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Investing in Blue Natural Capital to secure a future for the Red Sea ecosystems

Maha J. Cziesielski^{1*}, Carlos M. Duarte¹, Nojood A. Aalismail¹, Yousef Al-Hafedh², Andrea Anton¹, Faiyah Baalkhuyur¹, Andrew C. Baker³, Thorsten Balke⁴, Iliana B. Baums⁵, Michael L. Berumen¹, Vasiliki I. Chalastani⁶, Brendan Cornwell⁷, Daniele Daffonchio¹, Karen Diele⁸, Farooq Ehtsaam⁹, Jean-Pierre Gattuso^{10, 11}, Song He^{1, 12}, Catherine Lovelock¹³, Elizabeth McLeod¹⁴, Peter I. Macreadie¹⁵, Nuria Marba¹⁶, Cecilia Martin¹, Marcelle M. Barreto¹, Periyadan K. Krishnakumar¹², Perdana Prihartato¹, Lotfi Rabaoui¹², Vincent Saderne¹, Sebastian Schmidt-Roach¹, David Suggett¹⁷, Michael Sweet¹⁸, John Statton¹⁹, Sam Teicher²⁰, Stacey M. Trevathan-Tackett¹⁵, Thadickal V. Joydas¹², Razan Z. Yahya¹, Manuel Aranda¹

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Author contribution statement

MJC, CD and MA conceived the idea. MJC wrote the manuscript. All authors contributed critical feedback.

Keywords

blue economy, Red Sea ecosystems, Marine policy, sustainability, Blue carbon, coral reefs, Environmental Policy

Abstract

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For millennia, coastal and marine ecosystems have adapted and flourished in the unique environment of the Red Sea. Surrounded by deserts on all sides, the Red Sea is subjected to high dust inputs receiving very little freshwater input and so harbors a high salinity. Coral reefs, seagrass meadows, and mangroves flourish in this environment and provide socio-economic and environmental benefits to the bordering coastlines and countries of Saudi Arabia, Yemen, Sudan, Egypt, Eritrea, and Djibouti. Interestingly, while coral reef ecosystems are currently experiencing rapid decline in health on a global scale, those in the Red Sea appear relatively in better shape. That said, they are certainly not immune to the stressors which cause degradation. In many regions, ecosystems are already severely deteriorating and are further threatened by increasing population pressure and large coastal development projects. Degradation of these marine habitats will lead to environmental costs, as well as significant economic losses, and will therefore result in a missed opportunity for the bordering countries to develop a sustainable blue economy and integrate innovative nature-based solutions. Recognizing that securing the future of the Red Sea ecosystems must occur in synergy with continued social and economic development, we developed an action plan for the conservation, restoration, and growth of marine environments of the Red Sea. We then investigated the level of resources for financial and economic investment that may incentivize these activities. This study presents a set of commercially viable financial investment strategies, ecological innovations, and opportunities for sustainable development, which can, if implemented strategically, help ensure long-term economic benefits and promote environmental conservation. We make a case for investing in blue natural capital and propose a strategic development model that relies on maintaining the health of natural ecosystems to safeguard the sustainable development of the Red Sea.

Contribution to the field

Coastal ecosystems such as coral reefs, mangrove forests and seagrass meadows are hotspots of biodiversity and provide services with an estimated global value of >9.9 US\$ trillion per year. Many countries in tropical regions, including countries bordering the Red Sea, depend heavily on these ecosystems for shoreline protection, fishing grounds and as an important source of revenue from ecotourism. The KAUST Research Workshop 'Securing a Future for Red Sea Ecosystems' (March 11 -14, 2019) brought together national and international experts from academia, industry and government to develop feasible policy and economic strategies for the future of the Red Sea ecosystems. In this article, we formulate a concise list of goals and actions that consider the marine environment early on, allowing Red Sea coastal developments to lead and take advantage of new development strategies for the 21st century. We analyzed Red Sea specific ecosystems, their current states, assessed our knowledge base and defined a set of overarching sustainable actions. Based on these, a blueprint for recommendations of sustainable development of coastal habitats of the region was created. These recommendations were formulated into the attached manuscript and a two-page action plan that can be easily downloaded and used by stakeholders and policy makers.

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59 Coral Reefs, Environmental Policy

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61
62 **Abstract**

63
64 For millennia, coastal and marine ecosystems have adapted and flourished in the unique
65 environment of the Red Sea. Surrounded by deserts on all sides, the Red Sea is subjected to
66 high dust inputs receiving very little freshwater input and so harbors a high salinity. Coral reefs,
67 seagrass meadows, and mangroves flourish in this environment and provide socio-economic
68 and environmental benefits to the bordering coastlines and countries of Saudi Arabia, Yemen,
69 Sudan, Egypt, Eritrea, and Djibouti. Interestingly, while coral reef ecosystems are currently
70 experiencing rapid decline in health on a global scale, those in the Red Sea appear relatively in
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72 In many regions, ecosystems are already severely deteriorating and are further threatened by
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74 marine habitats will lead to environmental costs, as well as significant economic losses, and
75 will therefore result in a missed opportunity for the bordering countries to develop a sustainable
76 blue economy and integrate innovative nature-based solutions. Recognizing that securing the
77 future of the Red Sea ecosystems must occur in synergy with continued social and economic
78 development, we developed an action plan for the conservation, restoration, and growth of
79 marine environments of the Red Sea. We then investigated the level of resources for financial
80 and economic investment that may incentivize these activities. This study presents a set of
81 commercially viable financial investment strategies, ecological innovations, and opportunities
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83 economic benefits and promote environmental conservation. We make a case for investing in
84 blue natural capital and propose a strategic development model that relies on maintaining the
85 health of natural ecosystems to safeguard the sustainable development of the Red Sea.

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Introduction

The first evidence of human distribution and development along the Red Sea coastline dates back 125,000 years (Walter et al., 2000). Ancient local populations benefited from the marine resources provided by the Red Sea, compared to the otherwise harsh and unproductive surrounding land. It has been suggested that early utilization of the Red Sea like had an important role in the dispersal of early humans out of Africa (Walter et al., 2000; G. Bailey, 2010) and continues to play a vital role in supporting local communities of this region (Carlos M. Duarte, 2014). By providing natural resources as well as primary trade routes, the Red Sea facilitates cultural exchange and the advancement of societies (Wengrow, 2010). The region has attracted the attention of explorers and been subject to substantial scientific research, with the first documented European marine biological exploration dating back to 1761 (Hansen, 1962). The first descriptions of mangroves in western science originated from the Red Sea (Schneider, 2011), as well as the first descriptions of the major nitrogen-fixing organisms in the ocean, the cyanobacterium *Trichodesmium*, by Ehrenberg in 1830 (Janson et al. 1995), as well as many Indo-Pacific scleractinian corals (Forsskål, Forsskål, & Niebuhr, 1775)

The cultural, scientific, and economic importance of the Red Sea continues today, due to its unique coastal and marine environments. Latitudinal gradients in temperature, salinity, and nutrients (Raitsos, Pradhan, Brewin, Stenchikov, & Hoteit, 2013; Chaidez, Dreano, Agusti, Duarte, & Hoteit, 2017; Carlos M. Duarte et al., 2018) as well as minimal freshwater inflow and high rates of evaporation, both combining to produce a wide range of habitat conditions within a relatively small geographic range (DiBattista et al., 2016). Furthermore, low precipitation and freshwater limitations have, in the past, inhibited intense development. The region is thus marked by relatively low human population density and sparse distribution of economic activity (M. Fine et al., 2019), which has prevented the watershed from being severely altered.

Under these conditions, mangrove, seagrass, and coral reef ecosystems along the coastline of the Red Sea have provided socio-economic as well as environmental services to bordering countries (Box 1). While global climate change and anthropogenic stress have impacted the Red Sea ecosystem, its relatively undeveloped coastlines and low coastal population densities have left it relatively intact when compared to similar ecosystems around the globe. Long-term records indicate that Red Sea coral reefs, especially in the northern region, have experienced less severe bleaching events and may, in some regions, be less sensitive to thermal anomalies than those in other regions (Osman et al., 2018). Coral reefs in the Red Sea have also exhibited the capacity for rapid recovery after bleaching events if no further stresses are imposed (Monroe et al., 2018). Additionally, while mangrove forest cover is in decline globally, mangrove habitats in the Red Sea have expanded by 13% in the last 50 years (Almahasheer, Aljowair, Duarte, & Irigoien, 2016). Finally, seagrass meadows are abundant and diverse throughout the lagoons and sandy banks of the Red Sea (Qurban, Karuppasamy, Krishnakumar, Garcias-Bonet, & Duarte, 2019).

The relatively healthy state of some marine habitats within the Red Sea ecosystems represent an abundant 'blue natural capital' resource for the region. The term 'blue natural capital' defines the three marine ecosystems (coral reefs, mangroves, and seagrass beds) in terms of the ecosystem services that result from their functional integrity. Hence, preserving current states and restoring natural ecosystems represents an investment in blue natural capital. This investment directly supports climate change adaptation and mitigation efforts, whilst

150 simultaneously creating sustainable and resilient marine ecosystems that are the foundation of
151 a sustainable blue economic model. This model fosters development of a number of economic
152 sectors that directly and indirectly benefit from marine resources, such as tourism, fishing,
153 aquaculture, and offshore oil and gas, but also less obvious benefactors, for example, service
154 providers in engineering and consulting. A sustainable 'blue economy', therefore, seeks to
155 promote economic growth and social development while ensuring the environmental
156 sustainability of the oceans and seas (OECD, 2019). New economic development and
157 investment opportunities under 'blue economy' aim for socio-economic growth that does not
158 degrade the natural environment, but instead depends on its continued health in order to thrive.
159 Blue growth depends on ensuring the preservation and continued investment in blue natural
160 capital which, in turn, leads to continued economic growth. Thus, major development projects
161 that are in preliminary stages around the Red Sea can ensure significant long-term benefits by
162 incorporating investments into increasing blue natural capital into their designs. Given that
163 these ecosystems still remain relatively intact, 'blue growth' investments are feasible and likely
164 to render significant economy success. Hence, the Red Sea represents a unique opportunity for
165 the region to establish a new vision and become global leaders in designing a model of
166 sustainable socio-economic growth that is linked to the building and conservation of 'blue
167 natural capital'.

168
169 Here, we investigate opportunities that will enable the continued economic growth of the region
170 while ensuring long-term sustainable development. Our aim is not to revise the trajectory state
171 of the Red Sea under a business-as-usual emissions scenario, something which has already led
172 to a decline in marine life globally. Instead, we aim to formulate a new vision that places the
173 marine environment at the center whilst still enabling sustainable economic development
174 (Figure 1). In a similar fashion to the 'one health' directive (Destoumieux-Garzón et al., 2018),
175 initially proposed ten years ago, the proposed model re-evaluates economic growth and
176 development by incentivizing the commercial viability of environmental protection and
177 conservation through investment opportunities. We advocate 'blue natural capital' investment
178 opportunities and present sustainable development approaches that, if executed appropriately,
179 will encourage growth and expansion of blue natural capital and provide both economic and
180 environmental benefits for the foreseeable future.

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183

184 **BOX 1. Marine ecosystems of the Red Sea**

185

186 **Coral Reefs**

187 Scleractinian corals are a key building block of coral reefs. By laying down calcium carbonate
188 skeleton in nutrient-poor waters, they create habitats for other organisms and establish highly
189 diverse and rugose ecosystems over time. Furthermore, reefs dissipate wave energy, protecting
190 the shoreline from erosion (Earp, Prinz, Cziesielski, & Andskog, 2018). Corals live in a
191 symbiotic relationship with the unicellular algae of the family *Symbiodiniaceae* (LaJeunesse et
192 al., 2018), which provide them with over 90% of their energy demands (Davy, Allemand, &
193 Weis, 2012), thus enabling their rapid growth. Coral reefs provide a number of ecological and
194 economic services, including protecting shorelines, reducing coastal erosion, sustaining
195 fisheries, and supporting tourism (see review Moberg & Folke, 1999).

196

197 Under stress, the coral-algae relationship breaks down, leading to the loss of the algae from the
198 coral tissue and a consequent loss of color - a process known as bleaching (Cziesielski,
199 Schmidt-Roach, & Aranda, 2019). Rising sea-surface temperature, ocean acidification,

200 variation in salinity, and pollution, all of which have been linked to human-induced climate
201 change and anthropogenic activities, are increasingly threatening corals globally, including
202 corals in the Red Sea (Hughes et al., 2018). Consequently, the rate and intensity of coral
203 bleaching events (Hughes et al., 2018), outbreaks of disease (Mohamed & Sweet, 2019), as
204 well as other forms of coral reef degradation (Knowlton, Lang, & Keller, 1990; McCook,
205 Jompa, & Diaz-Pulido, 2001), have continued to increase at alarming rates around the globe.

206

207 Coral reefs span the entire coastline of the Red Sea and are known for their high productivity,
208 biodiversity, and endemism (Berumen et al., 2013). Due to the gradient of environmental
209 conditions across the Red Sea, coral reefs live in a range of habitats that have resulted in
210 heterogenous patterns of bleaching and stress exposure. The northern Red Sea coral reefs,
211 particularly in the Gulf of Aqaba, have demonstrated significant thermal tolerance and
212 bleaching resilience (Kleinhaus et al., 2020). Meanwhile, more severe bleaching events have
213 been recorded in the central and southern Red Sea (Osman et al., 2018). Most recently, the
214 2015/2016 El Niño event broadly affected reefs in the southern Red Sea, causing high mortality
215 (Monroe et al., 2018; Voolstra & Berumen, 2019) and an estimated decline in coral cover of
216 about 45% (Anton, Randle, et al., 2020). The full extent of thermal stress on corals and
217 bleaching events has been suggested to remain vastly underrepresented in the Red Sea
218 (Genevier, Jamil, Raitsos, Krokos, & Hoteit, 2019).

219

220 **Vegetative coastal habitats**

221 Mangrove trees have adapted to live in (sub-) tropical saline intertidal zones. They are a
222 nursery for many commercially-important shellfish and fish species that migrate to coral
223 reefs and the open ocean once they have reached maturity (Dorenbosch, Grol, Nagelkerken,
224 & van der Velde, 2006; Mumby, Hastings, & Edwards, 2007). An array of goods can be
225 harvested from mangroves, including fisheries resources, timber, and firewood (Spalding,
226 Kainuma, & Collins, 2010; Ward, Friess, Day, & Mackenzie, 2016a). Mangrove vegetation
227 also provides ecosystem services, such as sediment trapping and erosion protection, flood
228 protection, and nutrient cycling (Duarte *et al.*, 2013; Saderne *et al.*, 2018). Additionally,
229 mangrove forests are capable of trapping and sequestering pollutants, such as heavy metals,
230 hydrocarbons and plastic particles from the water column (Ashok et al., 2019; Martin,
231 Almahasheer, & Duarte, 2019; Rabaoui et al., 2020). Mangroves capacity to improve water
232 quality is particularly beneficial for aquaculture practices. Studies have shown that
233 mangroves can act as natural filtration systems, capable of reducing inorganic nitrogen and
234 phosphate, while increasing oxygen levels and thereby increasing the resilience of
235 aquaculture farms to disease outbreaks (Peng, Li, Wu, Peng, & Chen, 2009; N. Ahmed &
236 Glaser, 2016; Nesar Ahmed & Thompson, 2019). Moreover, mangrove ecosystems are noted
237 for their large carbon stores per area. This carbon is mainly stored in anoxic mangrove soils
238 and known as 'blue carbon' in the policy arena and also occurs in seagrass habitats
239 (Nellemann et al., 2009). In the Red Sea, mangroves form mainly short monospecific stands
240 of *Avicennia marina*, with few occurrences of *Rhizophora mucronata* (Almahasheer et al.,
241 2016), and are distributed all along the coastline.

242

243 Seagrass meadows are another major vegetative coastal habitat and are closely associated with
244 other ecosystems, including mangroves and coral reefs. There is strong evidence that a healthy
245 seagrass beds enhance the productivity of these other systems. Seagrass meadows provide
246 shelter and food for many marine organisms and serve as nurseries for commercially-important
247 fish and shellfish species (Jackson, Rees, Wilding, & Attrill, 2015; Nordlund, Unsworth,
248 Gullström, & Cullen-Unsworth, 2018; Unsworth, Nordlund, & Cullen-Unsworth, 2019). Their
249 high rates of primary production, oxygenate and remove nutrients from the water column. Their

250 roots trap sediment, maintaining water clarity and quality, contributing to stabilization and
251 protection of the coast from erosion (Potouroglou et al., 2017). Through sediment trapping and
252 (photosynthesis), seagrasses can sequester CO₂ from the atmosphere into their roots and
253 sediment (Howard et al., 2017). Thus, along with mangroves, seagrass meadows are important
254 contributors to blue carbon sequestration and storage (Garcias-Bonet et al., 2019; Shaltout,
255 Ahmed, Alrumman, Ahmed, & Eid, 2020). Specifically in the Red Sea, two species of
256 seagrasses, *Halophila stipulacea*, and *Thalassia hempricii* appeared as the most vulnerable to
257 warming and will likely be affected by future thermal stress in the southern region (Anton,
258 Baldry, Coker, & Duarte, 2020).

259
260 Development, aquaculture, and associated increasing pollution across the coast pose immediate
261 threats to these ecosystem's health, not only through land use and destruction but also through
262 changes in the topography of the coast (PERSGA, 2004). In addition, the consequences of
263 climate change (such as sea-level rise, temperature increase, higher frequency of storms ,and
264 changes in ocean currents) present equal if not greater threats to these vegetated marine habitats
265 (Ellison, 2015). Seagrass distribution and survival is controlled by air and sea temperatures, as
266 well as light availability (Short, Carruthers, Dennison, & Waycott, 2007; Ward, Friess, Day, &
267 Mackenzie, 2016b; Earp et al., 2018). Loss of mangroves and seagrasses leads to the
268 subsequent loss of ecosystem services, including current and future carbon and pollutant
269 sequestration capacity, as well as the release of previously sequestered carbon and pollutants
270 through oxygenation and remobilization of sediments (Donato et al., 2011; Mcleod et al., 2011;
271 Lovelock et al., 2017; Ashok et al., 2019).

272
273 Mangrove, seagrass, and coral reef ecosystems are all interconnected, depending and
274 facilitating the healthy existence of one another (see review Earp *et al.*, 2018). Most recently,
275 these marine ecosystems of the Red Sea have been shown to provide thermal refugia for coastal
276 ectotherm animals, whereby the photosynthetic activity enhanced by increased temperatures
277 favors seawater oxygen supersaturation that fuels the peak of animal oxygen demand, thus
278 providing protection for the fauna during the summer thermal stress (Giomi et al., 2019).

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283 **The case for investing in Blue Natural Capital**

284

285 The Organization of Economic Co-operation and Development reported that blue economy
286 industries contributed \$1.5 trillion to the global market in 2016, or approximately 2.5% of the
287 world's gross added value (OECD, 2016). Blue economic activities and investments have been
288 steadily rising (European Commission, 2018; Wenhai et al., 2019) and importantly are predicted
289 to increase their economic value by 2030 (OECD, 2016). Underpinning the success of the blue
290 economy is the continued health of ecosystem services provided by, blue natural capital.
291 Sustainable development approaches are predicted to increase the value of the blue economy
292 by USD\$500 billion more than in a business-as-usual scenario by 2030 – which will continue
293 to increase in the future (OECD, 2016). A sustainable blue economy could generate 43 million
294 jobs by 2030, 7 million more than under an unsustainable scenario (OECD, 2016).
295 Development of the fishery and tourism sectors will contribute to higher employment rates,
296 which coincidentally depend on healthy coastal and marine environments to do so.

297

298 Considering that tourism and fisheries, with artisanal fisheries accounting for 49% of the catch
299 (Tsfamichael, 2016; M. Fine et al., 2019), are among the most important economic activities

300 of the Red Sea, investing in blue natural capital will clearly deliver significant and measurable
301 long-term benefits. First, signs of anthropogenic impacts on the loss of natural marine habitats
302 that support both of these economies are already evident across the coast (Box 1). Increasing
303 environmental pressure, through unprecedented development and investment in infrastructure
304 along the coast of the Red Sea (Kleinhaus et al., 2020), requires direct investment into ensuring
305 the best possible outcome for blue natural capital in order to allow stakeholders to enjoy the
306 benefits of a blue economy. Next, the predicted population growth in the region (M. Fine et al.,
307 2019) will also increase pressure on marine ecosystems and services, through direct effects on
308 their health, as well as increased dependence on natural resources. Further, other anthropogenic
309 impacts (in addition to uncontrolled urbanization and coastal development) such as those posed
310 by marine resource exploitation such as deep-sea mining will cause as of yet unknown impacts
311 to a part of the Red Sea ecosystem which is least well understood (Halfar & Fujita, 2002).
312 Thus, unsustainable management of blue natural capital would not only have severe
313 consequences on the economy, but would also reduce livelihood and food security across Red
314 Sea nations (Visbeck et al., 2014; Hamza, Alhasseen, & Mohamed, 2017).

315
316 Conserving the valuable habitats of the Red Sea offers windows of opportunities to position
317 the region as a global investment hub and a potential leader of sustainable development. We
318 acknowledge that there is an ongoing debate regarding the success of conservation in light of
319 development (Miller, Minter, & Malan, 2011; Caro, Darwin, Forrester, Ledoux-Bloom, &
320 Wells, 2012; Kareiva & Marvier, 2012; Soulé, 2013). However, we advocate for a vision that
321 entails not only conserving, but also growing blue natural capital to enhance natural resources
322 which will benefit local communities and society as a whole. Suggested steps formulated in
323 our action plan (Supplementary Table 1), as well as investment opportunities outlined below,
324 are focused on those strategies that promote health and prosperity for both environment and
325 economy (Kareiva & Marvier, 2012). We categorized blue natural capital investment
326 opportunities tailored to the Red Sea into three categories: financial strategies, ecological
327 innovations, and sustainable coastal development.

328

329 **Financial investment strategies and Blue Carbon**

330 Financial strategies and instruments to conserve and rebuild blue natural capital already exist.
331 These include; biodiversity offset and credits (Curran, Hellweg, & Beck, 2014), banking credits
332 (Fujita et al., 2013), restoration of natural capital credits (Blignaut, Aronson, & de Groot,
333 2014), environmental (green/blue) bonds (Shishlov & Morel, 2016), portfolios of ecosystem
334 services (Fujita et al., 2013), taxes, subsidies, charges and fines, for example (Stavins, 2001; I.
335 Bailey, 2002). The green economy (which has to date primarily focused on sustainable
336 development without degrading terrestrial systems) has been modeling ways in which such
337 market-based incentives, which apply monetary values to products and activities/services of
338 the environment, can support environmental management in the blue economy.

339 The term Blue Carbon refers to organic carbon captured and stored by vegetated coastal
340 habitats, such as seagrass meadows and mangrove forests. These ecosystems can lock carbon
341 in underlying sediments, into living biomass above and below ground, and within non-living
342 biomass for millennia (Duarte, Middelburg, and Caraco, 2005; Nellemann et al. 2009; Mcleod
343 *et al.*, 2011). Although these ecosystems cover an area less than 0.02% of the seafloor, they
344 account for 50% of the carbon buried into oceanic sediments (Carlos M. Duarte, Losada,
345 Hendriks, Mazarrasa, & Marbà, 2013) (Box 1). Loss of these ecosystems has been of
346 significant concern due to the potential implications of extensive conversion of standing carbon

347 pools below ground into the atmosphere as greenhouse gas (Duarte *et al.*, 2010; Hejnowicz *et*
348 *al.*, 2015, Lovelock *et al.* 2017).

349
350 Blue Carbon ecosystems can be integrated into financial incentive strategies, as blue carbon
351 credits could be used to offset carbon and be traded in the carbon markets (Xie He, 2016).
352 Since the sequestration of carbon in these habitats is highly efficient (Sanderman *et al.*, 2018),
353 conserving, restoring, and expanding Blue Carbon ecosystems of the Red Sea could also attract
354 lucrative international investments by providing a framework for businesses to become carbon
355 neutral. To incentivize local investment into the protection and conservation of blue carbon
356 habitats, payment for environmental services (PES) schemes can be implemented. PES allow
357 for providers of environmental services (*i.e.*, local communities) to receive income or funds
358 from buyers interested in using the perceived benefits that habitat offers (*i.e.*, private
359 organizations, service sectors) (Lin & Nakamura, 2012; Hejnowicz *et al.*, 2015). When
360 incorporated into the aquaculture industry, such financial strategies, along with education,
361 could lead to the development of sustainable integrated aquaculture-mangrove systems (N.
362 Ahmed & Glaser, 2016). In this case, catastrophic losses of mangrove ecosystems (which have
363 occurred in many other regions of the world and causally linked to coastal aquaculture
364 practices) could be avoided (Box 1). Implementing, these financial strategies (amongst others)
365 not only diversifies the economy but also promotes stewardship of the environment in the
366 community while enhancing community livelihoods.

367
368 The success of blue carbon, or any environmental finance scheme for that matter, is tightly
369 linked to policy and governance mechanisms being established that encourage implementation
370 and enforce accountability (Macreadie *et al.*, 2019) (Fig.1, Supp. Table 1). However, it has
371 been recognizably difficult to incorporate certain schemes into markets due to inadequacies
372 with assessments of the value of environmental services. Indeed, price tags on environmental
373 services have been heavily criticized for being somewhat oversimplified, *i.e.* not considering
374 the costs and benefits of biodiversity, as well as the additional cost of rehabilitating destroyed
375 ecosystems (Wright *et al.*, 2006; Rinkevich, 2015). Many questions regarding the actual values
376 of ecosystem services are still unanswered, and require evaluation (Himes-Cornell, Pendleton,
377 & Atiyah, 2018). For the Red Sea, the principle unanswered questions include: what are
378 ecosystem services like nutrient cycling, coastal protection, biodiversity, and CO₂
379 sequestration actually worth? In this regard, financial strategies still require significant
380 improvements. Importantly, they should not be viewed in isolation from, or as an alternative
381 to, direct investment into conservation and restoration of marine ecosystems. Instead, economic
382 decision makers should consider conservation and restoration at every step to enhance
383 sustainable growth both in current and future development strategies.

384
385

386 **Ecological innovations along the Red Sea**

387
388 The development of new methods and technology for rebuilding and conserving marine
389 habitats, and therefore protection of blue natural capital has the potential to create important
390 sought after blue technology, marine bio-products, and associated intellectual property. These
391 new discoveries could lead to new business models, attract investment funds, and create new
392 marine industries.

393
394 For example, the Red Sea coral reefs are considered to be among the least vulnerable to climate
395 change impacts, with lethal thermal limits of around 36°C (Anton, Randle, *et al.*, 2020), placing
396 them in a globally important position to potentially facilitate the regeneration of other coral

397 reefs in the future (Hoegh-Guldberg, Kennedy, Beyer, McClennen, & Possingham, 2018). In a
398 Global Coral Reef Conservation Portfolio study, coral reefs of the Red Sea were assessed to
399 provide a good return on investment with low risk of loss (Hoegh-Guldberg et al., 2018).
400 Compared to the southern Red Sea, northern parts are characterized by cooler sea surface
401 temperatures and lower temperature maxima (Chaidez et al., 2017) (Box 1). In the Gulf of
402 Aqaba, coral reefs have withstood significant warming events without severe mass-bleaching,
403 successfully sustaining a healthier state (Osman et al., 2018). Indeed, northern Red Sea corals
404 have higher thermal resilience than elsewhere, and hence, the northern region has been deemed
405 a potential coral refuge to increasing ocean temperatures (Maoz Fine, Gildor, & Genin, 2013;
406 Krueger et al., 2017; Osman et al., 2018). In the Central Red Sea, two coral species
407 (*Pocillopora verrucosa* and *Stylophora pistillata*) have been described to have high lethal
408 thermal limits of around 36°C (Anton, Randle, et al., 2020)(Anton et al. 2020). Therefore, coral
409 species inhabiting this region are suitable candidates for restoring and protecting coral reef
410 health around the globe (Kleinhaus et al., 2020). Harnessing the natural resilience of Red Sea
411 corals could allow the re-seeding of reefs globally that have been severely degraded by
412 temperature-induced bleaching events. However, significant research is required to ensure
413 success. Fundamentally, characterizing the traits that make certain coral species more resilient
414 than others is required, and is currently being investigated (Dixon et al., 2015; Howells,
415 Abrego, Meyer, Kirk, & Burt, 2016; Kirk, Howells, Abrego, Burt, & Meyer, 2018; Manzello
416 et al., 2018). Understanding genetic traits and conditions that are responsible for higher thermal
417 resilience in corals can enable effective breeding of offspring with desired traits. Research into
418 coral genetics and development of optimized methods for upscaling the spawning and rearing
419 of corals ex situ (Craggs et al., 2017) could assist global efforts in accelerating the rate of
420 naturally occurring evolutionary processes, known as assisted evolution or assisted gene flow
421 (van Oppen, Oliver, Putnam, & Gates, 2015; van Oppen et al., 2017). The genetic resources
422 obtained would also be a significant contribution to efforts in establishing a coral gene bank
423 for future coral restoration (Hagedorn, Spindler, & Daly, 2019). However, some have
424 suggested we move with extreme caution when implementing such practices linked with
425 upscaling reef restoration, including but not limited to aspects in and around assisted evolution
426 or assisted gene flow (i.e., the use of probiotics to increase thermotolerance and/or disease
427 resistance; (Sweet, Ramsey, & Bulling, 2017). Regardless, the Red Sea holds the potential for
428 exploration of much unexplored marine genetics and presents itself as an invaluable investment
429 opportunity into genetic resources (M. Fine et al., 2019).

430

431 In contrast to the north, the central and southern Red Sea coral reefs have experienced severe
432 thermal bleaching events (Monroe et al., 2018; Osman et al., 2018) (Box 1). The loss of reef
433 habitat provides an opportunity for another significant category of investment: rebuilding and
434 restoring coral reefs. While the northern Red Sea provides valuable opportunities for genetic
435 research in coral reefs, the southern Red Sea offers a testbed for reef restoration methods.
436 Economic assessments have shown that although coral reefs have the highest value with respect
437 to natural capital, they have the lowest benefit-cost ratio due to relatively high restoration costs
438 (de Groot et al., 2012). Additionally, restoration of coral reefs is complex and has so far been
439 difficult to achieve on a large scale (Blignaut et al., 2014). Thus, there is a market interest in
440 developing new technology and methods of scaling coral reef restoration (Baums et al., 2019).
441 The degraded reefs of the southern Red Sea allow for the testing and optimizing of restoration
442 tools such as in situ coral propagation (Schopmeyer et al., 2017), larval re-seeding
443 (Chamberland et al., 2017) and recruitment (Liversage & Chapman, 2018) and coral
444 transplantation (Horoszowski-Fridman & Rinkevich, 2016). Selecting new restoration sites for
445 long term success will require significant research and environmental monitoring to ensure
446 highest chance of success (Bayraktarov et al., 2016; Suggett et al., 2019). Furthermore, the

447 intellectual capital of research institutes across the region can foster the development of
448 innovative technology and locally-tailored approaches associated with reef restoration. Topics
449 could include, amongst others; testing new larval seeding and recruitment protocols, creating
450 nurseries and trialing new designs, establishing lab-based coral spawning that allows for year-
451 round sexual reproduction, and developing cryo-preservation methods for future interventions.

452

453 Finally, identifying and understanding the role of bacterial communities in the Red Sea has
454 been of increasing interest for innovative restoration and protection of reefs and coastal
455 habitats. The bacterial communities associated with animals, plants, seawater, and sediments
456 are emerging as important components of ecosystem diversity (Cuellar-Gempeler & Leibold,
457 2018), regulators of plant and animal resilience to stress and of habitat functioning (Trevathan-
458 Tackett et al., 2019). Recent studies have indicated that bacterial communities may support
459 coral resistance to bleaching (Rosado et al., 2019) or may elicit root growth for an earlier
460 establishment of mangroves propagules (Soldan et al., 2019). Therefore, research into the
461 bacterial communities present in the Red Sea and associated ecosystems and/or organisms
462 represent another major avenue of 'blue gold', i.e. beneficial to the organisms in question but
463 also to humans in the form of novel drug discovery (Blockley, Elliott, Roberts, & Sweet, 2017).

464

465 These active forms of protection and restoration of coral reefs are obviously linked to one
466 another; research in the northern Red Sea has the high potential to result in new selective
467 breeding and seeding programs that can then be tested and implemented in the more damaged
468 and degraded southern ecosystems. Since these strategies are at an early stage, ecological
469 innovation investments presented here focus on advancing technology as well as increasing
470 research funding, generating knowledge, and fostering transnational collaboration.

471

472

473 **Blue development of Red Sea coastlines**

474

475 When developing strategies for the future of blue natural capital in a socio-economic context,
476 a third avenue, besides conservation and restoration, must be considered for the investment to
477 be profitable in the long term: advancing with blue natural capital. Population growth and
478 planned large-scale coastal developments could be seen as a significant risk to the future of the
479 Red Sea ecosystems, as seen in the impacts of other regions, such as the Arabian Gulf (Burt &
480 Bartholomew, 2019). However, if carefully planned, managed, and executed, they could
481 become internationally significant investment and development prospects that are made more
482 valuable by the blue capital that they conserve and grow. Future coastal development projects
483 demand a commitment to sustainability with a focus on balancing ecosystem, social and
484 economic benefits. Integrating the marine environment and blue natural capital into coastal
485 development allows Red Sea projects to lead the way and take advantage of innovative
486 technology and investment strategies while securing the desired blue natural capital of the
487 region.

488

489 To date, coastal infrastructure has been designed with limited consideration of marine habitats,
490 consequently debilitating surrounding ecosystem services. Sustainable coastal development
491 technology and nature-based solutions are continuously expanding and include not only the
492 creation of artificial habitats (Feary, Burt, & Bartholomew, 2011; Dafforn et al., 2015) but also
493 new approaches in constructing coastal infrastructure supporting the establishment of marine
494 ecosystems (Ido & Shimrit, 2015). Incorporating marine habitats into development projects
495 enables blue natural capital and socio-economic investments to grow together. Large
496 development projects, such as those related to Saudi Arabia's Vision 2030 (i.e., NEOM, The

497 Red Sea Project, and Amaala), could be exemplary economically sound models that achieve
498 net-positive conservation impact and social equitability. Besides including current methods of
499 ecosystem engineering, such as using eco-friendly concrete and other methods of ecological
500 enhancement of marine infrastructure (Ido & Shimrit, 2015; Hall, Herbert, Britton, & Hull,
501 2018; Mayer-Pinto, Dafforn, & Johnston, 2019), cities of the future can invest in new
502 technology and development strategies. Examples include (but are not limited to) the
503 incorporation of: coral nurseries and coral farms into ecological aesthetics of coastal cities,
504 coastal mangrove forest boardwalks and piers that serve as natural attractions as well as coastal
505 protection (Satyanarayana et al., 2012), and building threat mitigation into development plans
506 to protect coastal marine ecosystems. Obviously, these initiatives should also target the use of
507 renewable energy and zero-emission technologies. However, it is worth mentioning that the
508 implementation of coastal ecological engineering and nature-based solutions can also balance
509 carbon emissions and removal, thus facilitating the establishment of a circular carbon economy
510 in the region (Langergraber et al., 2020). By incorporating current ecological engineering tools
511 and investing in the advancement of new technology, the Red Sea region could lead innovative
512 development strategies of the 21st century.

513
514 Needless to say, investing in the incorporation of marine habitats into coastal development
515 would allow the expansion of the ecotourism sector and bring the Red Sea to a global audience.
516 Marine tourism, specifically reef tourism, is already one of the major economic activities of
517 many Red Sea bordering countries (M. Fine et al., 2019). With many new Red Sea tourism
518 projects in development, interest in marine tourism is expected to increase steadily.
519 Importantly, growth of the tourism sector into a major economic player can lead to new
520 management program built around stewardship as well as new research partnerships. Economic
521 and environmental instruments associated with novel ecotourism concepts are therefore an
522 important and profitable investment opportunity which can diversify the local economies.
523 Furthermore, ecotourism concepts can be directly linked to the enhancement of environmental
524 education as these attractions allow the general public to experience, appreciate, and value
525 natural marine habitats. Particularly, vegetated ecosystems are easily made accessible to the
526 public through piers or park structures, if appropriate infrastructure and management are
527 applied. Environmental education investments can act as platforms for the conservation of local
528 culture and capacity development, ultimately leading to new service opportunities in other
529 economic sectors (Blignaut et al., 2014; M. Fine et al., 2019).

530
531 It is important that nations and developers strive to give equal priority to the quality and
532 quantity of tourism. The future of sustainable ecotourism depends on increasing the scale of
533 tourism that will result in environmental stewardship, incentivize best practice methods, and
534 reduce environmental impacts (Fujita et al., 2013).

535
536

537 **Ensuring the future of blue natural capital in the Red Sea**

538

539 Failing to invest in adaptive management strategies, those aimed at protecting and maintaining
540 blue natural capital, will inevitably catalyze environmental degradation, and a significant lost
541 opportunity to harness natural resources that would benefit marine habitats and the regional
542 economy. Investing in conservation and building of the Red Sea's blue natural capital offers
543 avenues to diversify the regional economy with globally relevant assets and lead international
544 efforts in sustainable development. However, sustainable governance is necessary in order for
545 these opportunities to exist, and for blue natural capital to grow.

546

547 Marine protected areas (MPA) and marine spatial planning (MSP) are fundamental tools
548 utilized by governments (globally), to assist in the management and protection of coastal and
549 marine ecosystems (*i.e.*, to conserve blue capital). Marine Spatial Planning (MSP) constitutes
550 a public process of analyzing and allocating the spatial and temporal distribution of human
551 activities in marine areas to achieve ecological, economic, and social objectives that are usually
552 specified through a political process (Ehler & Douvère, 2009). The principles of MSP are often
553 used for the designation of MPAs worldwide, as MSP can help to ensure compensation and
554 replacement for interference in the natural environment (Schachtner, 2017). MPAs are defined
555 regions that manage specific conservation objectives, and some can be no-take zones to protect
556 local fish stocks or define areas banning mangrove wood harvesting. MPAs are fundamental
557 for the MSP process as they ensure the sustainable use of natural resources while supporting
558 the concept of blue economy and providing investment opportunities in the marine sector
559 (Kelly, Gray, Shucksmith, & Tweddle, 2014).

560

561 A number of MPAs have been declared in Red Sea waters, with many more under review
562 (Marine Conservation Institute, 2019). Egypt has led by example through the implementation
563 of MPA's back in 1986. However, Egypt long struggled with successful implementation due to
564 lack of socio-economic and alternative resource dependencies as well as raising awareness,
565 compliance, and enforcement (N. A. Marshall, Marshall, Abdulla, & Roupheal, 2010; Samy,
566 Sánchez Lizaso, & Forcada, 2011). Lessons learned in developing successful MPA's in Egypt
567 can be used to inform strategic management and implementation throughout the rest of the
568 region. The Regional Organization for the Conservation of the environment of the Red Sea and
569 Gulf of Aden (PERSGA), an intergovernmental body dedicated to the conservation of coastal
570 and marine environments of region, and similar organizations will play an important part in
571 facilitating the exchange of information and ensuring the success across borders. However, so
572 far, relevant policy frameworks promoting MSP have not yet been established in any of the
573 areas considered by PERSGA.

574

575 The first step for an MSP application in the Red Sea has recently been made through the Red
576 Sea Project, a core component of Vision 2030, which aims to develop the tourism sector of the
577 Kingdom of Saudi Arabia (The Red Sea Development Company). Unfortunately, the absence
578 of formal MPA, MSP, and general fisheries management arrangements in the broad area,
579 results in habitat destruction and conflicts between industry and artisanal fisheries (Hariri et
580 al., 2002). Marine ecosystems are by their very nature interconnected and transboundary *i.e.*
581 they do not restrict themselves to country borders. Hence, collaborative efforts to manage
582 threats occurring beyond national boundaries and accounting for connectivity between
583 ecosystems is essential in order to manage and sustainably develop marine resources to their
584 maximum potential (Roberts, 1997). This is particularly important when discussing fisheries
585 management and stock quotas. Establishing transnational collaborations incentivizes shared
586 stewardship practices and fosters a culture of peace and unified prosperity to the coastal nations
587 sharing interdependent marine resources (Supp. Table 1).

588

589 For policy frameworks to be successfully implemented, managed, and maintained, conflict
590 resolution mechanisms and incentives for coordination and cooperation must be in place. This
591 also requires adequate assessment and monitoring strategies of marine ecosystems, with a
592 motivation to share data. Additionally, procedures must be developed to conduct common
593 environmental impact assessments (EIA) focusing on biodiversity risks of new infrastructure
594 investments. This will require transparency, baseline data collection, identification of costs and
595 benefits, and implementing mitigation measures. Without such mechanisms and robust data,
596 effective management and planning cannot occur. This would result in a lack of accountability

597 that could risk unsustainable and likely destructive uses of blue natural capital. Successful Red
598 Sea management requires sound scientific knowledge describing its local and regional status.
599 Nations will have to develop and communicate effective data-collection frameworks that can
600 be used for evaluation and long-term monitoring. Initiating baseline datasets is paramount to
601 overcome the current data deficiency in the Red Sea and to accurately inform policy actions.
602 Continued monitoring and assessment are necessary to ensure that implemented policies are
603 effective and have a measurable indicator for performance against established goals (Day,
604 2008). Citizen-science programs and engagement of local communities can be a valuable asset,
605 as well as directly contributing to local education and awareness programs (N. J. Marshall,
606 Kleine, & Dean, 2012; Branchini et al., 2015). Additionally, stakeholder nations must invest
607 in conducting risk assessments of blue natural capital in the Red Sea to understand
608 vulnerabilities (i.e., pollution, climate change) and to protect and ensure growth, rather than
609 loss, of assets and investment. Finally, in order to facilitate collaboration across borders, joint
610 targets and objectives must be set, outlining roles and responsibilities that are clearly aligned
611 with best practices globally. Ultimately, the financing strategies for these targets must be set
612 out in the planning stage to ensure that social, economic, and environmental challenges are
613 accounted for.

614

615 As such, communication and stewardship across governments, as well as national departments
616 and agencies, must be improved to create an integrated ocean management plan. A
617 collaborative effort is essential for the proper planning and management of Red Sea resources,
618 which can be achieved through the active involvement of third parties or organizations, such
619 as conservation NGOs and The Regional Organization for the Conservation of the Environment
620 in the Red Sea and the Gulf of Aden, help to mediate this process (M. Fine et al., 2019).
621 However, such regulatory bodies must be sufficiently empowered to enforce regulations and
622 provide accountability to non-compliance. Inevitably, the effective delivery and rapid
623 implementation of blue natural capital-related policies will depend on communication,
624 transparency, accountability, and inclusivity (Hejnowicz et al., 2015).

625

626 **Conclusion**

627

628 Here, we show why private and public sectors must invest in the protection, preservation, and
629 enhancement of blue natural capital of the Red Sea. The relatively pristine condition of many
630 of the coral reef, seagrass and mangrove ecosystems present a significant source of
631 environmental and socio-economical investment prospects for the region. Taking advantage of
632 these investment opportunities in natural assets could place local nations as global innovators
633 of sustainable ocean projects and economies. However, to ensure that these environmental and
634 financial ventures are enacted sustainably (without the loss of local biodiversity) and return a
635 profit in the long term, significant proactive policies to protect and restore the wealth of blue
636 natural capital in the Red Sea are required. Sustainable ocean management is, in its essence, a
637 political process that requires coordination across governments as well as relevant
638 stakeholders, including scientists, local communities, and industries. Hence, communication,
639 participation, and transparency of all involved parties are required in order to successfully build
640 a blue economy that thrives with its natural resources. Considering the opportunities at stake,
641 failure to invest in blue natural capital of the Red Sea would represent a substantial loss –
642 economically and, most importantly, environmentally and socially. Securing a future for the
643 Red Sea does not merely require sustaining the current ecosystems but maintaining their health
644 for the long-term.

645

646 **Author contributions**

647 MJC, CD and MA conceived the idea. MJC wrote the manuscript. All authors contributed
648 critical feedback.

649

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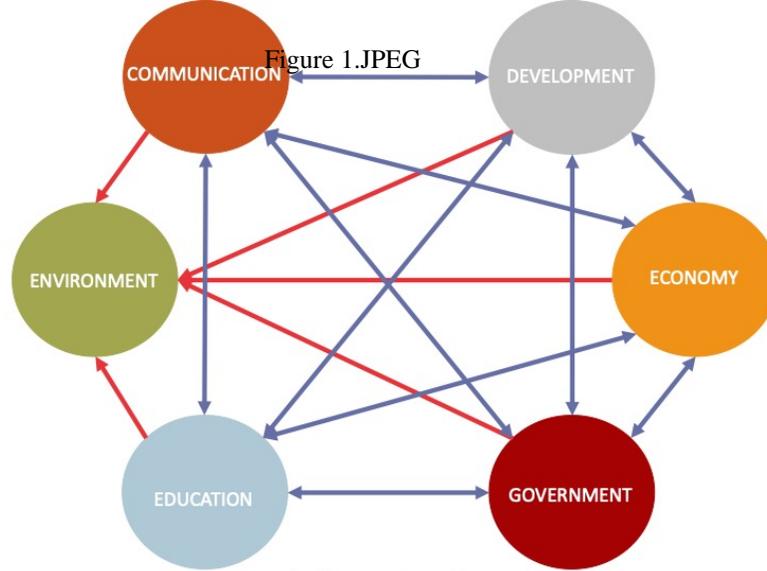
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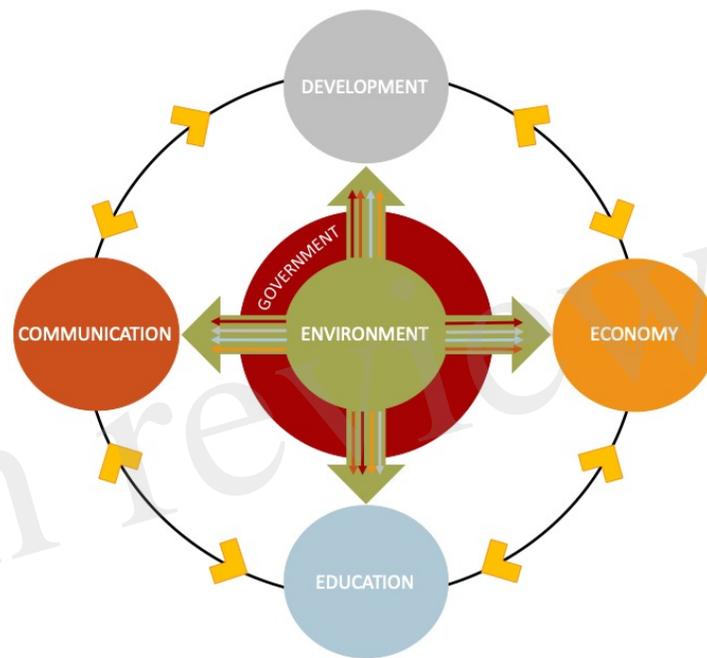
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A. Current system



B. Sustainable Development

Figure 1. – Strategic development models have relied on the exploitation of the environment. Investing in blue natural capital and a sustainable future requires an evolution of the current development model (Fig 1A). A revised model needs to center the environment, valuing creation over destruction and regulating management through well-planned and executed governmental policies (Fig 1 B). (A) In the current system, all sectors are interconnected but primarily linked to the environment through exploitation (red arrows). In this model, there is a lack of acknowledgment of the impact of the environment on the success and prosperity of any developmental project. Economic opportunities are therefore often missed, and the importance of the environment is undervalued. Thus, the incentive towards protecting, preserving, and rebuilding the health of natural ecosystems is reduced. Consequently, financial benefits and long-term economic growth are reduced or threatened. **(B)** The newly proposed environmental-centered (sustainable) development model (presented here) aims to recognize the socio-economic importance of the environment's health on strategic development, by placing it at the center. The success and failure of each sector directly impacts the environment as well as indirectly itself and all others. When the environment is placed at the core of the system, the inter-connectivity of sectors is clearly linked through the sustained health of ecosystems– the environment is effectively the heart of social and economic wealth. In this model, governance is not a sector like any other; governments are in fact the key custodians of natural environments. Governments' collaboration, proactive policies, and enforcement are required and essential to ensure net-positive outcomes of the environment as a whole and, thus, the viability of all other sectors. Hence, governments have the responsibility to implement governance arrangements that act as a shield preventing unsustainable use and negative interactions of other sectors with the natural environment.