adopted by the UN fail to avoid [7], and to some extent, even promote [22], environmental degradation. Overexploitation of the planet, claimed by the elites and the governments that they control as absolutely necessary to bring about human well-being, has not solved hunger and other pressing socio-economic issues.

In the meantime, we watch the grabbing and privatization of natural resources [23,24] and the socialization of environmental damages. Though under the "sustainable development" tinkering pragmatism, which has been extensively proven to be unable to avoid the exhaustion of diverse environmental goods and services, dreaded "business as usual" scenarios continue to unshakably rule over the anxiously-desired-but-yet-delusional, capital-friendly alternative paths. These findings are not new, and neither are the solutions, nor the urgency of the problems at hand. As such, the paradigm of "sustainable development" crashed against an unquestionable truth: it is not possible to reach human equality and stop the overexploitation and consequent degradation of nature in time, in economic systems or modes of production whose soul is permanent growth, increased consumerism and inequality, and wealth accumulation [2,25,26]. Indeed, humanity (but mainly rich countries) is consuming more than the planet (whose natural resources are finite or only slowly multiplying) can replace, and this clear truth constitutes the background of our work: no planetary net economic growth can be ecologically sustainable [2,8,17,27].

Countless ecosystems have suffered fragmentation and degradation, and among them, wetlands are highly affected. Coastal wetlands are extremely important LSEs, removing carbon dioxide from the atmosphere and sequestering it in long-term carbon sinks, as plant biomass and soil refractory carbon compounds, and providing important climate adaptation and resilience services [28]. Beyond the threats of global warming (rainfall shortage, increase in temperature, and sea level rise) coastal wetlands face encroachment, intense exploitation, changes in hydrology and pollution [29]. Over 60% of the world coastal wetlands have been lost in the last century [30].

Among these wetlands, mangrove forests are some of the most important ecosystems, with a high provision of goods and services in relation to their extension [31–38]. Mangroves are salt-tolerant trees that inhabit the mid and upper intertidal coastal fringes (mainly estuaries and deltas) of tropical and subtropical regions [39,40]. Rainfall, tidal height, salinity, soil characteristics (nutrients and oxygen content, grain composition and humidity), and biotic factors, like herbivory, are among the main ecological factors determinant of their development, diversity, and high biomass [40,41]. On a global scale, Indo-West Pacific mangroves, with around 40 tree species, have six times more species than the Atlantic-Caribbean-East Pacific mangroves (7 species) [39]. Their position between land and sea has made them especially vulnerable to clearing and conversion into infrastructural enterprises, aquaculture ponds, salt works, cattle breeding areas, and human settlements [42–44]. Total mangrove ecosystem carbon stocks (vegetal biomass and soil) can reach an average of 856 ± 32 MgC/ha, approximately 11.7 PgC globally [45], which is more than 2.3 times the yearly carbon emissions of the USA in 2018 [46]. Hence their conservation and eventual restoration keep a huge amount of carbon locked in the ecosystem, which would accelerate atmospheric warming if released.

However, despite a slight reduction in forest loss rates, mainly in the Americas, Africa, and Australia [47,48], mangrove clearing and fragmentation continues, mainly in Southeast Asia [47,49,50]. Worse yet, recent research highlights widespread indirect

impacts, which result in a reduction of ecosystem services, and in the resistance and resilience to environmental impacts [51]. Necessary ample reforestation programs have not been implemented, although conservation of these forests should motivate supranational efforts. The opportunities of mangrove restoration are many, and their restoration is possible and strategic to stop the "economically and socially illogical" destruction of these forests. In the last four decades, only around 2000 km^2 of mangroves have been restored. However, 8120 km^2 of lost mangroves worldwide are yet restorable, and, if they were rehabilitated, 69 million tons of atmospheric carbon could be sequestered (equivalent to the annual emissions of 25 million American homes), also enhancing small-scale fisheries and increasing coastal protection [52].

The urgent conservation and restoration of vital LSEs is globally recognized as a key step to improve the Earth's capacity to meet humanity's aspirations [4,53], but is impaired by high consumerism standards and military spending of the developed world. The arguments presented here find support in existing scientific and economic literature, expert-based approaches, and published checked-media articles. Therefore, this review is based on a non-systematic literature review. We discuss how and why the use of mangroves has not been and cannot ever be "sustainable" under the current developmentalist, capital-oriented systems. A lack of proper indicators of the state of restoration of mangrove LSEs still hampers modeling of the resistance and resilience of these forests to the present degree of environmental pressure. A driver–pressure–state–impact response (DPSIR) analysis of Latin America and Caribbean mangroves, proposed by Lacerda et al. [44], if validated at a global scale, may help to bridge this gap. A set of indicators is proposed to gauge the effectiveness and progress of such recommendations. We show that the threats posed by the current development and exploitation paradigm over mangroves is one part of the same threat to all biosphere ecosystems, and, finally, we review paths to slow down and hopefully reverse the collapse of these unique LSEs and of the biosphere itself.

2. Social Economic Imbalance of Mangrove Conversion, or Why Mangrove Conservation Is Incompatible with "Sustainable Development"

2.1. Mangroves and the Developmentalist Framework

In Southeast Asia, mangrove loss and degradation between 1996 to 2016 were the highest at the global level, followed by North and Central America and the Caribbean, with South America in third place. The most extensive losses relative to regional mangrove area were in North and Central America and the Caribbean (7.18%), followed by Southeast Asia (5.83%), with the Middle East (4.54%) in third place [52].

The Matang Mangrove Reserve (Perak, Malaysia) is considered an example of sustainable mangrove forestry, with a rotation cycle of clearing of a different part of the forest every 30 years, followed by planting [34,54]. However, regardless of whether in the so-called "developed" or "developing" countries, the way mangroves are managed and treated is currently within the capital-oriented framework. This means that, despite mangroves being public natural heritage, they have been transferred to private owners/capitals in the name of economic development and under the false pretense of job creation, yielding profit for investors, and taxes for governments. Indeed, the profit of capital comes from exploiting (nearly) cost-free resources, like environmental ones. As occurs with countless ecosystems, degradation and losses are socialized after the resources are depleted and/or entrepreneurs abandon their exploitation, deepening socioeconomic disparities [55,56]. The same approach leads to the devastation of countless extensions of mangrove for the rise of touristic infrastructures (e.g., the Maya Riviera in Mexico [57,58]). Similarly, the permission to extend urban infrastructure and human occupation onto mangroves (e.g., the Brazilian New Forest Code, Lacerda et al. [44]) obeys the logic that human needs are above those of any natural system and of other beings therein, which is the same view that has led to the present imminent exhaustion of LSEs, putting at risk the whole biosphere and a significant proportion of traditional human populations. Aquaculture, particularly intensive shrimp

farming, typically exemplifies this conversion of public natural heritage into private capital, becoming the major source of mangrove degradation in many parts of the world [44].

As with other ecosystems, the main sources of degradation, habitat loss, and land conversion over mangroves in so-called "developing" regions do not necessarily come from the poor people, but are the results of intentional destructive land and resource use practices by large-scale commercial interests, like forestry interventions, salt production, oil extraction, aquaculture, agriculture development, mass or luxury tourism, and others [55,56,59]. The settlement of marginalized people often degrades mangroves in urban environments, since governments fail to provide appropriate dwelling alternatives for these people to avoid housing in mangroves. In fact, there should not be poverty, an outcome only attributable to the current socioeconomic systems. In shrimp exporting countries, for example, politically connected investors turn highly productive complex ecosystems into a single use private domain. The many traditional people who depend on mangrove and coastal fisheries for their livelihoods are eventually displaced. Conflicts over land tenure rights are at the core of the conflicts related to shrimp farming [55].

Mangroves are social–ecological systems [60,61]. As such, they require strong community engagement and participation so that conservation initiatives are successful [62]. Current possibilities for stakeholder participation in decision-making, including conservation policy development and effective respect for it, is currently being undermined in capitalist societies, especially under its more recent stage, neoliberalism, which is connected to a widespread disbelief in oligarchic "democratic" institutions and policy-making processes. Therefore, focus should be redirected towards an approach to mangrove management that includes people governance and tenure arrangements, and to bridge this focus with biophysical and ecological aspects [63]. Common tenure regimes of mangroves continue to be deteriorated elsewhere through new policy instruments (e.g., Brazil's 2012 Forest Code) [64].

The effectiveness of area-based conservation strategies (e.g., protected areas) also depends on regional characteristics, and can require state-owned or shared tenure of mangroves. Sometimes, private individuals are forced by their adverse material conditions to infringe on laws (e.g., temporal fishing closures), which distances these actors even further from formal institutions and policy-making processes [65]. For Asante et al. [66], private ownership can be viewed as more effective, as observed in a case study in Ghana, where the involvement of government legal enforcement in a co-management framework showed to be more effective for conservation. Farley et al. [67] offered a quite different perspective: "We found that the economic and ecological benefits of intact mangroves outweigh the returns from aquaculture. Perversely, however, private property rights to mangrove ecosystems favor inefficient, unjust and unsustainable allocation of the resource—a tragedy of the non-commons". Indeed, as exemplified in several SE Asian countries, state appropriation or privatization of these resources leads to the destruction or conversion of wetlands [68]. In some Central America countries, several forests are in privately owned lands, much of them presumably under commercial use, and conflicts have emerged between communities and private landowners around access and use, as well as between landowners and the government, over compliance with management constraints associated with the Ramsar classification [69]. The relatively new transoceanic canal in Nicaragua, prompted by the Nicaraguan government and Chinese entrepreneurs, completely disregards the key biodiversity corridor between the Americas and displaces many traditional communities [70]. In Mexico, where around 7% of the world mangroves can be found, privatization of land and conversion of their collective or common rights into private properties is also rampant [24].

Mangroves present key features that point to the need to adopt an anti-capitalist approach to this ecosystem's conservation strategies. These key features demand that specific requirements be met so that conservation initiatives can yield positive results. These requirements, in turn, can be met by applying anti-capitalist solutions that target the root causes of threats to mangrove conservation (Figure 1).

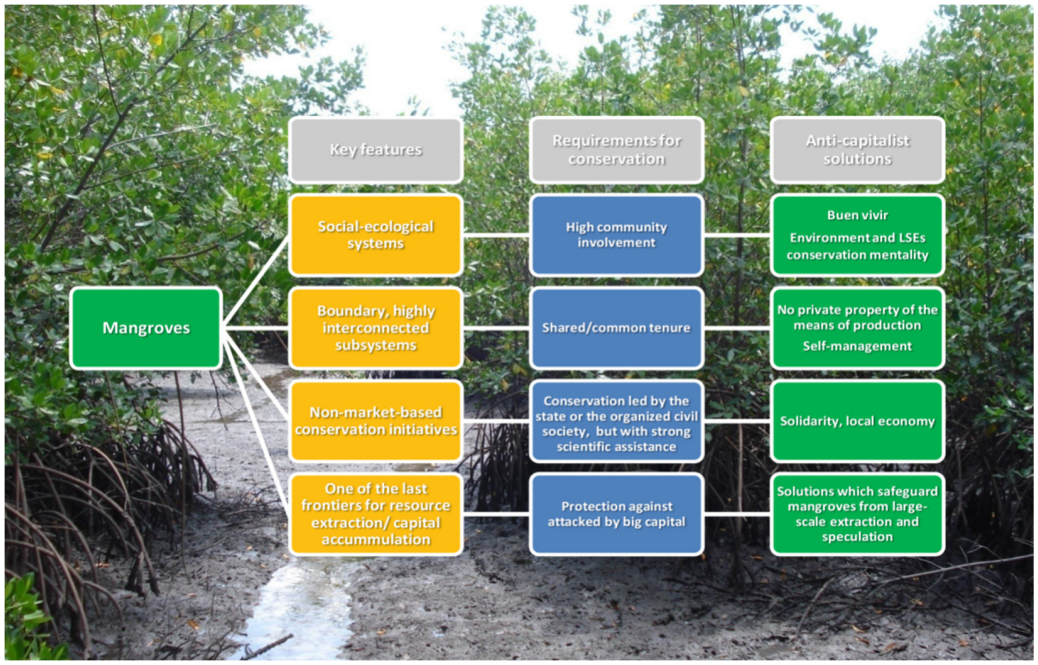

Figure 1. Key features of mangroves that translate into specific requirements and related anti-capitalist solutions. *Buen vivir* ('*Good living*") proposals of an economy based on harmony, solidarity, and reciprocity are addressed by Acosta [71].

2.2. An Overview of Major Drivers Affecting Mangroves and Impact Indicators

2.2.1. Climate Change

Climate change represents an increasing threat to mangroves [28,72,73] (Table 1). Even though, in some places, extreme events related to climate change could favor mangrove expansion or productivity [74–76], worldwide mangroves are vulnerable to the effects of these global changes. Sea level rise can increase soil and pore-water salinity and contamination of biological resources through remobilization of pollutants (i.e., trace metals) [44,77]. Drowning and erosion of coastal forests and burying of basin forests are also expected effects, along with decreasing extension and biodiversity of stands [44,78].

Table 1. Drivers of degradation, pressures and impacts on global mangroves by region [North, Central and South America (N., C. & S. America), West and East Africa (W. & E. Africa), Middle East, South and Southeast Asia (S. & SE. Asia), Australasia, and Pacific Ocean (Data from UNEP [54] (global) and Lacerda et al., 2019 (Americas and Caribbean)) and societal responses to (or results from) impacts. Importance of drivers by region: (1) high; (2) medium to high; (3) medium; (4) low to medium; (5) low; (6) unknown; (7) no agreement among consulted specialists [54]. Predicted trend of driver by region: (1) increasing (↑); (2) decreasing (↓); (3) continuing (→); (4) unknown or no agreement among consulted specialists (?) [54]. The UNEP assessment [54] presents Aquaculture and Agriculture grouped under "Agri/aquaculture Conversion" driver, and Urbanization, Industrialization and Tourism together as "Coastal development" driver; consequently, the Importance and Predicted trends of driver were attributed to UNEP grouped drivers (except for North, Central, and South America, where each driver was assessed separately (Lacerda et al., 2019)). Some responses are from society and others from economical/political systems, and were included in the perspective of maintenance of the current "developmentalist" paradigm.

Driver	Pressures/Impacts	N., C. & S. America	W. & E. Africa	Middle East	S. & SE. Asia	Austra-lasia	Pacific	Responses/Results
Climate Change §	Destruction of forests by storms; erosion of coastal forests; burying basin forests; flooding of low littoral forests; increasing soil and porewater salinity; changes in sedimentary profiles; contamination of biological resources by remobilized pollutants; mangrove migration.	High Importance ↑	Unknown/ no agreement ↑	Unknown ?	No agreement ↑	No agreement ↑	High Importance ↑	Increasing with economic growth/development. Rampant criminal deforestation/burning of global forests without an effective response from governments and multilateral agencies. Increasing and strengthening of conservation laws, though most still do not consider climate change as a variable. Rehabilitation of deforested or degraded mangrove forests, after cessation of an activity (e.g., saltworks, aquaculture ponds) are still absent from most pieces of legislation. Incipient, isolated attempts to evaluate resistance/resilience threshold for mangroves. Increasing forest reforestation/afforestation practices; often with non-native species (many times with economical purposes). In the case of mangroves, restoration is mostly promoted by the third sector.

Table 1. *Cont.*

Driver	Pressures/Impacts	N., C. & S. America	W. & E. Africa	Middle East	S. & SE. Asia	Austra-lasia	Pacific	Responses/Results
Aquaculture ¥	Deforestation; carbon dioxide and methane release; pesticide poisoning; eutrophication; heavy metal pollution; siltation; introduction of non-native species; land and natural resources privatization; highest emission factors for nutrients and metals.	High Importance ↑	Medium to high importance ↑ #	Unknown ?	High Importance ↑	Low Importance ?	Low Importance ?	Increasing with economic growth and development. Continuity of deforestation and productive models that increase emissions; recognition of mangrove conversion as a significant source of GHGs starts being included in major multilateral discussion on climate change. Setbacks on protective legislation are being promoted by political influencing productive sectors as counter measures. Unrestricted support to aquaculture from multilateral organizations is being substituted by un-fed species, mostly algae and mollusks; however, 75% of aquaculture still depends on fishmeal-based aquafeeds. Strengthening sanitarian measures by importing countries is curbing agrochemicals use and chemical contamination, but the globalized market and multinational factories easily bypass such rules. Increase in alternative aquaculture practices (silvofishery, mixed mangrove shrimp systems, polycultures). Increasing public awareness of threats from agriculture, but restricted to the third sector.
Agriculture ¥	Land reclamation; deforestation; carbon dioxide and methane release; eutrophication; contamination of the biota; waterways diversion; soil degradation. Major impacts from intensive irrigated agriculture.	Medium Importance →						Increasing with economic growth and development. Continuity of deforestation and productive models that Increase emissions. Increased use of agrochemicals, despite restrictions in some countries.

Table 1. *Cont.*

Driver	Pressures/Impacts	N., C. & S. America	W. & E. Africa	Middle East	S. & SE. Asia	Austra-lasia	Pacific	Responses/Results
Damming, changes in water flow, Sedimentation, and/or salinity ©	Erosion of coastal forests; burying basin forests; Impacts on sediment profiles, salt balance and nutrient fluxes; increasing soil and porewater salinity; effects on biodiversity and fisheries. Deforestation and resilient salinity of abandoned saltworks.	High Importance ↑	No agreement ↑	No agreement ?	Medium importance ↑	Low to medium importance ?	Low to medium importance ?	Increasing with economic growth and development. Conflicts on use of water and watercourse deviations and altered hydrological conditions have result among countries, despite would be relatively well approached by integrate basin management. As a rule, this management has failed to integrate the basin-coastal zone continuum, resulting in severe impacts on mangroves. Necessity to expand post-operational or decommissioning existing protocols for some extractive activities, such as mining, to the recovering of abandoned salt and aquaculture ponds. Increased community-based management at the watershed level.
Urbanization Д	Mangrove eradication and conversion; pollution; waste accumulation; contamination of the biota; eutrophication; hydrology changes.	Medium Importance →	Medium to high importance ↑ #	No agreement ↑	High Importance ↑ Ω	Medium to high importance ↑	Medium to high importance ↑	Threat of coastal zone management plans, improvements in waste treatment, and incentives for urban mangrove protected areas by economic expansion and increasing population growth. Conflict of governmental subsidies to enterprises that impact mangrove forests, in particular harbor facilities, with stronger regulations improving wastes treatment, technology, strengthening security and contention tools. Urban mangrove protected areas.
Industrialization Д		Medium importance ↓						
Tourism Д	Forest conversion and deforestation; waste disposal; eutrophication.	Low importance ↓						Growing tourist activities leading to increased infrastructure and potential mangrove conversion. Work exploitation: changes in traditional local work relations and subsistence practices require training and human capacity building not generally involved in development plans. Tourism environmental regulations and supporting eco-tourism.

Table 1. *Cont.*

Driver	Pressures/Impacts	N., C. & S. America	W. & E. Africa	Middle East	S. & SE. Asia	Austra-lasia	Pacific	Responses/Results
Forestry, Overexploit-ing θ	Deforestation.	Low importance ↓	High Importance ?	Low to medium importance ?	High Importance ?	Low Importance ?	Medium Importance ?	Legislation on restraining mangrove wood use; creating extractive reserves and the introduction of community-based management. These responses however, are threatened by growing population and poverty. Traditional non-predatory practices (silvo-agri-aquaculture and others) recognized as a feasible economic activity.
Fisheries £	Overfishing and decreasing stocks;tree cutting for fishing gears.	Low to medium importance →	Unknown ↑	Low importance ?	Low to medium importance ↑	Low importance ?	Low importance ?	Community-based management and establishing temporal closures decrease pressures on stocks. Increasing the incentives for non-depleting traditional practices.

Table 1. *Cont.*

Driver	Pressures/Impacts	N., C. & S. America	W. & E. Africa	Middle East	S. & SE. Asia	Austra-lasia	Pacific	Responses/Results
Rehabilitation and Replanting α	Increasing mangrove area; increasing carbon sequestration, natural resources availability and protection; reduced erosion.	High Importance ↑	Low Importance ?	Unknown ?	High Importance ↑	High Importance ?	Low Importance ?	Mangrove (and wetlands) conservation still not addressed as a global-responsibility matter. Multiplication of restoration projects at the local level, however, incipient at national level. Also, delayed effective participation of science in field restoration efforts, still hampers some endeavors. Recognition by multilateral agendas of the link between mangrove restoration and mitigation of climate change effects (e.g., carbon sequestration and shore protection). Introducing community based managed projects and increasing public awareness.

§, There is no agreement on importance among consulted specialists by UNEP [54] in spite of increasing trend in North, South America and Caribbean. ¥, Aquaculture and Agriculture (rice farming, biofuels) are drivers low to medium important and of unknown future trend in North America [54]. #, In West and Central Africa, importance of Aquaculture/Agriculture and Coastal development drivers has no agreement among specialists [54]. ©, In UNEP [54] this driver (Pollution and indirect disturbance) includes oil pollution. Д, Coastal development (Urbanization, Industrialization, and Tourism) is an important driver but of unknown future trend in North America, while of medium to high importance and increasing in Caribbean and South America [54]. Ω, In South Asia, medium to high importance [54]. θ, Overexploitation (timber, fuelwood, and charcoal), is of low to medium importance and increasing in North America, but medium to high importance and continuing trend in South America [54]. £, Due to the lack of accurate measures of the impact of Fisheries over mangroves (overfishing and tree cutting for fishing gears), we categorized the importance of this driver in West and East Africa, Middle East, South and Southeast Asia, Australasia and Pacific Ocean based on [79–81]. For the predicted trend of the driver, and except for the regions where data are lacking, we assumed that the current COVID-19 pandemic will increase pressure over mangroves in regions of traditional high use of them, higher population density and lower income, such as Central and South America, West and East Africa and mainly South and Southeast. Asia. Hence, using this reasoning, we increased this driver from "Low" to "Low to medium" importance and from "Decreasing" to "Continuing" in North, Central and South America in relation to our previous work [44]. α, There are no unified global data about extension of restored mangrove areas, mainly by the countless restorations efforts not published (registered in the gray literature), and also by the lack of monitoring (of success or failure) of several restored areas. To approximately categorize this driver, we used the number of extant restoration projects (since there is no accurate information on the size of several of these areas) in relation to mangrove area of the region [52,82], so this categorization could not exactly fit.

It is clear today that the climate crisis is intricately linked to the excessive consumption of a wealthy lifestyle, since the richest countries are mainly responsible for the historical GHG emissions, and most of them have, in fact, the highest per capita emissions [2,6]. Thus, reducing emissions needs urgent deep structural changes in the economic and governance relationships on the planet, as we comment later in this article. In the meantime, and whenever possible, mitigation and restoration measures need to be implemented urgently to avoid the effects of climate change. Among them, avoiding land fillings and human occupation in areas where mangrove will migrate, pushed landward by sea level rise, such as estuaries, salt-flats, and others, and the conservation of extant mangroves and restoration of deforested/degraded stands to address the direct and indirect effects of climate change (Section 3.2) [44,83].

Major Indicators: Two types of indicators closely respond to the impacts of climate change: (i) sedimentation rate, a relatively easy index to obtain, which is cheap and demands low technological requirements to support a globally spread network of monitoring stations. Its major limitation is the relative absence of historical records of measurements; and (ii) remote sensing, which, on the other hand, is relatively expensive and requires a high level of technology, can provide historical records for the past 50 years [84]. Comparative analyses of remote sensing images can be improved greatly using vegetation indexes, such as NDVI, capable of evaluating indirect impacts on mangroves, including ecosystem's functioning, prior to losing proper plant cover [51,85,86].

2.2.2. Aquaculture

Aquaculture, in particular shrimp farming, typically exemplifies the mentality of profit-making above ecosystem-support capacity. Formerly viewed as a "green" industry producing extensively required protein and with high job generation capacity, aquaculture ended up focusing on expensive products, dislodging local populations and compromising traditional fisheries through environmental impacts, such as eutrophication, to the point of becoming a major source of mangrove degradation (through deforestation and fragmentation) in many parts of the world [44,49] (Table 1). Under the current capitalist mode of production, the socioeconomic benefits of shrimp aquaculture do not compensate for the social and environmental externalities that the activity generates [44,55,56,87]. In the short term, intensive shrimp farming is highly profitable for the companies. However, it results in major environmental and economic losses for the local communities: degraded environment, displaced communities, loss of traditional livelihoods, and human rights violations. These are the pillars of intensive, export-led shrimp farming, which, at the global level, has also implied overfishing and depletion of the seas, due to the preferential use of fish meal in aquafeeds [51,55].

Intensive aquaculture as most often practiced today in mangrove forests needs to be banned. Also, the policy of granting public environmental patrimony to private individuals or enterprises should be interrupted [88,89], even more so in the context of producing monocultures. For example, one hectare of preserved mangroves in Brazil is home to around 5.1 t of mangrove crab, *Ucides cordatus*, and yield around 20 t of animal biomass per year, including crustaceans, mollusks and fishes [90,91]. This biomass feeds countless fishers' families, in contrast to the private profit monoculture of an equal area of converted mangrove [51]. Urgently, other forms of aquaculture preserving mangroves and estuaries need to be adopted. Alternatives to traditional intensive shrimp farming practices in Asian countries have shown positive social outcomes, like mixed mangrove–shrimp systems (*tambak*) with lower capital requirement, diversification through polyculture, provision of regular income and recognition as organic farming practice [92,93]. For example, silvofishery is an ancient management concept of low-input sustainable aquaculture, integrating mangrove tree culture with brackish water aquaculture.

Economic activities that were already established over mangrove deforestation should be subjected to the restoration of deforested stands, and new enterprises forbidden from

establishing in or close to mangroves, to avoid pollution or alterations to mangrove functions [43,51]. After finishing their activities, shrimp and saltwork enterprises should be forced to restore damaged mangroves and remove dams and enclosures of ponds, which impair the deposition of waterborne propagules and the regeneration of soil features, delaying mangrove recovery, sometimes by decades [94].

Major Indicators: Although comparing forest areas against aquaculture pond areas is a straightforward association, the impacts of shrimp farming are far from only deforestation, and decreasing of forest health and functioning seems to affect much larger areas than previously suggested. The normalized difference vegetation index (NDVI) compares photosynthetic activity at different spatial or temporal scales allowing the monitoring of structural, phenological and biophysical parameters of forest canopies. NDVI can determine the decrease of green spectrum absorption that reflects the health of a forest track, and thus has been suggested to present a higher fidelity picture of the mangrove state of degradation due to shrimp culture [85,86,95]. Hydrochemistry, mostly nutrient concentrations and concentration ratios between elements, as well as eutrophication variables (e.g., dissolved oxygen and carbon, Eh, chlorophyll), can be used to trace the extension of impacts from shrimp farm effluents on water quality [86]. Time series evaluation of emission factors and emission loads can also be used in inventory of nutrient and pollutant discharges and compared to natural and other anthropogenic sources [96].

2.2.3. Agriculture

Expanding large-scale intensive agriculture contributes to increasing land reclamation, deforestation, and the damming of rivers and waterways diversion, the highest impacts being from intensive irrigated agriculture [44,59,97] (Table 1). An increase of nutrients and pesticides in water, contamination of biota, and eutrophication are common outcomes. In Asia, mangroves were converted to extensive paddy rice fields and palm plantations, while the production of sugarcane in the Americas and oil palm, mainly in Central America, also affect mangroves [42,56,98,99]. Displacement of local communities to establish such agricultural enterprises is a common way of acting by capital, in association with governments at several levels [55,100]. Extensive cattle breeding can increase herbivory pressure over mangroves [101], so semi-intensive breeding is an alternative to reduce the impact on forests, particularly in semi-arid realms.

Major Indicators: Small adaptations, the same remote sensing indicators, as well as emission factors and emission loads, suggested as indicators of aquaculture impacts, can be applied to monitor agriculture impacts on mangroves.

2.2.4. Damming, Changes in Water Flow and Sedimentation

Excessive water withdrawal from rivers for human consumption, agriculture, and other uses decrease the rivers' freshwater flux to the coast. Water withdrawal or damming cause impacts, such as coastline erosion, increasing saline intrusion, nutrient depletion, and, in some areas, sediment accretion due to marine sand deposition in estuaries, all of which significantly affect mangroves [56,78,102] (Table 1). Even though sediment deposition and further mangrove colonization may occur in some realms, erosion by higher tidal flux and winds, and the occupation of new littoral areas of estuaries by populations, can impair the upstream and landward expansion of forests. Further effects over estuarine and coastal biodiversity and fisheries have also been observed [102].

Many coastal zones are affected by a reduced flow of fresh water and sediment as a result of dams, barrages, and water diversions (e.g., Indus, Nile, Mekong, Volta) occurring at short or long distances upstream, affecting large mangrove extensions and generating conflicts among countries [56]. This hydrological linkage between the coastal zone and inland river basins needs to be addressed with a collaborative framework out of the capitalist logic of competition and confrontation. An ecosystem-based approach/management and multi-scale conservation planning to manage such social–ecological systems are neces-

sary [60,103]. While conflicts persist, countless species go extinct and human populations are affected by medium–large scale environmental changes [104,105].

Major Indicators: Historical data series of river fluxes abound globally; they can be a secondary indicator of the impacts of land use taking place in river basins. Unfortunately the so-called "ecological flow" is difficult to estimate [106], but comparisons of pristine conditions may render a scale of displacement from a pristine reference. Other relatively easy datasets are the sediment load of a given river, which are also available for most rivers and are linked with sediment accumulation; this indicator can be worked out in consonance with the sedimentation rates and the remote sensing monitoring of river margins and fluvial islands mentioned above.

2.2.5. Urbanization and Industrialization

Urbanization and industrialization are strongly associated with intense migrations of populations to coasts and the need for job creation, land reclamation, and water and food supplies for growing urban settlements [44,107,108]. These drivers triggered an overexploitation of mangrove products worldwide, in particular a growing demand for fuel wood, timber, and associated fisheries products by traditional populations [54,109]. An increasing population leads to encroachment on mangroves in large metropolitan areas, increasing forest deforestation and degradation, and spill of urban solid and liquid waste to estuaries and coasts [44,110] (Table 1). Again, the logic behind the deforestation of mangrove forests to set urbanization is that human needs and infrastructure expansion are more important that any natural system, as if these LSEs were not fundamental to maintaining the biosphere homeostasis and the proper human being. In Mexico, around 60% of original mangrove cover has been deforested by infrastructure enterprises [111].

Major Indicators: Apart from remote sensing, monitoring of urban area expansion over mangroves, that again cannot represent the full impact of the activity, can be used as an indicator. As mentioned, these indicators can be highly improved using vegetation indexes. However, an easily obtainable method is inventorying sources and estimating on annual or decadal basis the emission from these human activities. Emission factors, instead of measuring water quality parameters, may be easily applied to provide the potential contribution regarding pollutants and nutrients able to trigger eutrophication. In addition, changes in industrial and urban procedures and techniques and their actual increasing or decreasing impacts on mangroves, can be assessed by comparing them with emissions from natural processes only [96,112].

2.2.6. Tourism

The tourist industry can be a driver of mangrove destruction through the construction of highways, roads, and the building of major hotel facilities [54,55,57]. The construction of great touristic enterprises for high income users have been done in several places, leading to ecosystem conversion and the displacement of native communities [107] and workforce exploitation (Table 1). As with aquaculture, the claimed "job offer" and economic developing advantages are far overcome by the social and environmental damages [43], often irretrievable. The touristic development of the Cancun region in Mexico alone, for example, resulted in the loss of 1270 ha of forests in less than a decade [44,58]. Low-impact eco-tourism in mangroves can be a way to ecological awareness of urban dwellers and a source of income for traditional communities [113]. Made under control, and fully preserving the integrity and habitats of resident flora and fauna, low-impact tourism set an alternative to privatization by great enterprises.

Major Indicators: Typical socio-economic indicators of a given area could be used to monitor the growing importance of tourism over a region. Support capacity has been established in many areas, with restrictions to certain activities, such as boating or beach driving. Records of infractions of such prohibition are frequently available and can be used for monitoring purposes. Remote sensing, NDVI, and loads of nutrients can also be use as indicators of tourism impacts on mangroves.

2.2.7. Forestry and Fisheries

Forestry and fisheries, when promoted under traditional procedures by coastal populations have rarely resulted in extensive impacts on mangroves. Examples abound; the rearing of the wood-boring teredinid mollusk *Teredo* spp., locally called *turu*, by felling mangrove trees and leaving the trunk to decompose in the forest floor, typical of traditional inhabitants of northern Brazilian mangroves [114]; the silvi-agri-aquaculture traditional practices such as *tambak* and *tumpang-sari* in Indonesia and *pokkali* and *bheri* in India, as well as in many places of South and South-East Asia [115]; silviculture in Malaysia [116], are examples of long-term use of mangrove goods and services. These focus on the maintenance of local populations rather than generating capital. Also, they are most frequently regulated by community-based decision-making processes.

The extraction of timber, wood, and other products is more significant in Asia and Africa, where mangroves are basic livelihood items with diverse uses. In times of economic crisis, such as the current one, governments and more marginalized people in developing countries increasingly turn to mangrove resources for further exploitation or simple survival [44]. Therefore, these drivers need to be closely monitored (Table 1).

Major Indicators: Surveys of biodiversity, frequency of sensitive species, population ecology, and the emergence of invasive exotic species are excellent monitoring tools for the eventual impacts from forestry and fisheries on mangroves. The relative economic importance of traditional fisheries can also inherently measure mangrove ecosystem services to local communities.

3. Protecting, Conserving, and Restoring Mangroves

3.1. Protection and Conservation

The most cost-effective and efficient measure for carbon sequestration management is to conserve existing mangroves [48,117]. Although losses have been far greater than gains, some gains in mangrove areas have been detected in specific locations, with South America having the higher rate of gain in respect to losses (0.48), followed by North and Central America and the Caribbean (0.26), and Southwest Asia (0.17) [52].

Around 39% of remaining global mangroves are inside protected areas (PAs), mainly in the American Continent and South Asia, where Brazil, Indonesia, and Mexico have the largest extensions of mangrove PAs [52]. However, this does not necessarily mean full protection, but it at least lowers the levels of degradation. Most mangroves and other coastal–marine Pas are governed centrally by the state, and their effectiveness is limited by being isolated within environmental agencies with poor interinstitutional collaboration, conflict among several management authorities, jurisdictional and regulatory ambiguities, and pressure of economic sectors [43,63]. In other cases, degradation outside Pas can reach the protected mangroves, as in the case of impact over estuarine or coastal mangroves by alteration of water or sediment flux, or pollutants, upstream rivers.

Relentless efforts to preserve mangroves need to continue, since attempts to setback achieved advances will be made by developmentalist policies. In Brazil for example, the protection of the "permanent protection areas" category under which mangroves are is extremely weak, and does not curb their deforestation by aquaculture or infrastructure establishment, for example. Furthermore, under recent amendments to Brazil's *Forest Code* promoted under strong lobby of the agro-business sectors, approximately 6000 km^2 of previously protected coastal areas will be available for conversion, mostly to intensive shrimp aquaculture [44], tourism infrastructure, and others. Yet, the Brazilian government recently attempted to implement further setbacks in mangrove protection, although these attempts were stopped, at least temporarily, by judicial order [118].

Considering the periodic political and economic crises in many developing countries and the increasing livelihood-sustaining relevance of natural resources, it is imperative to work in more participatory ways with local communities to ensure conservation of mangroves. Community-based protected areas have shown good conservation results [43,119,120], and in some countries legal framework of some forests tenure

has changed from state-based to society-based, like in Vietnam, the Philippines and Ecuador [63]. Many coastal communities (including indigenous groups) have traditional practices of mangrove management and conservation integrated to their social structures [63]. In general, where communities are empowered and granted legal rights and authority to manage their own forests, the derived community-based management has proved effective in rationalize the use of mangrove goods and services, like in some places of Asia and Africa [63,121,122]. In Latin America and Caribbean, these strategies were broken by large capital investments, particularly the large-scale intensive shrimp farming and harbor development by large national and multinational corporations that, in general, oppose conservation and sustainable-use initiatives [44]. The effectiveness of PAs has been under discussion in Brazil, where some of them lack management plans and have adopted rather vague fishery management measures so far [123,124].

3.2. Restoration

Presently, about 8120 km^2 of lost global mangroves are restorable, an extension 33% higher than the mangrove losses in last 25 years, and their restoration is strategic and possible [52]. Around 2000 km^2 of mangroves have been restored worldwide in the last 40 years, though undocumented restorations at different scales could double this area [52]. Some projects supported by international conservation institutions and/or funds and NGOs, and sometimes governments, have advanced in mangrove restoration. Though in some places needing methodological adjustments, large scale restorations have been successful, like in Mekong River, East Africa, and the Philippines [117,125,126], as well as many rehabilitation, planting, and restoration projects worldwide supported by the International Society for Mangrove Ecosystems [127], all showing that such endeavors are possible.

The possibilities and conditions for mangrove restoration are many, and their rehabilitation/restoration is possible to stop their rampant destruction [43,52] (Table 1). However, inability or nescience of governance levels, and influence of economic interests focused on profit at the expense of environmental heritage areas, have impaired such endeavors in several countries. Still, instead of supporting endeavors and joining efforts of restoration with local populations, governments usually support economical enterprises that destroy mangroves and are viewed as "economic development" and "job creators" [43,51,52]. This behavior also explains why some countries have purposely failed to coordinate and establish effective policies and promote societal campaigns to restore the mangroves. Governments rarely join scientific/technical support with civil organizations and native populations, to promote and help initiatives to restore these life-supporting wetlands. Native/indigenous populations, artisanal fishers, etc., should be encouraged and assisted to restore mangroves [60], and even with success or failure, their attempt to restore their livelihood environment are extremely positive in terms of self-management and awareness [128] (Table 1). Ideally, methodologies and knowledge need to be constructed with these populations so that they can restore mangroves on their own, using sound methodologies [43,60].

When governance level fails, scientists have the obligation to help and promote restoration endeavors together with coastal communities [43,60], testing and suggesting methodologies liable of higher success. Science has been part of many actions, but their contribution needs to be ampler. Indeed, mangrove restoration has even been discouraged, with arguments that monospecific plantings are not a solution to restore functionality of mangroves [129–133]. However, these studies disregarded that in some low tree diversity stands (1–2 species), the monospecific planting of autochthonous mangroves (more suited for harsh environmental conditions, higher growth and primary production, and/or more efficient to promote key faunal groups return), can be an effective way to start the progressive return of degraded forest recover and their functionality [134–138]. Also important, it impairs the use of areas by other activities more destructive of soil and with longer term impact (herd breeding, shrimp culture, salt making, garbage dumping) and

generates collective awareness [43]. It is clear, however, that there is a need for better protocols to restore mangroves aiming at maximum biodiversity, long-term functionality, and foreseeing the effects of climate changes. For example, since mature *Rhizophora* lacks epicormic resprouting, in regions with predicted increase of great storms, a stand of these trees could be seriously damaged and may not recover [83], so it is better to initially restore these mangroves with several species. In semiarid climates, initial restoration with mangroves resistant to hypersalinity (*Avicennia* spp.) and drought can facilitate the growth of mangrove stands [134].

Mangrove (and ocean) restoration is also fundable [52,53,139]. Highly pollutant and environmentally aggressive industrial activities, like oil extraction, petrochemical, and logging, could be forced to disburse part of their profits to finance restoration. Fines charged to forest devastators need to be increased and effectively imposed and used in restoration. If the more than 8000 km^2 of global restorable mangroves were rehabilitated, they could sequester close to 70 million tons of atmospheric carbon, increase fisheries on the order of thousands of millions of tons of crustaceans, mollusks, and fishes, and protect many people from coastal flooding. Around 1400 km^2 of the total restorable mangrove area are degraded forests which can be rapidly restored with lower effort and investment, and several of them need to be only protected to recuperate by themselves [52,136]. In the American Continent and the Caribbean region, where mangrove losses are proportionally more extensive mainly due to shrimp aquaculture, damming and global warming, there are around 3845 km^2 of restorable areas, plus close to 233 km^2 of degraded ones [44,52].

It is necessary to stress that mangrove restoration need to be integrated with a strong effort to protect and rebuild degraded marine ecosystems, aiming to increase the abundance of keystone species and key habitats, and restoring the three-dimensional complexity of benthic ecosystems [53]. Ocean protection is a central topic to biosphere homeostasis, and oceans and forests are increasingly impacted by colonial/capital-oriented predation. These, and other, LSEs, such as wetlands, rivers, and lakes, continue to be explored to obtain more and more materials and/or energy to sustain capital-oriented systems of endless "development", until complete resource exhaustion of a closed system like planet Earth.

4. Broadening the Scope of Challenges beyond Mangroves

4.1. Economic and Environmental Inequities

With only 14.4% of the world's population, the USA and Europe, together, currently consume more than one-third of the world's energy (33.8%) (in tons of oil equivalent), with more than half of this amount consumed by the USA [140,141]. If we add China, these three consume 55.41% of the world's energy (British Petroleum, 2019). The huge military expenses of the countries, beyond their immorality and uselessness, represent a waste of resources, and a great energy consumption and hence contribution to GHG emissions. Close to one trillion USD are spent by the USA and China annually on weapons and military activities [142]. The most armed European countries (the UK, Germany, France, and Italy) spend more than 173 billion USD yearly and the 4th world biggest spender is India, a country with serious inequality problems. This waste of resources needs to stop; the yearly spent of the ten more-armed countries should be used to restore an average of 8700 km^2 of degraded marine coastal habitats [139], such as mangroves. Protection and effective management of a taxonomically comprehensive network of natural areas would cost around 76 USD billion/year, a small part of the direct value earned by countries through touristic visitation of protected areas, around 600 billion USA$/year [143]. Rebuilding/restoration of marine life through extending protection to 50% of ocean space by 2050 would be possible by allocating US$ 20 billion/year [53].

Degrowth (through an agrowth start), i.e., to abandon the limitless growing concept promoted by capital owners [144], needs to be put into practice by rich countries. It has been claimed that it would be "immoral" to request economical degrowth to developing countries, but attempts of economic development in the present environmental crisis put them in a route of failure and higher technological and social dependence of rich coun-

tries [144,145]. A "post-extractivism" framework emerge as a measure to break dependence of global South of revenues from extraction of raw materials by transnational companies, which since the beginning of the colonial time, however, only benefited national oligarchies and still leads these countries to an "impoverished growth" [71]. In an example of long-lasting dependent mindset, the last sessions of the Economic Commission for Latin America & Caribbean (CEPAL) [146,147] claimed for "sustainable development" of Latin American and Caribbean (LA&C) economies, again begging for help of international funding banks, and without any mention of how the same dependent capital-oriented mode of natural resources extraction and exportation to dominant countries will stop the continent environmental crisis, like desertification, rivers dry-outs, silting up and pollution, and deforestation of mangroves, woodlands, and the Amazonian rainforest. This ecocide is responsible for the most natural (and socio-economic) losses in LA&C countries through climate change, species extinction, and also indigenous community displacement, owners of ancestral low-impact agricultural practices.

Despite this centuries-long expropriation, developing countries still have great amount of natural heritage of LSEs that need to be managed properly and responsibly, aiming to preserve them for their own welfare and biosphere homeostasis. However, without a fundamental redistribution of wealth, any intent to reduce energy flow and decrease the pressure over natural resources will fail. Since the wealth of several rich nations has been built, from colonialist occupation to present imperialism, at the expense of the Global South, the former has a moral and yet concrete debt with poorer countries. For example, a conservative estimation of the cost of the damage on climate, agricultural expansion and intensification, deforestation (including mangrove loss) and overfishing, inflicted by high-income countries on mid- and low-income countries (these two latter contain all the tropical rainforests of the world) reach several trillion US$ [148]. These damages, however, reach the whole planet. This money and the scandalous fortunes of the richest individuals in the world should be also shared out and allocated to countless poor families which base their subsistence in activities that impact the ecosystems integrity, and to restore such ecosystems. Tens of trillions of dollars are used to assist banks and other financial institutions after periodic financial crises [149], but not to diminish impacts on the planet.

Several developing countries aim to grow and develop to become rich, but this necessarily implies the destruction of their traditional culture and natural patrimony. Several of them have built a massive industrial infrastructure, but they can no longer secure adequate amounts of nonrenewable energy to keep the economic machinery running [10]. Yet, there is an asymmetric resources flow (raw materials, energy, land and labor) flow from poorer to richer regions [150]. Hence, developing countries should end the tireless deforestation of rainforests, by foreign or local, legal and illegal logging companies [23]. Among 50 and 90% of forest exploration in the Amazon, Indonesia, and Congo Basin is illegal, but is masked as legal [149]. These crimes against humanity, rainforest people, and all life forms need to be halted. As the destruction of the rainforests of South Asia [98,151], recent rainforest wildfires in the Amazon and the Pantanal swamps, neglected (and even informally encouraged) by the current federal government in Brazil, government officials should be judged by the International Criminal Court. It is doubtful, however, that commercial partners would allow for such judicial process to even begin, since deforestation is promoted by soybean, cattle breeding, and oil palm, products purchased from Brazil and SE Asian countries mostly by China, the European Union, and the USA [152,153]. Indeed, only between 1970 and 2013, 22% of Amazonian rainforest, close to 763,000 km^2 (twice the size of Germany) were cleared, and the Amazon continues to be deforested [149], so not only Brazil can be held responsible for such ecocide.

The present agricultural crisis in the most part of the developing world, results from the flop of the development dominant paradigm [154] where food provision is driven by a market economic model that depends upon continuous maximization of growth in consumption. Around 38% of Earth's land cover is occupied by agriculture, which is the world single largest driver of global environmental change with the livestock production

chain responsible for close to 18% of anthropogenic emissions [155–157]. Agriculture emissions together with forestry and land use reach among a quarter and a third of total anthropogenic emissions [20,158,159]. Most modern (industrial) agriculture is related to forestry and land use, since it is driven by an industrial intensive agri-food system controlled by few transnational corporations (grain, fiber, and animal producers/processers, and chemicals), aiming increasing production and profit at lower costs [18,20]. These private and public corporations, and also governments and neo-colonial policies (i.e., using lands in poor countries) perpetuates this agricultural practice, whose known "externalities" are poverty, forests and grasslands destruction and further biodiversity loss, privatization and depletion of water resources, agrochemical and organic pollution of land and watercourses, and soil degradation [18–20].

4.2. Some Indicators and Paths

Global tree cover loss doubled up in last twenty years, and between 2015 and 2020 the rate of deforestation was estimated in 10 million hectares/y. Africa has the highest net loss of forest area between 2010–2020, having lost 3.94 million hectares/y, followed by South America with 2.60 million hectares/y [160]. Deforestation needs to stop immediately, and restoration of at least 5 million km^2 of degraded forests, soils and lands is urgent [149]. Timber extraction, cattle breeding, fire, mining, hydroelectric dams, and urbanization are the main drivers of deforestation [149], all fueled by the race for economic development. Development banks and other agencies (International Monetary Fund, World Bank, World Trade Organization, regional development banks) promote several "development projects" that favor deforestation, monoculture planting, and impact over native communities, arguing development and land regularization, but driven by private commercial interests [89].

Forests and their biodiversity need to be maintained, so monocultures did not always represent a good solution, neither the monetization of reforestation to allow destruction in other places [89]. Although Reducing Emissions from Deforestation and Forest Degradation (REDD+) initiatives represent a form of payment for ecosystem services to developing countries, it also represents a political offset to low commitment of developed countries to reduce domestic emissions, a form of market environmentalism, whose legitimacy and effectiveness have been questioned [161–163]. Advance of human populations over forests and other LSEs needs to be prevented, which also contribute in avoid zoonotic outbreaks [164]. Restoration of 15% of selected converted lands globally could reduce at extremely comparatively low cost the current global extinction debt, and mitigate expected emissions from next years in 95 and 89%, respectively [165].

Oceans are the largest reservoir of organic matter on Earth, but today the whole ocean is affected by human influence, with 41% of the areas strongly impacted [166]. While several fisheries exhaust resources, destroying more than they capture (mainly pelagic high-bycatch fishing), degradation of coastal and benthic habitats, aquaculture, invasive species and pollution threats marine life, and climate change is impacting ocean biogeochemical cycles and biodiversity [5,166,167]. Oceans are the first LSE, and abovementioned degradation drivers need to be seriously and effectively deterred, for example applying severe punishments to subsidized and pirate floats that overfish and devastate marine benthonic habitats. A recent study demonstrated that bottom trawling can release from seabed 1.47 Pg of carbon/year, equivalent to carbon losses from farming in land [168]. In addition, heavy taxes need to be charged to oil and petrochemical industries, to finance the retirement of countless million tons of plastics spilled in oceans, which these same industries increasingly produce to maintain profit growth [169].

A necessary shift in the present agricultural practices needs to oppose to all their adverse effects. Instead of relying on industrial-scale agriculture, other agricultural approaches (including agroecological ones) maintain and restore healthy soils and greater diversity in crops and animals while relying on few inputs from off the farm [18,154]. It is urgent encourage and support agricultural practices based in systems of multiple use, preserving biodiversity, conserving and regenerating natural resources (soil, water, forests,

fauna and flora, mainly benefic one), recycling of nutrients (organic matter) and natural biological control [154]. Already, at least 75% of 1.5 billion family farmers, smallholders, and indigenous populations in 350 million small farms produce food in this way and account for at least 50% of the agricultural output for domestic consumption [19].

Agroecological practices are based in the diversification of farming systems, promoting spatial, temporal, and regional diversification of crops, intercropping systems, agroforestry systems (that include non-timber or timber trees in land-use systems), livestock integration (integration of trees with livestock production in silvopastoral systems) and others. Agroecology-based projects and similar focused initiatives in the developing world have been documented in Africa, Latin America, and Asia [19,158,170], resulting in food sovereignty, social strengthening, economical solutions and peasant autonomy and independence. Urban agriculture also needs to be expanded [20]. As far as emissions are concerned, avoided deforestation, reforestation, ecosystems preservation, and agricultural, and agroforestry practices that sequester carbon in vegetation and soil avoiding emissions from inorganic fertilizers, can contribute to climate change mitigation [158]. However, this production system can only expand to feed the planet with a stable production, integrated in a social organization that protects the integrity of natural resources and establishes a harmonic integration among humans, production system, and environment [154].

5. Resource Exhaustion and System Change

According to universal thermodynamic laws, in a closed system like Earth, material entropy must ultimately reach a maximum, moving from an ordered state (low entropy) to a disordered state of maximum entropy, where available energy has been totally dissipated and diffused. Terrestrial low-entropy stocks of energy and materials are irredeemably limited, except the renewable sources, which if exploited to exhaustion become nonrenewable [9]. Even material recycling requires additional energy to collect, transport and process the used materials, which increases the overall entropy of the environment, meaning that while matter is continually recycled, degradation increases until total material exhaustion [10]. Thus, the greenhouse crisis represents the final bill of the Industrial Age and is the result of part of humankind's, mainly in developed countries, refusal to harmonize its production and consumption practices with ecosystem conservation, in a healthy metabolism between humans and the rest of nature [10].

Solar energy is renewable and the amount practically unlimited, but the rates and patterns that reach the planet are limited. Nevertheless, humankind's only chance is to use it, though solar infrastructure derives from and depends on nonrenewable resources, and will not support highly industrialized economies [10]. There is no quick technological solution to the exacerbation of the greenhouse effect caused by increasing greenhouse gas emissions. The first task is to urgently eliminate the source of the problem, the civilization paradigm of the need for permanent economic growth and development [2,149]. There is no doubt that we need a radical, global system change, and that the transition from a capital-oriented world to another societal organization needs also social and cultural transformation [12]. This means a change in people's attitudes in relation to consumerism, a shift in human food intake to lower levels of the food chain, and an ethical and anti-predatory political stance towards animals, which have been exploited since they are seen as private property [20,171–173].

The call to "permeate capitalism cracks" to establish new societal relations to corrode the system from the inside is valid [174], but superficial state reforms cannot promote the changes necessary to halt the chaotic situation towards which the world is walking towards [174], even if the political instruments of capital and oligarchy would allow such reforms, which history has already shown to be very unlikely [2]. Indeed, this reform proposal is well-aligned with the sustainable development paradigm. Such solutions, however, in any way could stop in time imminent resources collapse. According to Rifkin [10], "Our social structure, geared as it is for a maximum energy flow, is no longer sustainable. Our institutions (their configuration, their purpose, their method of operation) need to be

radically transformed. Transition from the Industrial Age of nonrenewable resources to a new and still undefined age based once again on renewable sources of energy need to be done in little more than one generation".

6. Conclusions

In a world with signs that warming can be faster than expected [175], mangroves and other LSEs continue to be destroyed to obtain more and more materials and/or energy to promote nature-predatory economic models' endless need for "development". The lack of environmental priorities in countries' development plans is sustained by political leaders, which see necessary actions as inopportune truths [7]. Reports presented at the 26th United Nations (UN) Climate Change Conference of the Parties (COP26) in 2021 showed how climate change unequally affects rich and poor countries, since some of the latter spend proportionally higher percentage of their resources facing climate impacts. Yet, most rich countries continue limiting effective financial help to developing nations to cope with climate change, such as the lifting of patent rights. Despite agreements by some countries to abandon coal, reverse increasing deforestation, reject imports of soy produced over deforested lands, and the financial shelter promised to cleaner energy sources, changes will not stop presenting harmful effects of warming if not implemented in the next few years. The empty and vague words in the final document headed by India and China, with commitments to a reduction instead of urgent elimination of coal and subsidies to fossil fuels, is, at least, a delay that the planet cannot support. In a demonstration of criminal irresponsibility, lobbies formed by Australia–Saudi Arabia–Japan, and Argentina–Brazil, pressed the UN to withdraw from the resolutions of any mention about the need to reduce fossil fuels and beef consumption, respectively, to reduce global warming [176].

For several people, collapse is inevitable [13]. Someone would criticize our approach here arguing that we do not present a practical roadmap on how substitute capital-oriented systems in the short term [174]. Though this was not the main scope of this work, revisited ideas and literature herein give an insight on how and where to start. Putting into practice ecological knowledge is needed, and ecologists, environmental scientists, and indigenous peoples could contribute to halting ecosystems and biodiversity loss, if they were more effectively involved in local and higher-level governance arenas. As Saito [177] emphasizes, a true rehabilitation of nature is only possible once capital-oriented systems are completely abolished. The current imbalances in the material world, caused by these approaches (what Marxists call the "metabolic rift"), hinder a truly "free and sustainable development of humankind" and force us to "fight for a new social system beyond capitalism" (our translation). Any solution that does not immediately stop business as usual LSE destruction and warming generated by the developmentalism of nature-predatory systems will be ineffective in avoiding environmental collapse.

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