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Towards a flourishing blue economy: Identifying obstacles and pathways for its sustainable development

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ABSTRACT

The current discourse addressing the need for sustainable development in the blue economy is necessary to promote effective mitigation and adaptation responses in times of rapid climate change. However, thus far, said discourse lacks foundational and specific principles to provide critical pillars able to shed light on socio-economic processes needed to achieve sustainable development across sectors and scales. This article discusses ten recently-described nature-based principles for achieving and sustaining a regenerative blue economy while advocating for an age of factuality. These scientifically-derived principles are built on well-accepted concepts of socio-ecological system dynamics and undergird a healthy blue economy.

1. Introduction

The Blue Economy (BE) has been defined in different ways (Smith-Godfrey, 2016) and is essentially a subset of the global economy linked to ocean resources (renewable and non-renewable) while also acting as a strategic framework for ocean sustainability (Wenhai et al., 2019). The Blue Economy was valued at 1.5 trillion USD in 2020, which includes both marine-based and marine-related activities. For the former, these include activities such as marine living resources (capture fisheries and aquaculture), marine minerals, marine renewable energy, desalination, maritime transport, and coastal tourism, while the latter considers seafood processing, biotechnology, shipbuilding and repair, port activities, etc. Such activities are expected to double by 2030 (European Commission, 2021). To prevent negative impacts on those resources, as happened with terrestrial ones (Golden et al., 2017), the BE embeds the concept of sustainability, by definition (Pauli, 2010). Under the premise that what is bad for the ocean is bad for humankind, sustainability-enabling economic processes accommodate the exchange of many products, services, and information while responding to a single high-level driver: the human need for goods and services, e.g., Auad and Fath (2021).

Natural capital provides marine-based ecosystem services (Baker et al., 2020). Therefore, the BE is based on recycling, renewing, and regenerating properties found in nature. Recent work on the circular economy also includes these aspects, but a BE goes further (e.g., Haski-Leventhal, 2019; Huxley, 2022). Furthermore, BE dynamics mirror ecosystem dynamics in that renewable ecological resource availability proceeds through an initial growth phase (early stages of succession) until reaching an operational and continuously adaptive functioning system (late stages of succession), both of which are influenced by diurnal, seasonal and decadal pulsing. These processes must consider different dynamics, e.g., the slow rate of growth of deep-sea organisms, which can live thousands of years, and make many aspects of those ecosystems effectively non-renewable, in addition to minerals, for timescales spanning a few generations. Many resources can thus be harvested at a sustainable rate as long as extraction does not exceed the rate of regeneration. Sustainability entails essentially living off the flows, keeping the flow-generating stocks intact. Non-renewable aspects of the BE, e.g., mineral extraction, are inherently constrained by initial supply. In some instances, elements and functions of the BE are well-known and have been extensively studied (Pauly, 2018), but in others, considerable work is needed, e.g., the use of marine microalgae to produce cosmetics (Mourelle et al., 2017) which are in turn used by, among others, the entertainment industry, a sector not readily associated to the BE. In what follows and for this analysis, we regard the BE as far-reaching and broad as long as ocean-produced resources can be

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traced to end-consumers and users, as in that example.

Because of this need to at least consider growth and sustainability, studies addressing BE dynamics and structure (Bennett et al., 2019) often invoke two overarching and required elements: 1) the need for systemic resiliency, and 2) the availability of resources (Goerner et al., 2015). The latter authors provide fundamental conceptual underpinnings needed to achieve systemic health, a desirable goal for both Blue and global economies. Complex adaptive systems exhibit self-organization and emergent behavior and can be represented as a dynamic network of interactions (Patten et al., 2002). It is therefore imperative to understand how complex adaptive systems, such as the BE, are ecologically hardwired, what properties they have and need to function efficiently, and most importantly, how they can best balance growth, development, and sustainability.

The literature does provide substantial information on different aspects of the BE, from local and regional perspectives (Carver, 2019), through the lenses of planning and risk (Hodgson et al., 2019) and the future workforce (Hotaling and Spinrad, 2021), to the BE role in governance issues (Choi, 2017), among other angles. However, much work is needed in terms of the growth-sustainability tradeoffs, consideration of sustainability in other adaptive stages, as well as on the need to identify vulnerabilities preventing or delaying progress towards a sustainable state. Our goals here are then twofold: a) provide initial background, analysis, and discussion on the requisites to harmonize sustainability, growth, and development, and b) identify key socio-cultural barriers needing the attention of the global community to advance the BE towards more mature stages. While the literature is rich in articles and books linking the BE to the need for sustainability, we were unable to find fundamental underpinnings or basic principles able to support its sustainable development on well-accepted knowledge and concepts. In what follows, we will address these aspects focusing on how healthy systems grow and are maintained, adopting guiding principles, as well as providing a brief outlook on a few fundamental issues needing further analysis and development.

Furthermore, we focus our analysis and synthesis on the processes that conform to the BE rather than on its particular elements. These are many and include industries such as fisheries, energy, and tourism but also extend to aquaculture, the arts, education, and the role of the media, e.g., television. Also included is the role of aquariums, biomedicine, conservation efforts, and very importantly the role of scientific research in producing actionable new understanding and knowledge. The processes on which we focus in the rest of this article holistically encompass all of these sectors and activities.

2. Becoming resilient to achieve sustainability

Resilience is a necessary but not sufficient condition for sustainability. Therefore, as a first step to improve the information for decision- and policy-makers it is important to start by constructing resilience assessments (Vugrin et al., 2011). Similarly, assessments of resources are of fundamental importance for reaching sustainable states in the BE. These need to be conducted simultaneously and iteratively for the BE system to remain continuously adaptive, as anticipated or unpredicted scenarios emerge. These scenarios could arise driven by either internal or external factors and need to be considered in preparedness plans (Abduragimova et al., 2022). Because the BE conforms to a complex system, these plans would need to assess the current state of the BE in terms of growth, conservation, liberation/crisis, and reorganization, all four being fundamental stages/states of the adaptive cycle (Holling, 1986) which is conceptualized in Fig. 1. Once this is achieved, proposed preparedness tactics (Fath et al., 2015) can be considered and implemented depending on the particularities of the present stage and its contextual and transactional elements and circumstances. For example, in the BE the demands for algae used in medicinal applications would require consideration of current environmental trends, seasonality, probability, and frequency of blooms as well as knowledge of regional human health conditions, common practices, and local traditions.

We find it useful to consider four measurable components of resilience: connectivity, diversity, flexibility, and redundancy (Auad et al., 2018a). A common approach to enhance social resilience is to develop connectivities through partnerships within and among sectors of the economic system under consideration, being mindful that high connectivity can also propagate negative disturbances such as the current socio-economic crisis exposing the many ramifications emanating from dependencies rooted in Russian oil and gas. These partnerships not only increase connectivity (Wiese et al., 2022) but also allow one to leverage effectively everyone's resources by focusing on overlapping and complementary goals. Connectivity promotes a sense of community and builds trust that is needed when improvising in the crisis stage of the adaptive cycle. Partnership creation has been identified as one of the 17

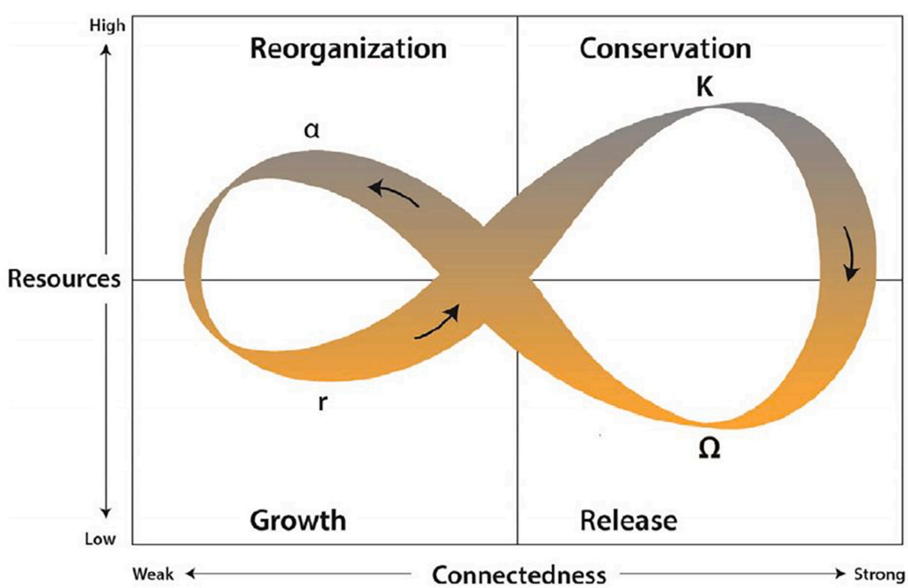

Fig. 1. The adaptive cycle is defined by Holling (1986). Four stages characterize the state of functioning of a given social, ecological, or socio-ecological system: 1) growth (r-stage), 2) stability or status quo (conservation, K-stage), 3) release or collapse (but not total destruction, Ω-stage), and 4) reorganization (α-stage). The cycle restarts with a new growth phase. This idealized representation will be supplemented below with more realistic elements.

fundamental goals agreed upon by the United Nations to support and invigorate sustainable development across nations (World Health Organization, 2015). For the BE, this cooperation is of fundamental importance to address multiple goals related to increasing knowledge, and science-informed decision-making for aquaculture, fisheries, offshore energy, deep-seabed mining, water use, transportation, recreation/tourism, and environmental stewardship, among others. Numerous efforts across the globe are already addressing these goals, e.g., the Belmont Forum (Paillard et al., 2014) launched a global initiative in 2018 to address ocean sustainability through international partnerships that focus on fundamental topics ranging from conflict transformation to offshore wind energy and environmental stewardship. Therefore, achieving sustainability in the BE needs to build and follow these and similar efforts, including investments across sectors, while integrating knowledge from different stakeholders representing local, regional, and larger scales.

In natural systems, a certain level of redundancy supports more resilient ecosystems (Ulanowicz et al., 2009). Analogously, economic systems also benefit from redundant structures and processes in such a way that if one of them becomes weak or non-operational other elements of the system can take over and sustain the productive functioning of the BE. This is one reason why societies try to avoid monopolies. Along the same lines, flexible systems can better adjust, adapt, or respond to external perturbation or stresses. Flexible systems involve preparedness and planning to be able to activate alternative elements and/or processes under certain circumstances. Finally, diversity is a well-known property of most healthy systems, e.g., biodiversity in an ecosystem. In economic systems, this diversity encompasses sectors, scale, e.g., small retailers as well as large ones, and diversity of demands by consumers. In what follows, we address the importance of responsible and appropriate growth while aiming for a healthy BE.

3. Growing and flourishing sustainably

The issue of harmonizing sustainability and growth has been discussed in the literature from different perspectives (Golden et al., 2017; Patil et al., 2018; Garland et al., 2019). For instance, even though the idea of economic degrowth is not new (Myrdal, 1978), it has recently been invoked and gained momentum due to several global socio-economic factors (Parrique et al., 2019; Carver, 2020; Ertör and Hadjimichael, 2020). This new trend emerged to counter reportedly irresponsible plights for imperative growth and is often termed in this context, as blue degrowth (Lillebø et al., 2017). However, this advocacy for a unidirectional trajectory (growth or degrowth) would be unrealistic. Complex systems such as economies can evolve, change, and function while alternating the direction of travel, in more than two directions and/or can grow and degrow simultaneously but on different spatial and temporal scales, e.g., a temporary downward degrowth part of a larger-scale growing trend where each responds to different drivers simultaneously. In other words, while some companies start and grow, others can be closing or bankrupting within a large complex economic system. Here, we highlight that the aforementioned degrowth theories, e.g., Kallis et al. (2012), and associated advocacy efforts are complementary (Kerschner, 2010), and do not compete with those focusing on steady-state economies (Daly and Daly, 1973). However, both are not enough for a comprehensive analysis of any economy and require the consideration of another two states characterizing systemic cycles of adaptation. Therefore, we focus the analysis below on a) the four well-known adaptive socio-ecological and socio-economic stages, i.e., growth, conservation, liberation/crisis or degrowth, and reorganization (Gunderson and Holling, 2001; Fath et al., 2015, among others), and b) the groundbreaking work of Elinor Ostrom (Ostrom et al., 1999). Her identification of fundamental socio-ecological variables and associated sub-categories provided the roots of the principles introduced below.

We also enlist concepts and principles from the theory of Energy Network Sciences (ENS), which has emerged over the last decade (Goerner, 2013:9) and since then it has been used to explain "how and why systemic ecological and economic health requires a balance of diversity and streamlining, flexibility and constraint; resilience and efficiency; and small, medium, and large institutions". As the name implies, ENS uses network analysis methods, in particular, ecological and information-theoretic-based approaches (Rutledge et al., 1976; Ulanowicz, 1986) to measure and quantify a system's growth and development based on the flow exchanges within the network. A well-articulated network in which there is a high degree of certainty about how material travels from node-to-node displays high information and high efficiency. A less-articulated network has multiple pathways leading to greater uncertainty and high redundancy. Research on available ecological networks revealed healthy ecosystems exhibit a balanced trade-off between efficiency and redundancy (Goerner et al., 2015). If resilience increases too much, then the efficiency of the system decreases; it becomes too rigid (poor flexibility) and is unable to perform effectively its needed functions without too high a cost (energetic or economic). Too much efficiency, on the other hand, also increases the system's vulnerability due to too low capacity for dealing with stress and perturbations, e.g., low connectivity and diversity of its elements. Systems that remain within that window demonstrate sustainability through optimum levels of resilience and efficiency. This raises the fundamental question of how do systems grow and develop to reach that stage, and whether these insights from ecosystem studies have saliency in socio-economic studies? Robert Ulanowicz and collaborators found that systems, such as ecosystems, do need to achieve this balance to remain sustainable, and therefore, there has to be an end to the growth stage if the said system is to remain healthy and even continue to exist (Ulanowicz et al., 1996). In other words, more and bigger only contributes to a healthy system within a natural threshold during a certain period of time. Beyond this point, an increase (decrease) in resilience (efficiency) erodes sustainability and threatens both health and survival. There is a right time for growth in the system dynamics, but it is not always. Here, it is important to note that the above-referenced balance can be achieved while the system under consideration is situated at any of the possible multiple states (Beisner et al., 2003) in which it can exist. When and if the system under study would transition or switch to another stable state, it is then helpful to consider framing its study within a panarchical structure or organization. The above statement on system balance is valid regardless of which one of these states the system is presently situated in.

In addition to these dynamics, the interaction network structure is relevant as well. An interaction network is defined by the currency of exchange connecting nodes. The reasons behind nature's repetition of certain structures and patterns are rooted in how systems self-organize when different currencies flow through them. These currencies could be anything as long as their flow keeps the system functioning and/or growing/developing (Goerner et al., 2015). For instance, information flows in computer systems, money in financial systems, energy in power grids, water in Earth's hydrological cycle, and nutrients in an ecosystem. In some systems, different currencies flow in opposite directions, e.g., oxygen and carbon dioxide in respiratory systems. The circular coupling is both substantive (material) and systemic (process) as it arises through the emergence of operational closure (Fath, 2014). In addition to the requisite of circularity, to reach all scales, they exhibit repetitive structures, with millennia if not millions of years of proven efficiency. As shown by them, the fractal structure of a river delta is also seen in the structure of a tree, a leaf, and a lung. Spiral-like structures are present in galaxies, hurricanes, in the horns of goats, and in the Nautilus shell. It is therefore relevant to consider these emergent and efficient designs and their dynamics when in the presence of incipient complex adaptive systems, such as the BE.

As stated above, the BE is comprised of many resources and consumption patterns, which all vary in space and time in terms of the specific balance or imbalance they display. The energy sector is an example of a combined trajectory, such that offshore oil and gas drilling are in a late stage whereas the exploitation of renewable resources is currently in an early growth phase (Beiter et al., 2016). The transition is taking place on several fronts. In Europe, this transition started earlier but other sources of energy besides wind are currently being developed, e.g., wave energy. The private sector is following this government-permitted transition because not only new companies are focusing on emerging markets of offshore renewable energy, but also traditional oil and gas companies are shifting to renewable sources as well, e.g., Statoil/Equinor, and Shell. For this reason, it is important not only to develop assessments of the BE system but also to implement monitoring plans that continuously update them. In this manner, through socio-economic and socio-ecological indicators, it will be possible to make adaptive decisions that are informed, appropriately and timely. Because of this, the system defined by monitoring, indicator-updating, and decisions needs to have a timescale similar to the timescale of change. This will ensure effective decisions across sectors and facilitate long-term sustainability of the BE. Other areas of the BE system such as aquaculture, are showing similar characteristics although with uneven growth rates in different regions of the globe.

4. Efficient and effective dynamics of a sustainable blue economy

The above insights have considered many elements, namely legislation, policies, organizational structure, partnerships, and governance in general. While all these need to be consistently brought together, it is necessary first to identify key concepts able to define the architecture and dynamics required to achieve sustainability in the BE. Consistent with the resilience and ENS considerations presented in previous sections, we invoke the scientifically-derived principles of regenerative economics presented by Fath et al. (2019) and based on the conditions for sustainability identified by Ostrom et al. (1999) for resource-dependent communities. These principles of regenerative economics enable nature-based solutions with vitality and health for economic systems, i.e., they are resource-dependent and with dynamic and varied linked elements that exchange different currencies over time. These flows of energy, matter, money, goods, services, and information enable growth and development, but also require continuous monitoring to prevent or at least adapt to undesirable situations or scenarios such as low efficiency or rigidity.

The 10 principles of regenerative economics developed by Fath et al. (2019) are listed in Table 1. We relate each of them to key elements and/or processes of the ocean economy in a first attempt to visualize a plausible pathway towards a flourishing BE:

• Principle 1: *maintain robust, cross-scale circulation of critical flows including energy, information, resources, and money*. This implies that from a panarchical (Gunderson and Holling, 2001) perspective all scales and adaptive cycles (Holling, 1986) need to be connected in such a way that healthy interactions are sustained over time. A large volume of flows moves efficiently through the sizable channels subdividing down, such that all players in the system are reached out to or contacted. In the BE, this would require, for instance, that artisanal fisheries share and exchange resources and information with at least medium-scale fisheries organizations to enable sustainable practices across scales and regions of operation. In turn, larger scale fisheries would also require similar interactions with global markets. Some progress has been made in this regard by promoting polycentric models of governance (Gelcich, 2014) while focusing on adaptive approaches in local socio-ecological systems.

• Principle 2: *regenerative re-investment*. The self-organizing processes that generate new resources should be used within the system for growth, development, and maintenance, and not siphoned off to other places for other purposes. The use and/or exploitation of ocean resources and services need to be accompanied by investments geared towards maintaining or increasing sustainability. This self-renewing implies a cyclic re-investment in monies and resources as well as knowledge, efficiency and technology, environmental stewardship, and public ocean literacy to maintain the functioning gradients that are being tapped for production. An approach focused only on taking and not giving back is the very definition of unsustainable exploitation. Reinvestment is beneficial for any socio-ecological system when it syncs in with nature's cycles to prevent major disruptions and therefore ensures the regular delivery of ocean services and resources. In other words, it is relevant to avoid 'out-of-kind' offsets, i.e., offsets benefitting one ecosystem when damage is done to another. In the BE, these investments would require devising an iterative (and strategic) learning cycle integrating existing knowledge, conceptualizations, socio-economic indicators, assessments, and targeted modeling (Gardner and Van Putten, 2008; Georgian et al., 2019). Other aquatic domains, such as the Great Lakes area in the United States, have very similar characteristics and requirements (Mayer et al., 2016).

• Principles 3 & 4: *maintain reliable inputs and healthy outputs*. In brief, this refers to renewability, from both the input and output perspectives. Societies that extract resources that produce unassimilable products, e.g., waste, which cannot be re-absorbed back into natural cycles, are destined to deplete those resources and will face the consequences of inducing disruptions in natural processes and cycles at different timescales. The industry of single-use disposable products has created a global load of compounds and products which, after extraction from nature, become unassimilable once they were discarded. World leaders have termed this practice "throwaway culture" (Francis, 2015) which in the BE is exemplified by the massive amount of floating and submerged plastics around the World Ocean (Ostle et al., 2019). This end-to-end problem, i.e., non-renewability and a dead-end for unusable byproducts, needs to be addressed through approaches leading to sustainable outcomes that ensure responsible growth and appropriate supplies of goods and services. Healthy inputs require that the energies and stocks driving BE activities are renewable and used at rates less than they are naturally replenished.

• Principle 5: *Maintain a healthy balance and integration of small, medium, and large organizations*. Specifically, this refers to having a large number of smaller players, a middle number of medium players, and a few large actors. A steady state is reached in nature when energy flows provide the necessary supply of goods and services across spatial and temporal scales. It is these balanced dynamics that prevent excessive accumulation of resources and which tend to counter scarcity. The balance between nutrients acquired from the soil and chemicals absorbed from the air allows a tree to grow within limits while simultaneously flourishing and having a fundamental role in the overall health of the forest. Specifically, a tree structure (literally and metaphorically) possesses multiple scales from fine root hairs extending into the soil matrix, through the trunk to branches that end in a vast array of photosynthesizing cells such that the leaf area index greatly exceeds the spatial footprint of the individual plant. In the BE, this cross-scale balance can be sought by balancing the needs for resources among small, large, and intermediate fish industry companies. For instance, large companies tend to harvest more than one species across regions and

Table 1
Summary of the 10 principles of regenerative economics developed by Fath et al. (2019)

- Principle 1: Maintain robust, cross-scale circulation of critical flows including energy, information, resources, and money.
- Principle 2: Regenerative re-investment.
- Principle 3: Maintain reliable inputs.
- Principle 4: Maintain healthy outputs.
- Principle 5: Maintain a healthy balance and integration of small, medium, and large organizations.
- Principle 6: Maintain a healthy balance of resilience and efficiency.
- Principle 7: Maintain sufficient diversity.
- Principle 8: Promote mutually-beneficial relationships and common-cause values.
- Principle 9: Promote constructive activity and limit overly extractive and speculative processes.
- Principle 10: Promote effective, adaptive, collective learning.

even globally including international waters. Through consistent and reflexive legislative approaches able to connect top-down and bottom-up requirements at different scales (Garmestani et al., 2013), it is possible to balance these multi-scale requirements by coupling large-scale regulation with small-scale self-regulative (regional) norms (Auad and Fath, 2021).

• Principle 6: *maintain a healthy balance of resilience and efficiency*. As stated above, ecosystems have been shown to have achieved a balance between resilience and efficiency (Ulanowicz et al., 2009). These optimum values of resilience and efficiency maximize the sustainability of ecosystems allowing them to consume, produce, and regenerate everything they need to maintain systemic health. Achieving that balance involves a trade-off among opposing characteristics, features, and properties between resilience (small size, dense connectivity, diversity, redundancy) and efficiency (large size, streamlining, high capacity). The BE as a system will therefore have similar tradeoffs that would need to be properly considered to achieve a healthy balance promoting and supporting sustainability. This balance would need to focus more on smaller scales (of businesses/users) and on increasing resilience because too much emphasis has been/is being placed on high efficiency and size (Lietaer et al., 2012). They show that in these situations too much efficiency can lead to brittleness and financial crises. It is argued then, that a balanced regulatory environment considering dynamic policies and reflexive legislation (Garmestani and Benson, 2013; Auad et al., 2018a) has the potential of addressing this and other principles being discussed here.

• Principle 7: *maintain sufficient diversity*. Systems that grow require diversity (of their elements, roles, species, and institutions) to maintain that growth, to a natural limit or threshold. This acquired and emergent diversity serves the system well as it continues to function sustainably at or near a carrying capacity. This natural limit is commonly characterized by an optimal tradeoff between resiliency and efficiency at which the system tends to flourish as a whole. As positive feedbacks build a system's centripetal forces, the resource-acquiring and resource-rich situation supports a larger, more specialized core and a more diverse periphery. Diversity begets diversity through autocatalytic exchanges (Jacobs, 2000; Cazzolla Gatti et al., 2020). In the same way that an expanding town or city requires more and different services, e.g., public transportation, larger companies, and new specialized workers in specific areas/labors, an expanding BE concerned with the sustainability of the resources that it draws upon, also requires a diversity of sectors, number of entities per sector, their location, and their sizes (Tisdell, 2013). This richness will enable flexibility and redundancies in the BE system to achieve healthy levels of both resilience and efficiency. However, the diversity of a system's elements is not enough and appropriate connectivity and processes linking them are also required, which is addressed in the next principle below.

• Principle 8: *promote mutually-beneficial relationships and common-cause values*. A given actor/node in a network can interact directly or indirectly with multiple other ones. Depending on the nature and character of those interactions, the outcome relation for our reference node can be positive (beneficial), negative (detrimental), or neutral. Fath (2007) classified these pair-wise relations into four different types and determined that a preponderance of positive relations will dominate, thus revealing ecosystems as primarily mutualistic or win-win relations. This positive character is carried largely through the complex network of indirect gains and losses of each node in the system. In a healthy BE, offshore energy, transportation, fisheries (at all scales), recreation, military, and research activities, among others, would also need to consider configurations that lead to mutualistic interactions across scales and boundaries. This is another area subjected to the influence of policies and legislation which do vary from state to state and nation to nation. While advances have been made, e.g., in Law of the Sea (Tanaka, 2015), additional work is needed to establish healthy dynamics among each element of the BE. It has been shown (Österblom and Folke, 2013; Auad et al., 2018a) that adaptive governance practices are common and successful in the U.S. and other nations. These nodal interactions would also need to evaluate their carbon legacy in such a way as to reduce, minimize, or eliminate emissions (relates to Principles 3 & 4). For instance, the needs of the research community often link academic, private, and governmental sectors. By increasing the use of low and no emissions data collection/generation approaches, e.g., the number of observations from autonomous (Jayne et al., 2017) and remote (aircraft and satellites) platforms, incentives to vessels of opportunity, and the number of modeling strategies, mutualistic relations among sectors/companies/entities could be improved while concomitantly reducing the carbon footprint.

• Principle 9: *promote constructive activity and limit overly extractive and speculative processes*. Similar to Principle 2, the gains that are endowed through self-sustaining dynamics should not be exploited but used to create further self-sustaining structures. These are known to significantly favor economic health (Rehan et al., 2011) across multiple scales, particularly long-term emphasis over short-term acquisition. More specifically, Fath et al. (2019) show that regenerative economics gives high importance to constructive (vs. speculative) activities because they create economic capital, jobs, and capacities across sectors. There, they also show that in 2010 the global economy was about 97.5% speculative, e.g., stock markets and currency exchanges, and only about 2.5% was based on the production and transportation of goods and services. Pairing these aspects with extractive activities of non-renewable resources results in processes and dynamics that erode economic health and natural capital. As noted by them, and making a parallel with the natural world, an economic necrosis is enabled when these (speculative and extractive) activities become dominant and fail to ignite and maintain positive feedbacks and interactions in the system in question. In the BE system, in particular, it is of fundamental importance to focus on renewable resources to produce goods and services, while powering it from renewable energy sources (LiVecchi et al., 2019). Concomitantly, it is also important to detach speculative activities and practices from those that create and maintain economic capital as well as local, regional, and global capacities that focus on the economics of goods and services (Keen et al., 2018), from production to delivery to consumers and users. More specifically, the desired dynamics of a healthy BE require a balanced presence of processes and feedbacks, within elements or linking different elements that prevent excessive growth or decay (Fath et al., 2019). Decoupling regenerative processes from other non-regenerative dynamics will favor healthy socio-economic outputs (Spalding, 2016) and socio-ecological resilience.

• Principle 10: *promote effective, adaptive, collective learning*. Individual and collective learning are the most important factors to enable a regenerative ocean economy. This becomes inherently critical when the learning process about socio-ecological and socio-economic issues is intertwined with resource management decisions. Adaptive management is an approach used to improve resource management decisions through iterative learning. It has been widely promoted and used by the U.S. Department of the Interior to manage land (McFadden et al., 2011) and ocean (Boland, 2010) resources. This methodology can be enhanced by combining it with other decision-informing approaches and including managing for resilience as its central goal (Auad et al., 2018a). There they show how offshore energy regulation can be made more efficient and effective by learning how internal social processes in a given entity can be arranged and planned depending on the particular stage of the adaptive cycle where learners are situated, i.e., growth, conservation, crisis, and reorganization (Fig. 2). However, that internal cycle does not exist in isolation and is connected to other adaptive cycles of the managing organization, as well as to the nested ecological adaptive cycles being managed. These adaptive techniques require in-depth, iterative, and continuous learning to effectively address critical issues affecting human well-being and socio-economic stability. Clear examples of collective adaptive learning and socio-economic sustainability in the BE include several coastal resilience frameworks developed to enable sustainability across different contextual environments and spatial scales

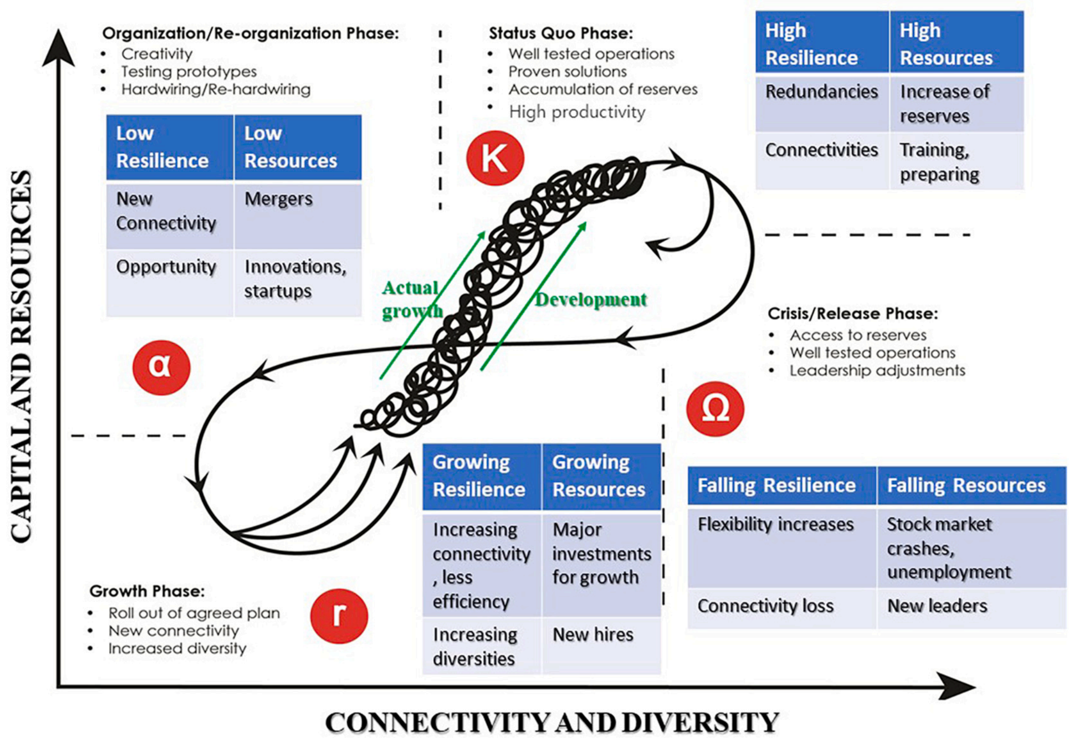

Fig. 2. Conceptualization of the Blue Economy as an adaptive cycle. The Figure shows a more updated version of the classic adaptive cycle shown in Fig. 1 following Fath et al. (2015). Different properties, dynamics, and economic processes are associated with the four different stages described in Fig. 1. These characterizations are general examples that facilitate visualizing the different stages of economic growth, development, crises, and reorganization and can help in developing preparedness and strategic plans.

(Peacock et al., 2010; Lloyd et al., 2013; Jurjonas and Seekamp, 2018; Almutairi et al., 2020). These frameworks and others integrate BE elements with socio-ecological considerations needed to achieve sustainability and regenerative economics.

4.1. Integration and implementation of the ten principles for a healthy blue economy

The ten principles are meant to propel and sustain a healthy BE. It is next relevant to consider how these elements can be integrated, structured, and interlinked. This requires the consideration of several elements such as overarching goals, legislation and policies, governance and management, and decision-informing tools. While it has been shown in this article that several frameworks, e.g., for coastal resilience, have been proposed, one of them has the capacity of integrating and aligning all of those aspects. Garmestani and Benson (2013) proposed a framework integrating law, governance, decision-making, and panarchical functioning of organizations, while Auad et al. (2018a) tailored it to a specific government agency. Fig. 3 summarizes these components that sustain a BE. The reader is referred to both articles above for more specific discussions and examples.

One example of this growth imperative in the BE is the false and somewhat common notion that data can drive at least some subset/s of the BE. Only human-centered elements such as Governments, Private initiatives, and/or the will of Societies, termed the GPS trident (Auad and Fath, 2021), can make decisions and drive demand and therefore act on resources and production. These human-driven actions include data acquisition planning, data collection, data analysis and interpretation, and subsequent decisions that use said interpretations by humans. While data and quality information are fundamental to fuel self-organization, a middle ground between liberal practices and extreme control. Plights for collecting massive amounts of data have generally omitted to address specific resilience and sustainability considerations as well as to present

Fig. 3. Integration of elements needed to sustain the blue economy using key concepts presented by Garmestani and Benson (2013) and exemplified by Auad et al. (2018a). A panarchical organizational functioning (top circle) includes social and ecological components linking the extraction of resources and resource management approaches and decisions, explicitly or implicitly present in all components of this framework. All elements in this framework emphasize adaptation in support of a resilience-centered overarching goal ensuring the usability of available resources to achieve sustainability in the BE (center).

a strategy addressing economic sustainability in their proposed enterprises (Fet, 2004). As noted in the Introduction, the careful and detailed consideration of the inner workings of sustainability in analyses and discourses of the BE cannot be omitted since it has been defined as a sustainable economy (Pauli, 2010; Wenhai et al., 2019; Cisneros-Montemayor et al., 2021). It is therefore important to frame different propositions with these considerations to demonstrate consistency. For example, a strategic combination of state-of-the-science coupled models together with observations from satellites, vessels of opportunity, and existing autonomous platforms, e.g., Jayne et al. (2017), would not only yield savings in the process of acquiring new information and knowledge but would also contribute to reducing emissions. For example, demands for excessive amounts of data could also be detrimental to the environment if implemented without consideration of resilience assessments and goals aimed at enabling sustainable development.

In summary for this section, we have provided different examples for each of the ten principles needed to sustain a healthy BE. These are rooted in the well-known dynamics of the adaptive cycle, characterized by four stages or phases: growth/development, conservation, release/crisis, and reorganization. These four adaptive phases are, in turn, characterized by key properties enabling a resilient adaptation over time: connectivity, flexibility, redundancy, and diversity. The relative weights or importance of these four properties are different in each of the four phases of the adaptive cycle. For instance, as noted in Fig. 2, the role of connectivities and redundancies are highly relevant during the conservation (or status quo) phase. Then, Fig. 3 provides the main pillars on which the BE can be internally organized (organizational functioning and decision-making) and externally supported (adaptive governance and partnerships as well as reflexive legislation and dynamic policies). These four pillars provide the skeleton and underpinnings of a sustainable BE and jointly enable its resilient functioning.

4.2. *Barriers to a flourishing BE: towards an age of factuality*

Many are the barriers and challenges in the path of sustainable development of the BE. However, one stands above them all. In his review of the book *Calling Bullshit* (Bergstrom and West, 2020), the 2001 Nobel Laureate in economics, George Akerlof, stated, “It addresses the most important issue of our time: the decline in respect for Truth”. Misinformation, disinformation, and other departures from the truth take us away from sustainable development and ultimately from societal well-being. Earlier, renowned philosopher Harry Frankfurt defined the “age of bullshit” (AB) in his 2005 best-seller book (Frankfurt, 2005). In it, he notes that due to several socio-cultural factors, public actors ‘speak without regard on how things really are’ (Frankfurt, 2005:143), not having the desire to know the truth, and commonly to advance specific interests or agendas (Belfiore, 2009). This has also contributed to the institutionalizing of unsustainability (Stevenson, 2013) and raised numerous concerns about accountability and integrity when addressing global concerns in the international arena (Stevenson, 2020). This disconnect not only affects the BE but also its contextual and transactional elements as well as other components of the global economic system or any subset under consideration. Therefore, a data-based culture of decision-making, staffed by a knowledgeable and ethical workforce, is needed (now) to start constructing a resilient BE. Informed by facts and with an eye on the nature-based regenerative conditions described above, the implementation of a sustainable BE will be an iterative enterprise and require continued public support. Therefore, these observations, characterizing oceanic states and their spatiotemporal evolution, need to be acquired, handled, and delivered to the public with integrity and accountability, justifying socio-ecological and socio-economic decisions across sectors, and ultimately contributing to transitioning the current AB into an Age of Factuality (AF).

One important vehicle able to transition us towards an AF started with the so-called “citizen science” also referred to as “citizen monitoring” by which the general public can voluntarily contribute observed data on a wide number of areas while using portable technology, commonly cellular phones, to provide geographic coordinates, photos, videos, and sounds. Citizen science not only provides useful information that is commonly verified by a program office, e.g., the LEO (Local Environmental Observer network) as described in Okey and Brubaker (2016), but it also connects citizens to science and scientists giving them a true sense of ownership and enhanced credibility on findings. This also enables the participating citizens to connect data and associated findings to other disciplines. For instance, a beach survey program that uses trained volunteers to document the distribution and abundance of beached marine birds and mammals can provide insight regarding marine chemistry or management effectiveness, depending upon whether observed mortality resulted from harmful algal blooms, oil spills, or entanglement in fishing gear. Over the last decade, citizen science has expanded globally (e.g., Fritz et al., 2019) and, in the US, has received support from the U.S. White House on different applications such as marine science and medicine (Woolley et al., 2016). This engagement process (Dean et al., 2018) can turn unrealistic perceptions and false notions into factual information and thus lead to changed attitudes and decisions. Along these lines, great progress has also been shown by other initiatives which have created scientific networks that interact with policy-=makers. These synergies give scientists a voice and the opportunity to bring science to the policy conversation. The Deep Ocean Stewardship Initiative (Mengerink et al., 2014) is a specific example that has been addressing these issues for various components of the deep blue economy, e.g., fisheries, oil and gas, marine genetic resources, deep seabed mining.

Citizen science is a powerful example of a much-needed AB mitigator as well as an effective vehicle to enhance the public’s understanding of science (Bonney et al., 2016) and its positive impact on conservation programs and natural resource management efforts (Cigliano et al., 2015; McKinley et al., 2017). Fortuitous observations arising from citizen science activities have led to structured scientific research demanding large investments in ocean data collection (Lehtiniemi et al., 2020). Citizen science, as well as outreach efforts, are crucial in bringing awareness and in filling knowledge gaps. It has been shown, for instance, that major outreach efforts such as the 2018 OUTREACH Expedition to the Arctic Ocean (Auad et al., 2018b) have the power of changing attitudes and influencing decisions. New and existing transformative initiatives can contribute new knowledge and increase the scientific literacy of the public and governments.

In addition to this consideration for literacy and awareness, all involved in the ocean data-to-knowledge transformation must preserve the integrity of the scientific process. Without this integrity there would be no credibility and trustworthiness, therefore negatively impacting the overlying BE. To protect science, scientists, and American interests, the U.S. Department of the Interior launched in 2011 the first Federal policy addressing scientific integrity (Gundersen, 2017). Its purpose is to establish the expectations for how scientific and scholarly information considered in Departmental decision-making is handled and used. Information used in Departmental decision-making must be robust, of the highest quality, and the result of transparent, rigorous scientific and scholarly processes. Regardless of the reasons for lacking data and associated scientific-produced information and knowledge, the community, in general, has developed important safeguards (policies, training) and initiatives (outreach, citizen science) to inform different decisions with trustworthy knowledge. Therefore, integrity, trustworthy science, and scientific literacy are fundamental pillars of the BE.

With this in mind, we can then identify two powerful mitigators of falsehoods, including misinformation and disinformation, able to catalyze a transition from Frankfurt’s AB towards a (here) proposed AF: a) the acquisition (observations) and generation (models) of strategically planned information, and b) the fundamentally important increase of public literacy across sectors (Fauville et al., 2018; Fernández Otero et al., 2019). While quality and useful information certainly contribute to mitigating misinformation and disinformation in the AB over time, more data, e.g., Kalaydjian (2016), Rayner et al. (2019), does not necessarily imply improved conditions in socio-ecological states. These advocacies need to go beyond the issue of sustaining observations and assessing their socio-economic value, and additionally include propositions that demonstrate how acquiring them will impact socio-ecological resilience, and therefore the sustainability of societies, ecological systems, and the BE to which they belong. The acquisition of new observations has an inherent carbon footprint that has started to get quantified and evaluated in the scientific community (Moon, 2011; Achten et al., 2013). These can be accomplished by including the already mentioned processes and elements that can foster an iterative and useful learning cycle, where understanding, performance-tracking through monitoring, resilience assessments as well as sectoral inclusion and research, can all be integrated into an iterative cycle, such as the one shown in Fig. 4 for the BE. To further support managers, decision- and policy-makers there has been an increase in the use of the so-called “data translators” who act as bridges between scientists and high-level executives in the public and private sectors (Maynard-Atem and Ludford, 2020).

5. Discussion and concluding remarks

In today’s economies, the greater and common good is not achieved under the obsolete “more and bigger is better” but when growth and sustainability are in harmony, balancing resilience and efficiency in socio-ecological systems and socio-economies on the premises of the scientifically-derived and nature-based ten principles discussed in this article. Growth is the natural dynamic of a young and resource-rich environment, where positive feedbacks dominate the integration of those resources into further self-organizing structures. As the carrying capacity constraints impose themselves from above, negative feedbacks gain ascendency, and the growth gives way to maintaining and self-sustaining processes. Understanding and promoting this complete adaptive cycle as it applies to socio-economic systems is a critical step for sustainable development and supports our transition to an age of factuality. Significant work remains to transition the BE to a more mature stage where positive feedbacks can maintain the desirable functioning of the processes highlighted in this article. This future work should prioritize an increased understanding of the BE vulnerabilities to speculative practices, as well as an in-depth analysis of the BE as a self-organizing system able not only to sustain itself but also to positively influence peacebuilding and peace sustainability on global scales (De Coning, 2016).

For instance, the advocacy for economic degrowth has been on the rise across different socio-economic systems ranging from the agricultural one (Farley and Voinov, 2016) to the BE itself (Ertör and Hadjimichael, 2020). While this latter concept and the one advocated here, “Flourishing within Limits” (Jørgensen et al., 2015), have some similarities, they are also built on different grounds. However, given the unidirectional and largely incomplete arguments provided in the literature on balancing and/or addressing growth (or degrowth), steady states, and sustainability, we emphasize the importance of future studies, additionally, to address sustainability in connection with all stages of the adaptive cycle (growth, conservation, crises, reorganization). In other words, it is important to walk away from existing polarizations, growth vs. degrowth, and consider all possible dynamics amounting to adaptation and efficiency. A stage-by-stage adaptation and planning are thus needed to address sustainability requirements, as described in the navigational recipes of Fath et al. (2015). Therefore, steady-state and degrowth considerations are not enough; regenerative dynamics are also necessary for sustainability (Fath et al., 2019). Only then we will be able to comprehensively address the current and future challenges of the BE more efficiently and effectively. Environmental data collection remains an area where improvements could be implemented by requiring project-specific sustainability reports as currently done across different sectors and scales (Potts, 2003; Fet, 2004; Hahn

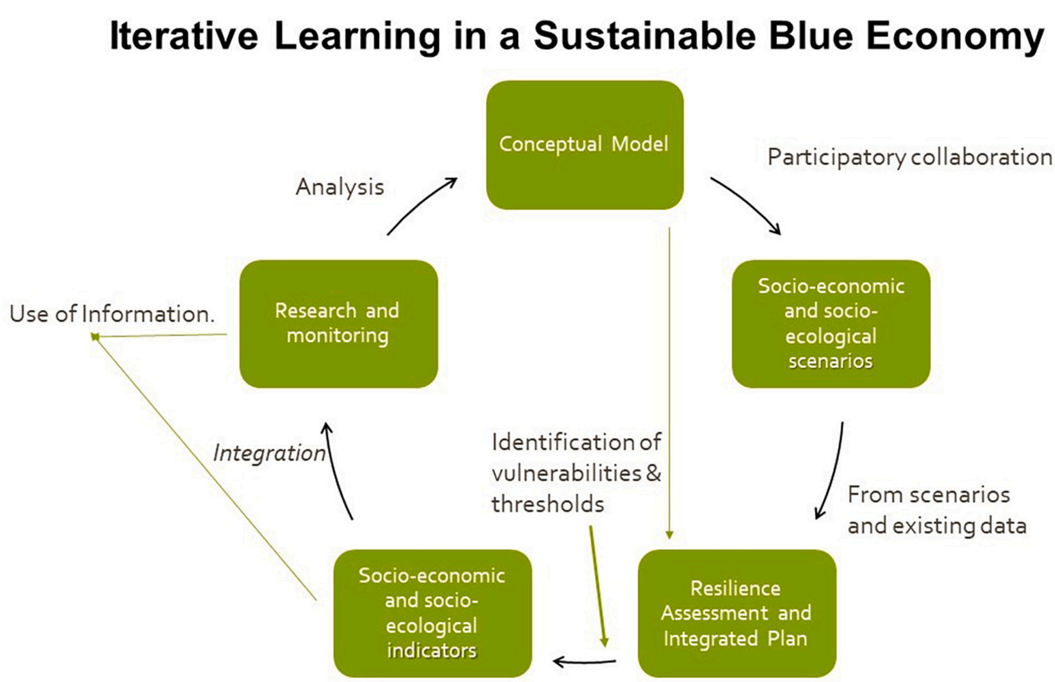

Fig. 4. Iterative cycle of learning summarizing stages and processes needed to inform decision and policy-makers as well as to promote ocean literacy. Given the continuous interplay between these elements, this figure can be regarded as an adaptive cycle where the initial hardwiring and re-hardwiring of its elements is accomplished during the conceptualization stage (top) and where the different scenarios (upper right) represent a likely or desired status quo (conservation) phase. The ten principles discussed earlier, are incorporated into these two stages (conceptualizations and scenarios). The cycle’s outputs (data, indicators) are part of the release phase of the adaptive cycle, while reorganization and integration take place after their (data and indicators information) analysis and associated integration of results. In this manner, there is a continuous arrival of new data and generation of new understanding and knowledge enabling adaptation through multiple processes; these are driven by the ten regenerative principles presented earlier.

and Kühnen, 2013) and in connection with citizen science (Millar and Searcy, 2020). These collections would need to be authorized by sustainability-trained managers when a net benefit for socio-ecological resilience and sustainability would be demonstrated. More specifically, these plans and reports should include pathways connecting a data acquisition plan to decisions and their potential societal benefits.

The roots of the ten principles discussed above lie in Ostrom's Theory of the Commons (Ostrom et al., 1999), for which she received the 2009 Nobel Prize in Economics. She showed that social systems or communities self-organize when facing adversities and/or needing to support vital initiatives to improve their economic well-being through the promotion of regenerative capacities in socio-ecological systems. This is fundamentally relevant to escape from the historical polarization presented by government- and market-controlled economies as self-organization arises as an additional alternative. From these concepts, Ostrom tried to answer the question of "When will the users of a resource invest time and energy to avert a Tragedy of the Commons" (Hardin, 1968). From there, and after selecting the ten variables that best described self-organizing in successful communities, she focused on their environmental sustainability and grouped them into six more general socio-ecological system variables, namely: 1) natural resource systems, 2) governance systems, 3) natural resource units, 4) users, 5) interactions and linked outcomes, and 6) related ecosystems. All these elements play a key role in self-organizing societies facing stressors or crises affecting their wellbeing. The 10 principles discussed in this article provide the underpinnings of a mature and robust self-organized BE system able to construct and maintain regenerative pathways and their interactions with the larger global economy. They constitute a nature-based solution defining the processes that will sustain the BE. This is why regenerative practices are a formidable coupler or connector between different subsets of the global economy. This is justified because some of its most productive sectors, such as agriculture, have already embraced regenerative approaches on a global scale (Sherwood and Uphoff, 2000; Rhodes, 2012; Rhodes, 2017). However, this self-organization can only succeed if misinformation and disinformation are kept away through targeted investments and strategic approaches aimed at reaching a new age of factuality, for which we advocate. Achieving sustainability goals through literate public and governments will involve regular assessments and monitoring of social, ecological, economic, and technological needs and vulnerabilities. Planning for these assessments will require, in the first place, the definition of metrics, as noted by Spalding (2016), when defining a "new blue economy". This will facilitate preparing, adapting, and mitigating to arrive and remain in desirable socio-economic states. The remarkable aspect of these regenerative economic pathways presented here is that they inherently incorporate ethical processes as a byproduct of societies' continuous needs to exist and thrive because targeting sustainable development processes and goals concomitantly implies remaining mindful of our legacies to future generations. In other words, ethics and well-being, lead to and require, respectively, sustainability.

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