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Assessment of the Chesapeake Bay watershed socio-ecological system through the Circles of Coastal Sustainability framework

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The concern with preserving natural resources for the future has been capturing global attention due to the state of decline of productive ecosystems. Chesapeake Bay, a large estuary located on the mid-Atlantic coast of the United States of America is such a productive ecosystem supporting thousands of animal and plants species, and the surrounding human population. Despite the concept of sustainable development, there has been continued pressure on the natural resources and the ecosystem services of the Bay. Institutional restoration and management efforts have been extensive, generating organizations, agreements, regulations and projects, among others. This research assesses Chesapeake Bay's sustainability in four domains: environment, social, economy, and governance, using the Circles of Coastal Sustainability methodology. Each of the four domains has five categories, and each category is evaluated by the authors' expert judgment using indicators related to the socio-ecological system and the definition of sustainable development. The article proposes a global sustainability score developed by a literature review of sustainability evaluated through the expert judgment of the authors. The results from the framework gave a "Satisfactory" score to the overall system; the environment and economic domains obtained the "Satisfactory" score, whilst the government and social domains obtained "Good" and "Poor" scores, respectively. The categories ranged between "Excellent" and "Poor" scores. The "Excellent" score was obtained by organization. The "Poor" score was obtained by five categories across the domains including social benefits, demographic, identity, security, and economic wellbeing. The assessment showed that the system has degradation problems, but the results have provided a general foundation for management bridges and barriers for sustainable development, with the barriers used to discuss new bridges towards holistic management proposals. The framework is a tool in progress to communicate to various actors the current sustainability development with the available information, provide a holistic system view, and find knowledge gaps in the research of a system. Similarly, the framework and assessment can be complemented, adapted, refined, and improved with each application as part of an adaptive management iterative cycle.

KEYWORDS

Chesapeake Bay watershed, socio-ecological system, indicators, sustainability assessment, coastal management

1 Introduction

The 1987 Brundtland Report was developed by the United Nations to propose "*a global agenda for change*" (Keeble, 1988). The report was the first to define the concept of sustainable development as "*development that meets the needs and aspirations of the present generation without destroying the resources needed for the future generation to meet their needs*" (Keeble, 1988). Concern about preserving natural resources for the future has been capturing the attention of the global public due to the state of decline of productive ecosystems (Keeble, 1988; Kuhlman and Farrington, 2010). This raises the question of how to assess the sustainability of a social-ecological system to reveal the management needs.

The Chesapeake Bay is a large estuary with an area of 6,100 km^2 located on the mid-Atlantic United States of America (USA) coast (Goetz et al., 2004; Bilkovic et al., 2019). The Chesapeake Bay watershed drainage covers 167,000 km^2 within six states of the country, Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia, and the Federal District of Columbia, the nation's capital (Boesch et al., 2001; Testa et al., 2017; McLaughlin et al., 2022). Currently, its natural resources support thousands of animal and plant species and a human population of approximately 18 million (Morgan and Owens, 2001; Phillips and McGee, 2016; Ator et al., 2020; Delia et al., 2021). However, since the mid-1900s, there has been a substantial loss of natural resource quality and productivity (Phillips and McGee, 2016; Hood et al., 2021; CBP-Who, 2023). In 1970, the nation's Congress sponsored a study to analyze the source of the Bay's degradation (CBP-Who, 2023). The main issue identified was cultural eutrophication, an excessive algae growth resulting from nutrient enrichment by human activities (Boesch et al., 2001; Kemp et al., 2005). Some of the nutrient enrichment activities in the region are agricultural fertilization, runoff of sediments and animal waste, and atmospheric nitrogen deposition from the fuel combustion of cars or industries (Boesch, 2006; Williams et al., 2009).

One of the results of these algae blooms is hypoxia, which occurs when organic matter from algae sinks into the deep water, where it is decomposed, depleting dissolved oxygen to a certain low level (Kemp et al., 2005; Du et al., 2018). Natural ecological processes in forests and wetlands around the watershed and the coastline tended to "buffer" and regulate nutrient enrichment. Some examples of "buffers" are forests, wetlands, oyster reefs, and submerged aquatic vegetation (SAV), which trap and absorb nutrients and sediments (CBP-Dev, 2023). However, land-use change to accommodate a growing population has compromised many of these natural systems (Kemp et al., 2005; CBP-Issues, 2023).

The development and exploitation of the Chesapeake Bay natural resources contribute billions of dollars and thousands of jobs to the region's economy and quality of life (McLeod and Leslie, 2009; Phillips and McGee, 2016; CBF-Fisheries, 2023). The Bay provides countless valuable and quantifiable economic goods and services, such as recreational activities, tourism, food, real estate, and shipping transport (Phillips and McGee, 2016). Further ecosystem degradation threatens the natural resources, which are the basis of the region's economy. The decline in water quality can affect the fisheries, esthetic, and human health (Kemp et al., 2005; Birch et al., 2011; Compton et al., 2011; Steinzor et al., 2012; Phillips and McGee, 2016; George, 2019; Miller Hesed et al., 2020; Kenney and Gerst, 2021).

In response to the observed ecosystem decline, the government promoted agreements to guide the effort to reduce pollution and restore ecosystem health. This is led by the Chesapeake Bay Program (Hood et al., 2021; CBP-Accomplishments, 2023; CBP-Who, 2023). The Chesapeake Bay Program (CBP) partner institutions gathered input from citizens, stakeholders, academic institutions, and local government to draft an inclusive, goal-oriented document that addresses current and emerging environmental concerns, the Chesapeake Bay Watershed Agreement (CBWA) (CBP-Who, 2023). The community-based management's initiative to incorporate, consult, and lead new actors to participate in the management has increased to benefit the system's wellbeing. The results are the Total Maximum Daily Load (TMDL), a federal "pollution diet" to restore the water quality, and "Watershed Implementation Plans," often called WIPs (CBP-TMDL, 2023; CBP-WIP, 2023). The WIP documents include specific steps and plans each jurisdiction will take to meet the goals of the TMDL by 2025 (CBP-WIP, 2023).

The extensive information and overall institutionalized management effort transcending six states and the USA's national capital in the Chesapeake Bay watershed makes it an ideal socio-ecological system for assessing sustainable development. There are several holistic frameworks that assess the sustainability of a system. However, most of them focus on only one sustainability domain (environmental, social, or economic) or evaluate the causes and responses to a particular issue, such as eutrophication. The framework chosen in this assessment is based on the Circles of Coastal Sustainability (De Alencar et al., 2020), further developed by Gallo-Vélez et al. (2023). This framework is designed to assess environmental, social, economical, and governance domains to understand the complex interactions of the region's development. Governance was added to the three previous pillars of sustainability (ecological, social, and economic) because the fragmented nature of governance and management has been recognized as one of the main limitations of sustainable development (Neumann et al., 2017; De Alencar et al., 2020).

At present, the method to evaluate sustainability is still in development, and the assessment is highly subjective because of the availability of quantitative and qualitative information from each domain (De Alencar et al., 2020; Gallo-Vélez et al., 2023). Moreover, evaluating sustainability requires the expertise of scientific professionals familiar with the system. Nevertheless, the assessment serves as a foundation tool for understanding the concept of sustainability within the system. It initiates dialog about the meaning of sustainability and aims to identify indicators that must be quantified for its achievement. The assessment, while acknowledging its limitations, can serve as a basis for developing comprehensive, holistic responses considering the environmental, economic, and social impacts.

2 Methods

2.1 Study area

The Chesapeake Bay is an estuary with a watershed 14 times the size of the Bay (11,603 km^2:166,000 km^2), located in the middle of the USA Atlantic coast (Figure 1) (Bilkovic et al., 2019). The Bay is approximately 300 km long from north to south, with the width

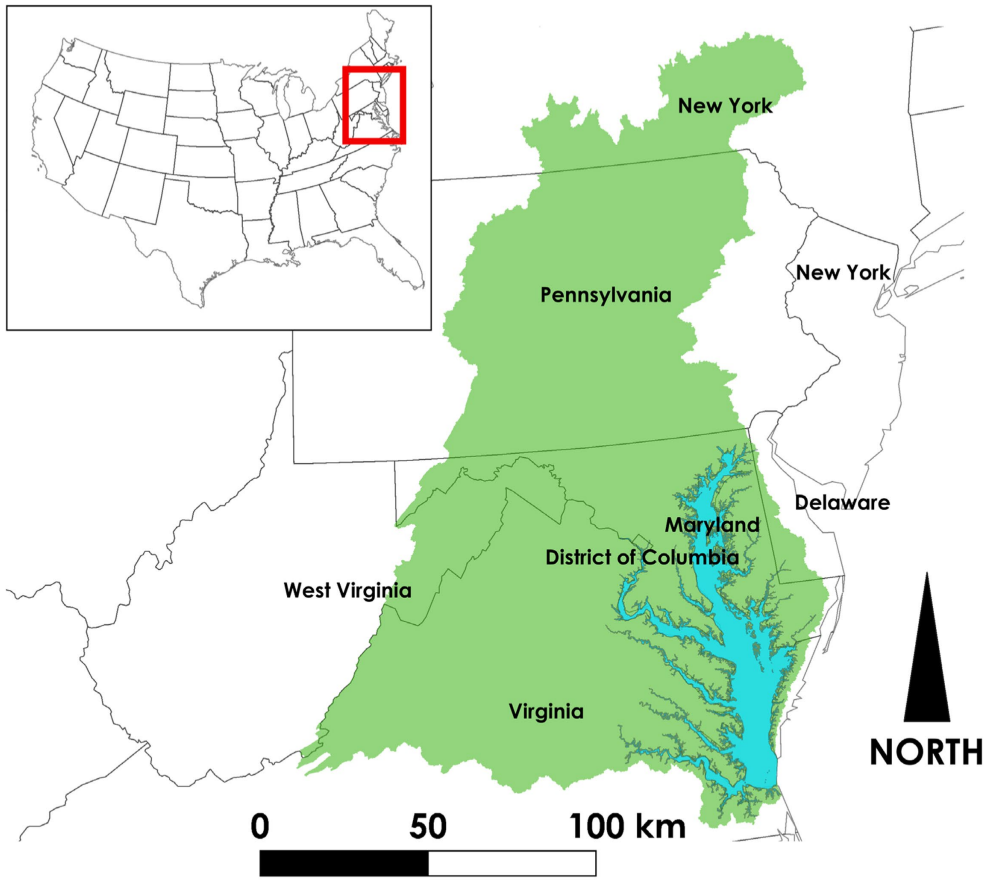

FIGURE 1
Chesapeake Bay Watershed boundaries and location in the United States of America.

varying from 20 km in its mouth to 45 km in the middle and a few km in the upper (Kemp et al., 2005; Garzon et al., 2018). The mean depth is 6.5 m, with the deepest point (53 m) located in the middle of the Bay (Hardaway and Byrne, 1999; Lin et al., 2002; Bilkovic et al., 2019; CBP-Facts, 2023).

Overall, the watershed remains mostly forested, with some urban development areas. The land use is divided mainly into agriculture and a mix of urban and rural development (CBP-LandCover, 2023). Agriculture dominates most of the watershed (CBF-LandUse, 2023), while the main expansion of metropolitan areas are Washington, D.C., Baltimore, Philadelphia, Richmond, and Hampton Roads (Ruark, 2010). Based on the 2020 USA Census data, the cities positioned between these major metropolitan areas have the highest population, with an estimated total of approximately 10 million people (Bureau, 2023). The population is growing, particularly near the waterfronts of the Bay's tidal waters (Walsh et al., 2019). On the shoreline, the major structural habitats are seagrass beds, marshes, and oyster reefs (Bilkovic et al., 2019).

The main source of freshwater input comes from the Susquehanna, Potomac, Rappahannock, York, and James rivers (Kemp et al., 2005; Du and Shen, 2017). The flow of freshwater drives the estuarine circulation and suppresses vertical exchange. Destratification can occur because of strong, episodic winds. However, stratification is quickly reestablished, retaining particulate and dissolved materials in the lower layer. The circulation of the Bay makes this a productive system, with efficient ecosystem nutrient use and a tendency for oxygen depletion from deep water (Kemp et al., 2005).

The socio-economic system of the Chesapeake Bay watershed is divided among six states of the USA. The north part of the watershed includes New York State, flows south to parts of Pennsylvania State, and then to Virginia at the southern border. In the middle, there are parts of Delaware and West Virginia States, most of Maryland, and the whole District of Columbia (Figure 1) (Arnold et al., 2021).

2.2 Socio-ecological assessment framework

The Circles of Coastal Sustainability framework was adapted from the Circles of Sustainability developed by De Alencar et al. (2020). The objective was to design a holistic framework to assess the sustainability of the socio-ecological systems of the world's coasts. The framework is divided into four domains (environment, social, economy, and governance), each with five categories related to any coastal environment. The categories were developed by the multi-disciplinary Scientific Committee of Future Earth Coasts[1] in 2016 and have been

1 https://www.futureearthcoasts.org/

applied to the Spanish coast (De Alencar et al., 2020) and Magdalena River delta in Colombia (Gallo-Vélez et al., 2023).

2.2.1 Sub-categories and indicators for the Chesapeake Bay watershed

The categories are generic qualities of coastal sustainability; they can be applied to a diverse range of socio-ecological systems and size scales. To adapt the framework to the Chesapeake Bay watershed, the categories were divided into sub-categories related to recognizable and comprehensive indicators from the region (Table 1).

Table 1 has a total of 129 indicators: 30 indicators for the environment domain, 33 for society and culture, 39 for economy, and 27 for politics and governance. The Chesapeake Bay watershed is one of the most studied places in the world (Arnold et al., 2021). The enormous availability of information, management, and communication makes it a challenge to choose indicators. Therefore, the selection of the indicator was based on the Chesapeake Bay Program (CBP-Issues, 2023) and a literature review of the system. The available information was adapted to the framework with the main commitment to reflect the "real-life" sustainability of the system.

2.2.2 Propose global sustainability score

The sustainability score thresholds were developed by De Alencar et al. (2020), as shown in Figure 2. The sustainability score has five levels ranging from "Excellent" optimal condition to "Bad" worst condition. The color range from De Alencar et al. (2020) was changed from red-blue, based on the European Union Water Framework Directive, to a more globally recognizable "traffic light" range of red-green, also used by Gallo-Vélez et al. (2023).

Gallo-Vélez et al. (2023) developed a score based on a decision tree adapted from Sachs et al. (2021) to define a threshold for each indicator. Each indicator obtained a numerical value according to its sustainability level: "Excellent" = 5, "Good" = 4, "Satisfactory" = 3, "Poor" = 2, and "Bad" = 1. However, this approach requires extensive details about each indicator, and the general result can be misinterpreted.

Therefore, this study proposes a different sustainability assessment based on an extensive literature review of "Sustainability development." The overall socio-ecological system is assessed on a simple Excellent-Bad scale, using the authors' expert judgment, as shown in Figure 2. This approach is based on the definition of sustainability by Keeble (1988), which represents "Excellent." The other grades ("Good," "Satisfactory," "Poor," and "Bad") represent degrees of deviations from "Excellent." The simplification is to convey a clear message about the current circumstances of the system to a non-scientific audience. For example, a "Bad" score would be given to a region during an economic crisis (recession, currency crisis, or others) because the system lacks one of the pillars for sustainability development. This could also be applied if the region has a crisis in any of the domains: a government crisis, such as a war or military coup; an environmental crisis, natural or man-made, such as a flooding area or oil spill; or a social crisis, such as homelessness.

The socio-economic crisis may not look related to a degraded ecosystem. However, according to Mensah (2019), a social crisis (such as poverty) has the potential to lead to environmental destruction and economic stability. The destruction of available natural resources can subsequently contribute to increased economic instability, leading to a cycle of further environmental destruction and increased social inequality (Mensah, 2019). It is important to note that this correlation is not universally applicable or instant; it may manifest over the years. Nonetheless, it is crucial to consider.

Furthermore, Figure 2 has two words that require to be defined: "barriers" and "bridges." These words were defined using Boesch's (2019) article as a metaphor for barriers against and bridges toward effective regional ecosystem management. Some examples can be seen in the same article, e.g., barriers could be limited knowledge of causes and consequences, managers' lack of authority and responsibility, limited public and stakeholders' concerns, and others. Some examples of bridges are education, enduring engagement of responsible managers, and effective communication of causes, risks, and benefits (Boesch, 2019).

The general score (Figure 2) was developed based on a literature review to propose a global sustainability score using the authors' expert judgment for each domain (Table 2) and each category (Table 3). The normalization process is done by using expert judgment to assess the collective set of indicators for each category and then using Table 3 to provide a general evaluation; then, each domain is assessed using Table 2; and finally, the overall system evaluation is conveyed to stakeholders in Figure 2.

It is essential to note that the evaluation of the Chesapeake Bay watershed was developed using indicators from Table 1, drawing from scientific and non-scientific sources spanning 1999 to 2023. Therefore, this evaluation remains valid for the duration of the specified timeframe.

2.2.3 Communication of science

One of the main goals of the sustainability assessment was to improve communication with stakeholders and the general public. Understanding sustainability development can be overwhelming when the interconnection between the domains can be incredibly complex. Therefore, science communication tools are helpful in knowledge-sharing with the general public and policy/decision-makers. This requires a modification of De Alencar et al.'s (2020) "bull's eye" image to make it more easily understandable as an assessment of the sustainability of a socio-ecological system. The new representation resembles a daisy-like flower, so the image is called "Sustainability Daisy" (Figure 2). The socio-ecological system's name is at the center of the new design, surrounded by each of the domain's divisions with its five categories as petals. On the outside of the wheel, IAN symbols represent the four domains[2]. These symbols can be locally adapted, e.g., Dollar $ represents the currency of the USA, and the blue crab represents the Chesapeake Bay ecosystem because of the cultural importance of the fisherman in the region (Paolisso, 2002).

3 Results

Table 4 has a total of 129 indicators, with the evaluation of each category using the authors' expert judgment coupled with the proposed global assessment (Table 3). The "Economics" domain has

2 https://ian.umces.edu/media-library/symbols/

TABLE 1 Sub-category and indicator used for the Chesapeake Bay watershed sustainability assessment with their corresponding reference.

Category	Sub-category	Indicator	References
1. Alteration of landscape	Watershed	Land use change	Williams et al. (2009)
		Protected land	CP-ProtectedLand (2023)
		Development	D'Elia et al. (2019), Goetz et al. (2004), Kemp et al. (2005), Ruark (2010), Walsh et al. (2019), Zhang et al. (2023)
	Shoreline alteration and consolidation	Armored shorelines	Patrick et al. (2016)
		SAV	Orth et al. (2017), CP-SAV (2023), Zhang et al. (2023)
		Bivalve tray	Kemp et al. (2005), CP-Oysters (2023)
2. Ecosystem function	Vital habitats	Oysters	Kemp et al. (2005), Leyva Ollivier et al. (2023)
		SAV	Davis et al. (2006), Orth et al. (2010), Webster et al. (2021)
		Wetland	CP-Wetlands (2023)
		Forest buffer	CP-Forest (2023)
	Biodiversity loss	Abundance of biodiversity	CP-AbundantLife (2023)
		Invasive species	CP-InvasiveSpecies (2023)
		Fish migration routes	CP-Fish (2023)
3. Global environmental change	Climate change	Sea Level Rise	Kemp et al. (2005), Najjar et al. (2010), Du et al. (2018), CP-Climate Change (2023)
		Increase in temperature	Du et al. (2018), Irby et al. (2018), Modi et al. (2021), Frankel et al. (2022)
		Precipitation	Du et al. (2018), Irby et al. (2018), Modi et al. (2021), Frankel et al. (2022)
	Predictions/regulations	Monitor process	Irby et al. (2018), CP-Climate Change (2023), Zhang et al. (2023)
		Climate change adaptation	CP-Climate Change (2023)
		Coastal Adaptation	RC-CoastalAdaptation (2023)
4. Change in hydrodynamics	Change in hydrodynamic	Extreme events	Bigalbal et al. (2018)
		Tidal amplitude	Zhong et al. (2008), Hong and Shen (2012), Ross et al. (2017)
	Modeling data	Modeling system	Boesch (2019), Hood et al. (2021), CBP-Modeling (2023), Zhang et al. (2023)
5. Biochemical and physical flows	Nutrient flows	Nutrient condition	Ator et al. (2020), CP-WIPs (2023), Zhang et al. (2023)
		Animal waste	Kaufman et al. (2021), Zhang et al. (2023)
		Sewage water	Ross et al. (2017), Ator et al. (2020), CBP-Pollution (2023)
		Oxygen conditions	Irby et al. (2018), Frankel et al. (2022)
	Pollutants	Air pollutants	Birch et al. (2011), CBP-AirPollution (2023)
		Metal pollutants	Najjar et al. (2010)
		Agriculture pollutants	Cuker (2020), Leyva Ollivier et al. (2023)
	Materials flow	Sediments	CP-WIPs (2023), Zhang et al. (2023)
1. Societal benefits from the ecosystem	Food provision	Agriculture	Kemp et al. (2005), Phillips and McGee (2016), Walsh et al. (2017), Bilkovic et al. (2019), Cuker (2020)
		Fisheries	Willacker et al. (2020)
	Good and services	Drinking water	IAN-EnvJus (2023)
		Clean air	Birch et al. (2011)
2. Demographic	Population	Population growth	Hood et al. (2021)
		Population structure	Bureau (2023)
		Diversity	CP-Diversity (2023)
	Migration/Immigration	Migration/Immigration	Ruark (2010)
	Housing distribution	Distribution	Goetz et al. (2004), Walsh et al. (2019), Ator et al. (2020)
		Urban population	Goetz et al. (2004), McKendry (2009)
		Rural population	Goetz et al. (2004), McKendry (2009)

(Continued)

TABLE 1 (Continued)

Category	Sub-category	Indicator	References
3. Social wellbeing and health	Health	Food system	Cuker (2020)
		Healthcare system	Rice et al. (2013)
		Mortality	Cuker (2020), Sterling and Platt (2022)
	Public	Wastewater	Tango and Batiuk (2013), CP-WIPs (2023)
		School	Bosch and Pearce (2003)
		Public transport	Garrett and Taylor (1999), Buehler and Pucher (2011, 2012)
		Public access	CP-PublicAccess (2023)
		Walkability	ReportCard_CBW (2020)
		Environmental Justice	IAN-EnvJus (2023)
	Homelessness	Homelessness	Batko et al. (2020), Rufo (2021), Willison (2021)
4. Identity	Sense of identity	Sense of place	McKendry (2009), Ardoin (2014)
		Regional identity	Allen and Schlereth (1990)
		Waterman	Paolisso (2002)
		Sense of self	CP-Stewardship (2023)
		Sense of justice	CP-Stewardship (2023)
	Volunteering	Public participating communities	ReportCard_CBW (2020)
		Public organization	https://www.chesapeakebay.net/action/join
5. Social resilience	Vulnerability	Social vulnerability	ReportCard_CBW (2020)
		Health Vulnerability index	Assari (2018), Cuker (2020), Hardy et al. (2018), IAN-EnvJus (2023), ReportCard_CBW (2020), Rice et al. (2013)
	Education	Environmental literacy	CP-ELIT (2023)
		Students	CP-Student (2023)
		Sustainable schools	CP-SustainableSchools (2023)
1. Security	Job security	Agriculture	Cuker (2020)
		Companies	Cuker (2020)
	Poverty	Poverty	McKendry (2009), Cuker (2020)
		Population	McKendry (2009), Cuker (2020)
	Safety nets	Poverty vulnerability	OECD (2020)
		Safety nets	Worts et al. (2010)
	Minorities	Gender Gap	WEF (2020)
		People of color	Cuker (2020)
2. Infrastructure	Energy supply	Energy sources	eia-state (2023)
		Renewable energy sources	Hirsch (2012)
	Transport	Public transport	Buehler and Pucher (2011, 2012), Garrett and Taylor (1999)
		Roads	CBP-Highway (2009)
		Cars	Garrett and Taylor (1999)
	Access	Airports	Morgan and Owens (2001)
		Ports	CB-Ports (2023)
	Infrastructure	Report Cards	ASCE (2021)
3. Economy wellbeing	Livelihood	Household incomes	ReportCard_CBW (2020)
		Housing affordability	ReportCard_CBW (2020)
		Transportation	Martin and Shaheen (2011)
	Job growth	Jobs	Cuker (2020), ReportCard_CBW (2020)
	Poverty	Quality of life	Worts et al. (2010)

(Continued)

TABLE 1 (Continued)

Category	Sub-category	Indicator	References
4. Industry	Extractive	Agriculture	Cuker (2020)
		Fisheries	CBF-Fisheries (2023)
		Energy industry	eia-state (2023)
		Touristic	Phillips and McGee (2016)
	Non-extractive	Sales and services	McKendry (2009)
		Construction and manufacturing	McKendry (2009)
		Government	McKendry (2009)
		Environmental jobs	Phillips and McGee (2016), CBF-Economy (2023)
5. Dependency		Fisheries	Phillips and McGee (2016)
		Recreational tourism	Phillips and McGee (2016)
		Real State	Hardaway and Byrne (1999)
		Port operation	Maryland Port Administration (2023), PortVirginia (2023)
		Ecological restoration	Allison and Murphy (2017)
	Non-related to coastal resource	Agriculture	McKendry (2009)
		Construction and manufacturing	McKendry (2009)
		Sales and services	McKendry (2009)
		Government	McKendry (2009)
1. Organization	Watershed	Coordination	US EPA (2013)
		Partnership	CBP-Who (2023)
	Bay	Fisheries coordination	MSA (2023)
		Organization	MidAtlantic-Fisheries (2023), MSA (2023)
2. Law and justice	Legislation	EPA	EPA-CBW (2010)
		Agreements	CBP-Who (2023)
		Enforcement	CBF-Mission (2023)
	Justice	Lawsuit	CBF-Courtroom (2023)
		Legal advice	ASMFC-Law (2023)
3. Representation and power	Government	Women	WEF (2020, 2021)
	Management	CBP management	CBP-Partners (2023), CP-Diversity (2023)
		Chesapeake Bay Foundation	CBF-History (2023)
		Fisheries management	MidAtlantic-Fisheries (2023)
4. Legitimacy and accountability	Accountability instruments	Chesapeake Bay Foundation	CBF-History (2023), CBF-Litigate (2023), CBF-Mission (2023), CBP-Who (2023)
		Fisheries management	NOAA-Fisheries (2023)
	Assessment	Chesapeake Progress	USEPA (2017), ChesapeakeProgress (2023)
		Report Cards	ReportCard_UMCES (2023)
	Corruption	Corruption Perception Index	CPI-USA (2021)
		Best Life Data	BestLife (2022)

(Continued)

the highest number of indicators (39), followed by the "Social" domain with 33. Finally, the "Environment" domain has 30 and the "Governance" 27.

Tables 5–8 have the authors' best judgment to evaluate each domain and category (Tables 2, 3) using the information provided by Table 4. Additionally, these tables have the main bridges and barriers toward sustainable development found by the indicators. It is important to note that some of these bridges and barriers can be connected; however, this is not applicable to all cases. Finally, the sustainability of the overall Chesapeake Bay watershed

TABLE 1 (Continued)

Category	Sub-category	Indicator	References
5. Resource Management	Management	TMDL	CBP-TMDL (2023)
		WIP	CP-WIPs (2023)
		Chesapeake Bay Stewardship Fund	NFWF-CBWF (2023), NFWF-INSR (2023)
		Chesapeake Decision tool	ChesapeakeDecisions (2023)
		Goal Implementation Team	CBP-GIT1 (2023)
		Oyster Alliance	OysterAlliance (2023)
	Accountability	Chesapeake Bay Foundation	CBF-History (2023), CBP-Who (2023)
	Communication	Report Cards	ReportCard_UMCES (2023)

Colors indicate the different domains as follows: environmental (Green), social and cultural (Blue), economy (Orange), and governance (Yellow). The color coding is kept through the documents.

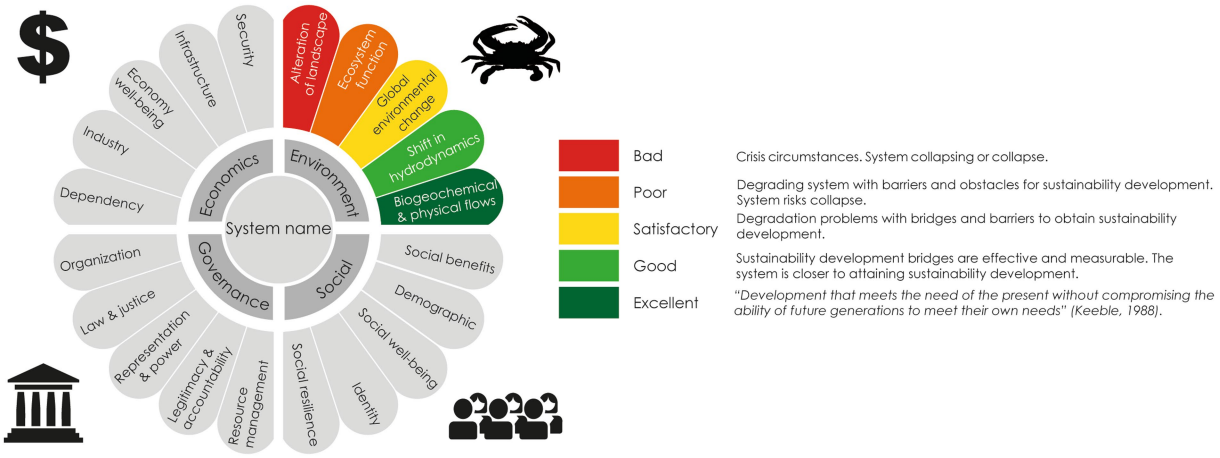

FIGURE 2
Design template representing the overall system, domains, and categories of the Circles of Coastal Sustainability framework applied to the Chesapeake Bay watershed, with its respective score system color palette and example. Additionally, the design includes the proposed global sustainability score system definitions. Adaptation from De Alencar et al. (2020).

socio-ecological system was assessed using the information provided by Tables 5–8 and the proposed global assessment (Figure 2).

The sustainability daisy of the Chesapeake Bay watershed using the Circles of Coastal Sustainability framework and proposed global evaluation is presented in Figure 3. This graphical representation summarizes the socio-ecological evaluation. The "Satisfactory" score is presented in the middle of the figure, which means the overall system has degradation problems with bridges and barriers to obtaining sustainable development. The following chapters of the results elaborate on each domain and category evaluation.

3.1 Environmental

The environmental domain obtained a "Satisfactory" score because the system shows ecological degradation with a human society trying to maintain, restore, and improve it. All the categories obtain the same "Satisfactory" score (Table 5). The "Alteration of Landscape" score was based on increasing land protection, and there are management programs to improve the restoration of the shoreline ecosystems (CP-ProtectedLand, 2023). The main barrier is increased development around the tidal water and in major rivers and increasing armored shorelines around the Bay as a sea level rise (SLR) response (Goetz et al., 2004; Patrick et al., 2016).

The "Ecosystem functions" category score is based on the management projects to improve nutrient filtration, stabilization of shorelines and river edges, and sediment buffers through what the management calls "vital habitats" (CP-VitalHabitats, 2023). Some examples are oyster reefs, SAV restoration, wetland management, and forest buffers. There are also management responses to support animal and plant species (CP-AbundantLife, 2023). Some challenges include habitat degradation and disease of oysters, increased shoreline armoring, decreasing SAV ecosystems, and invasive species endangering endemic species (Jackson et al., 2001; Patrick et al., 2016; CP-InvasiveSpecies, 2023).

The "Global environmental change" score is based on the climate change projections in SLR, increase temperature, and precipitation. The changes in these variables could hinder current management

TABLE 2 Categorical scales to globalize the score for each domain.

Domain	Bad	Poor	Satisfactory	Good	Excellent
Environment	The system has reached beyond a "Breaking point." This occurs due to changes in feedback processes that impart stability and resilience to the ecosystem's configuration (Selkoe et al., 2015). Overall, it is a regime shift, a large-scale, long-lasting, and normally sudden change in the nature, intensity, and/or frequency of ecosystem quality, property to phenomenon (Montefalcone et al., 2011; Borowy, 2013)	The system has ecological discontinuities affecting human development. It has no human intervention trying to improve the critical values going toward the ecosystem's "Breaking point." Ecological discontinuities are defined as sudden changes in any property of an ecological system as a consequence of a smooth and continuous change in an independent variable (Muradian, 2001)	The system has ecological degradation, and human society is trying to maintain, restore, or improve the ecosystem resilience (Muradian, 2001; Olsen, 2003)	The system is transitioning from ecological degradation to an ecological resilience system while maintaining resources used for human necessities. A resilient ecosystem is defined as the capacity of an ecosystem to tolerate disturbance without crossing a threshold into a different regime. Resilience imparts regime stability without precluding change, flexibility, and/or adaptation (Selkoe et al., 2015)	The system has a resilient ecosystem that meets the needs of the present generation without compromising the ability of future generations to meet their needs (Keeble, 1988)
Social	The system does not consider the individual's or general society's wellbeing. The culture is used as an instrument of control (Triandis, 2001; Birkeland, 2008; Soini and Birkeland, 2014). Additionally, social conditions bring environmental destruction (Mensah, 2019)	The system recognizes individual's or general society's wellbeing. However, there are no actions to address social inequity (Triandis, 2001; Vallance et al., 2011; Soini and Birkeland, 2014; Mensah, 2019). Additionally, social conditions bring environmental destruction or/and increase of inequality (Mensah, 2019)	The system recognized the local culture and the need for development as an instrument to address social inequity, considering the diversity of perceptions, values, and lifestyles. Society is concerned with the changes in behavior through education and social cohesion. Meanwhile, protecting individual and cultural identities (Triandis, 2001; Kong, 2009; Amberg, 2010; Vallance et al., 2011Soini and Birkeland, 2014). The social conditions aim to address inequity within their existing environmental and economic resource base (Mensah, 2019)	The system is transitioning to an equitable society and cultural vitality. Cultural vitality provides a sense of belonging, shared meaning, recognition of identity, respect for society, creativity, and education (Amberg, 2010). The social conditions aim to address inequity within their existing environmental and economic resource base (Mensah, 2019)	The system is an equitable society with a cultural vitality founded on sustainable development. This society actively supports the capacity of current and future generations to create healthy and livable communities (McKenzie, 2004; Soini and Birkeland, 2014). The social conditions aim for a healthy environment and economy (Mensah, 2019)
Economics	The system heavily depends on one or several resources that have been inefficiently overexploited, degrading the environment or social system (Anand and Sen, 2000; Goerner et al., 2009)	The system is obsessed with Gross Domestic Product growth, efficiency, and maximizing profit for owners regardless of the cost of overexploitation of resources. It can also be a system that obsesses with environmental health and lacks industrial development for the current or future generation (Foy, 1990; Goerner et al., 2009)	The system economy is efficient (the network capacity to perform in a sufficiently organized and efficient manner) or/and resilience (diversity of actions that can be used to develop the economy). However, there are no actions to reach economic vitality, which considers the limitation of natural resources and social wellbeing	The system economy is becoming more focused on a balance between efficiency and resilience, working toward economic vitality. This economic vitality considers the natural resource limitation and social wellbeing (Goerner et al., 2009; Mensah, 2019)	The system economy balances efficiency and resilience, with the optimal balance situated slightly toward the resilience side. Economic vitality considers the limitations of current and future generations' natural resources and social wellbeing (Goerner et al., 2009; Mensah, 2019)

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TABLE 2 (Continued)

Domain	Bad	Poor	Satisfactory	Good	Excellent
Governance	The system cannot effectively implement critical reforms and political measures (Stiftung, 2011)	The system governance is invested in the consumption/exploitation of resources without considering the future generation. It is only held accountable by specific individuals and collective actors (Stiftung, 2011)	The system starts with higher and local government reforms and policy-shaping to address the country's needs in environmental, economic, and social sustainability (Stiftung, 2011; Williams et al., 2020). Governance encompasses the actions of a wide range of actors, including the state, civil society, and the private sector (Ojwang et al., 2017)	The system's government reforms and policy-shaping have improved and transitioned to governance effectiveness (Stiftung, 2011; Williams et al., 2020). Governance effectiveness is defined as the successful decision-making process by configuring state, private, and non-governmental organizations and institutional arrangements to achieve desirable outcomes for the environment, social, and economic (Ojwang et al., 2017; Williams et al., 2020)	Governance effectiveness has achieved desirable outcomes for the environment, social, and economic for the present generation and future generations (Adger et al., 2003; Ojwang et al., 2017; Williams et al., 2020)

efforts to preserve ecosystem resilience (Du et al., 2018). Nevertheless, there are climate change and coastal management adaptations, according to current information in the Maryland Coastal Adaptation Report Card 2021 (RC-CoastalAdaptation, 2023). The main barriers identified in the report are inadequate data, static goals, and lack of funding.

The "Shift in hydrodynamic" category score is based on climate change that increases extreme events and tidal amplitude (Zhong et al., 2008; Hong and Shen, 2012; Ross et al., 2017; Bigalbal et al., 2018). However, management efforts have developed computer models to predict these changes and develop management responses to decrease the impact of this event on the ecosystem's resilience (Hood et al., 2021).

Finally, the "Biochemical and physical flows" category score is based on reducing nitrogen, phosphorus, and suspended sediments (Ator et al., 2020; Frankel et al., 2022; Zhang et al., 2023). The reduction has decreased hypoxia by 50–90 days (Frankel et al., 2022). The potential impact of climate change on the bay will be significantly smaller if the nutrient reductions continue improving (Irby et al., 2018). Therefore, more reductions are needed to accomplish ecosystem resilience and achieve a "Good" score. The main barrier is urban runoff due to the increase in land development in the last decade and the increase in future predictions (Goetz et al., 2004; Ator et al., 2020; Zhang et al., 2023).

3.2 Social

The social domain obtained the lowest score in the system. The "Poor" score was given because the social conditions bring environment destruction and increase inequity (Table 6). The same score for "Social benefits from ecosystem" is based on the degradation of natural resources, providing goods and services to the region's society due to the state of decline of the environment (Phillips and McGee, 2016). Some examples are the fish advisory consumption due to mercury, nitrate levels in drinking water wells, and the cost of illness of vulnerable groups due to fine particle pollution in the air (Birch et al., 2011; Cuker, 2020; Willacker et al., 2020; IAN-EnvJus, 2023).

The "Demographic" category "Poor" score was given because there is no regulation on population growth considered necessary for the economic model (Ruark, 2010). Additionally, the distribution is primarily sprawling, with no development regulation to decrease environmental degradation (Goetz et al., 2004; Ator et al., 2020). Finally, the "Identity" category obtained the same score because residents feel more connected by the political boundaries than the ecological ones, with little community or individual action to improve the Bay's environmental health (Ardoin, 2014; CP-Stewardship, 2023).

On the other hand, the "Satisfactory" score for "Social well-being" is based on the management efforts that have improved the public access for boating, swimming, and fishing; the walkability to a green area; and there is a proposal from the report cards to implement indicators to measure environmental justice in the region (ReportCard_CBW, 2020; CP-PublicAccess, 2023; IAN-EnvJus, 2023). Additionally, due to the TMDL, there is an increase in wastewater regulations (Tango and Batiuk, 2013), and homelessness has decreased on average on the study site from 2009 to 2019 (Batko et al., 2020). The main barrier is obesity mortality due to the high-calorie and

TABLE 3 Categorical scales to globalize the score for each category.

Category	Bad	Poor	Satisfactory	Good	Excellent
Alteration of landscape	The landscape alteration reaches the "breaking point," which has changed the resilience of the ecosystem configuration	The landscape alteration shows ecosystem degradation and is reaching the "breaking point." There are no actions to decrease the alteration of the landscape	The alteration of the landscape has increased ecosystem degradation. However, projects are trying to maintain, restore, or improve the landscape	The landscape alteration is based on ecosystem resilience and the needs of the current and future generations	The landscape alteration does not decrease the ecosystem resilience for the current and future generations
Ecosystem function	The ecosystem has lost most of its functions and services	The ecosystem is losing its ecosystem function and services, and there are no actions to improve its resilience	The ecosystem functions have degraded. There are efforts to increase ecosystem resilience to keep the ecosystem services	The ecosystem function is valuable and highly protected to increase ecosystem resilience and fulfill human life	The ecosystem functions sustain natural resilience and are useful to for the current and future generations
Global environmental change	Global environmental change has impacted ecosystem resilience	Global environmental change has caused ecosystem degradation. There are no climate change adaptations for future generation protection	Global environmental change has caused ecosystem degradation. There are projects to improve ecosystem resilience to decrease the effects of global climate change. Additionally, climate change responses and adaptations protect the region's residents	The projects have improve ecosystem resilience to decrease the effects of global climate change. Additionally, climate change responses and adaptation implementations protect the region's residents	The region mitigates global climate change. Global climate change does not affect the system for the current and future generations
Shift in hydrodynamics	The hydrodynamic shift has reached the "breaking point", changing the hydrodynamic regime	The shift in hydrodynamics has caused ecosystem degradation. There is no action to decrease the impacts on ecosystem resilience	The shift in hydrodynamics has caused ecosystem degradation. There is a commitment to decrease the impact	The ecosystem resilience has increased and has some capacity to resist the disturbance of hydrodynamic shift	The resilience of the ecosystem can resist the disturbance of shifts in hydrodynamics for current and future generations
Biogeochemical and physical flows	The biochemical and physical flow has a regime shift	The biogeochemical and physical flows have changed and caused ecosystem degradation. There are no actions to decrease the impacts on ecosystem resilience	The biogeochemical and physical flows have changed and caused ecosystem degradation. There are actions to decrease the impact and increase ecosystem resilience	The ecosystem resilience has increased and has some capacity to resist the disturbance of biochemical and physical flow changes	The resilience of the ecosystem can resist the disturbance of biochemical and physical flow changes for the current and future generations
Societal benefits from the ecosystem	The system's residents do not have the societal benefits from the ecosystem because the natural resources are degraded	The societal benefits from the ecosystem are degrading for most of the residents	The societal benefits from the ecosystem are degrading for some residents There are management plans to improve the social benefits for all residents	Most of the residents have societal benefits from the ecosystem	The system has societal benefits for all the residents, current and future generations
Demographic	The system has reached the carrying capacity (Hilborn et al., 1995)	The population is growing without regulation or control and approaching the ecosystem's carrying capacity	The system is close to the carrying capacity. There are regulations and controls about finite resources	The ecological footprint is increasing. An ecological footprint measures how much productive land and water an individual, a city, a country, or humanity requires to produce the resources it consumes and absorb the waste it generates using prevailing technology (Beatley and Wheeler, 2014)	There is a balance between the biological capacity and the human population's resource demands for current and future generations

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TABLE 3 (Continued)

Category	Bad	Poor	Satisfactory	Good	Excellent
Social wellbeing	Social wellbeing is not considered for the people living in the system	Social wellbeing is based on certain cultures, physical characteristics, or socioeconomic status	The socio-ecological system has recognized and taken action to improve most residents' social wellbeing	The system has social wellbeing for all the residents	The system has social wellbeing for all the residents, current and future generations
Identity	There is no sense of identity linked to the ecosystem	Only a few have a sense of identity linked to the environment. The population's effort to maintain, restore, and improve the ecosystem is low	Most residents have a sense of identity linked to the environment. Some individuals and communities are taking action to improve the ecosystem's health	There is a sense of identity linked to the environment, which develops awareness about ecosystem health. An individual and communal effort exists to maintain, restore, and improve the ecosystem	The sense of identity linked to the environment has developed local community management, improving ecosystem health for the current and future generations
Social resilience	Society is vulnerable to ecosystem degradation. There is no education, awareness, or societal cooperation against hazards	Some social groups are vulnerable to adverse impacts of natural hazards. There is no action (education, awareness, or emergency services) to address the inequity	Some social groups are vulnerable to the adverse impact of natural hazards. There are actions (education, awareness, or emergency services) to address the inequity	The actions to address the inequity have decreased the social groups vulnerable to adverse impacts of natural hazards	Society can cope with adversities, adjust to future challenges, and set the institutions or society that will help toward future crises (Keck and Sakdapolrak, 2013)
Security	There is no economic security for the population living in the system	There is no economic security for most of the population living in the system, or it can only be attained at the expense of environmental resilience or/and social inequality Economic security could be based on certain cultures, physical characteristics, or socio-economic status	The system recognized and took action to improve the economic security of all the residents in the system	Most residents in the system have economic security and are protected from financial instability and vulnerability	The system has economic security and is protected from financial instability and vulnerability for the current and future generations
Infrastructure	There is no infrastructure for economic development or/and the infrastructure is only increasing the degradation of the ecosystem	There is a lack of infrastructure or a poorly maintained one for economic development The current infrastructure affects most of the ecosystem's resilience. There are no actions to improve	The system recognizes the lack of or damaged infrastructure in the systems and takes action to improve it. The infrastructure is not designed to enhance efficiency and resilience of economic vitality	The infrastructure of the systems is designed to enhance the efficiency and resilience of economic vitality	The infrastructure of the systems is designed to enhance the efficiency and resilience of economic vitality for both current and future generations
Economy wellbeing	The system has no economic wellbeing for the residents of the system	Economic wellbeing is based on certain culture, physical characteristics, or socio-economic status. There is no action to improve	Economic wellbeing is based on certain culture, physical characteristics, or socio-economic status. There are actions to address the inequity	The actions to address the inequity have increased the economic wellbeing in the system for most residents	The actions to address the inequity have increased the economic wellbeing in the system for the current and future generations
Industry	The industry has taken the ecosystem's natural capital to the "breaking point" with no efficiency for economic growth	The industry has taken the ecosystem's natural capital to the "breaking point" with little or no efficiency for economic development. There are no actions to improve it	The industry has degraded some natural capital with some efficiency for economic growth. There is action to increase the ecosystem health and social wellbeing considering the economic growth	The industry has high efficiency and resilience. The natural resources and social wellbeing are considered in the economic growth	The industry has high efficiency and resilience. Natural resources and social wellbeing are considered in the economic growth for the current and future generations

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TABLE 3 (Continued)

Category	Bad	Poor	Satisfactory	Good	Excellent
Dependency	There is an economic crisis because the economy completely depends on one (or several) natural capitals that have reached the "breaking point." It can also be a crisis because industries have led to the loss of ecosystem services	Economic growth depends on one or several natural capitals or destructive industries close to reaching the ecosystem's "breaking point." There are no actions to diversify	Economic growth depends on one or several natural capitals close to reaching the ecosystem's "breaking point." There are actions to diversify the economy	There are economic diversifications and opportunities that consider natural capital recovery and industries (Muhamad et al., 2021)	There are economic diversifications and opportunities that consider natural capital recovery and industries for the current and future generations
Organization	There is no organization around the degraded socio-ecological system	There is some organization, but it is not around the socio-ecological system	There is an organization around the socio-ecological region	The organization has increased the health of the socio-ecological region with reforms and policy-shaping	The organization has increased the health of the socio-ecological region with reforms and policy-shaping for the present and future generations
Law and Justice	There are no laws and justice around the socio-ecological system. The lack of law and justice collapses the ecosystem	There are some laws and justice around the socio-ecological system. However, the ecosystem is still degrading due to corruption	There are laws and justice in the socio-ecological system. The ecosystem is recovering in some areas	The socio-ecological system's laws and justice have increased the ecosystem's health	The laws and justice of the socio-ecological system have achieved the desirable outcomes for the environment, social and economic present generation, and future generations
Representation and power	There is no government representation and power, and the socio-ecological system is degraded. Or the representation and power are given to specific individuals without considering the socio-ecological system	The government decisions are beneficial to specific actors. This could be based on race, socioeconomic status, gender, economic or government actors	The government's decision considers the socio-ecological system. Therefore, the decision-making process considers the complexity of environmental health, social equality, and economic development	The power and representations have increased the ecosystem's health, considering the complexity of social equality and economic development	The power and representation in the government achieve environmental health, social equality, and economic development for the current and future generations
Legitimacy and accountability	There is no legitimacy and accountability	Specific actors with authority wield legitimacy and accountability for their benefit	Diverse actors with authority wield legitimacy and accountability to improve environmental health, social equality, and economic development	Diverse actors with authority wield legitimacy and accountability have improved environmental health, social equality, and economic development	Diverse actors with authority wield legitimacy and accountability have improved environmental health, social equality, and economic development for the current and future generations
Resource management	There is no resource management around the socio-ecological system	Resource management has barriers and obstacles to effective management actions	Resource management is trying to attain environmental health, economic development, and social equality	Resource management has effective and measurable (indicators) environmental health, economic development, and social equality	The resource management plan has achieved development that meets the present's needs without compromising the future generation's ability to meet their own needs

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TABLE 4 Data for the assessment of indicators.

Category	Indicator	Data	Score
Alteration of landscape	Land use	Currently, the land is divided into forest (59%), agricultural (28%), industrial uses (<1%), and urban (4%)/suburban development (12%)	"Satisfactory" The alteration of the landscape has increased ecosystem degradation. However, projects are trying to maintain, restore, or improve the landscape
	Protected land	22% of the total land in the region is protected. According to the WIP agreement, this is 69% of the current conservation goal	
	Development	The development in the CBW has been growing close to tidal water and in major rivers with almost 2/3 of the region's residents. The residents are moving to bigger houses outside the city, creating a sprawl. It is estimated an increase in developed land area over the next 30 years of 80% primarily through suburban sprawl, which needs more road infrastructure around the Watershed	
	Armored shorelines	Eight sub-estuaries on the Bay are 50% armored, and 23 more are between 30 and 50% armored. Armoring will probably increase in the coming century due to the rising sea level.	
	SAV	Annual aerial surveys of SAVs have been taken since 1937. In 2014, the CBWA established a goal of increasing 185,000 acres with an interim goal of 130,000 by 2025. In 2022, the aerial survey estimated 76,462 acres. The increase has been linked to reductions of *in situ* nutrients, wastewater-treatment effluent N, and total suspended solids	
	Bivalve tray	Three of the 10 selected tributaries have been restored, and 11 have been added. Currently, the oyster abundance in the Bay has been reduced to ~1% of the 19th-century levels	
Ecosystem function	Oyster	Before the 19th century, the oyster population could filter a water volume equivalent to the upper and middle Bay in ~3.6 days. In the present, this has changed up to a 100 days. There are management efforts to increase Oysters. However, oyster restoration is still challenging due to reef habitat degradation and diseases. There is no information about the current filtration time	"Satisfactory" The ecosystem functions have degraded. There are efforts to increase ecosystem resilience to keep the ecosystem services
	SAV	The SAV is a natural nutrient and sediment buffer, nursery and refuge for diverse wildlife, and natural shoreline protection. Management efforts are being made to restore this vital habitat	
	Wetland	Wetland restoration is an important mitigation strategy for improving water quality and building climate resiliency. There are 16,000 acres of wetland created or restored, representing 18.8% achievement of the 85,000-acre goal	
	Forest buffer	The forest buffer has been restored to 230.5 miles in 2021. To protect the edges of the river, 70% must be protected. To achieve the WIPIII goals, over 3,000 miles of forest must be added annually between 2022 and 2025	
	Abundance of biodiversity	The region supports thousands of species from its Watershed to the Bay. The Chesapeake Program has several indicators to keep a record of the protection of wildlife and restoration of habitats to support the balance of the ecosystem	
	Invasive species	There are ~200 invasive species that may live in the region. This has put more than 40% of the endemic species at risk of further decline. There are management plans to reduce this number, and some of them consider the recreational value	
	Fish migration routes	The recent period of 2020–2021 had a decrease in miles open. However, in 2018–2019, it obtained 1,318.73, reaching the 2014 CBWA. Currently, the project is very active in reaching the biennial target of 132 miles	

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TABLE 4 (Continued)

Category	Indicator	Data	Score
Global environmental change	Sea Level Rise (SLR)	The SLR on the system is projected to increase by 0.7-1.6 m/century. The rising sea level can increase coastal flooding, affecting the shoreline habitats and flow exchange	"Satisfactory" Global environmental change has caused ecosystem degradation. There are projects to improve ecosystem resilience to decrease the effects of global climate change. Additionally, climate change responses and adaptations protect the region's residents
	Increase in temperature	Increase in temperature (+4.5°C) by the end of the 21st century. The warming of the Bay can change the biochemical concentration, impacting the ecosystem. One example is the oxygen concentration impacting the oxygen flux in the estuary	
	Precipitation	Increase in precipitation of 10% by the end of the 21st century. The changes in precipitation are projected to deliver higher winter and spring flow. This increases the nutrient and sediment input into the Bay	
	Monitor process	There has been recent progress toward the Climate Monitoring and Assessment outcome. Climate change indicators are prioritized to focus the management efforts information. Continued monitoring, modeling, and assessment are important for measuring progress, capturing recovery trajectory, and understanding the underlying mechanism	
	Climate change adaptation	Climate Resiliency Workgroup collaborates with other Goal Implementation Teams and communities to support the development and funding of new restoration projects	
	Coastal Adaptation	Maryland is the leader in coastal adaptation for climate change. The Maryland report cards of 2021 gave a score of 70/100. This is because there is a significant investment in flooding and socioeconomic adaptation. The main barriers presented in the report card are inadequate data, updated goals, and lack of funding	
Shift in hydrodynamic	Extreme events	Climate change is affecting the hydrodynamics of the Bay by increasing the wave height and causing extreme waves, such as hurricanes and tropical storms	"Satisfactory" The shift in hydrodynamics has caused ecosystem degradation. There is a commitment to decrease the impact
	Tidal amplitude	The prediction of tidal amplitude is 0.75 cm/century. With an increase in SLR of 1 m, the tidal amplitude will increase by 15–20% on the upper Bay. This can increase the issues mentioned on the SLR indicator	
	Modeling system	The modeling system developed to apply and assess the hydrodynamic is one of the main tools used to develop management plans. Past and future advancements in the scientific understanding of the Chesapeake Bay and its watershed are valuable resources that can inform the restoration of other ecosystems	

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TABLE 4 (Continued)

Category	Indicator	Data	Score
Biochemical and physical flows	Nutrient condition	77% of the nitrogen load reductions between 2020 and 2021 came from agriculture. 73% of phosphorus came from improvements to treatment technologies in the wastewater sector	"Satisfactory" The biogeochemical and physical flows have changed and caused ecosystem degradation. There are actions to decrease the impact and increase ecosystem resilience
	Animal waste	The concentrated animal feeding operation waste accounts for 17% of nitrogen and 26% of phosphorus delivered to the Bay and is treated as a nonpoint pollution source. The Best Management Practices is the management tool to manage this pollution	
	Sewage water	17% of nitrogen comes from stormwater running off parking lots, roofs, and other hard surfaces. 16% of discharges from wastewater treatment plants and factories are released directly. 4% drains fields of septic systems contaminated groundwater. There is little reduction in loads from urban runoff, mainly because land development has continued to expand	
	Oxygen conditions	The management efforts in nutrient reduction have made the CB more resilient to warming atmospheric temperatures and higher discharges years by preventing additional hypoxia from developing. 50–90 days of additional hypoxia would have happened if the reduction had not occurred	
	Air pollutants	CO2 levels will increase continually throughout the 21st century. 19% of air pollution comes from power plants and motor vehicles, which fall back to the ground and are washed into the waterways by rain	
	Metal pollutants	Trace metal distribution in the Chesapeake Bay is dominated by the input from the Susquehanna River. Other inputs are shore erosion, industry, atmospheric deposition, and municipal wastewater. Baltimore Harbor and the Hampton Roads complex account for most of the industrial metal output	
	Agriculture pollutants	The need for food security increases the use of fertilization and pesticides. The main non-federally regulated nutrient runoff sources are agricultural sources (fertilizers). In 2016, pesticides contaminated 47% of domestically produced food in the USA	
	Sediments	The sediment load reduction from 2020 to 2021 is above the average annual reduction from 2009 through 2020. However, there is a lack of process in the context of the TMDL	
Societal benefits from the ecosystem	Agriculture	The Watershed offers food security due to agriculture and the food industry. However, the benefits are degrading with the increase in pollution. Additionally, one of the primary sources of this pollution comes from agriculture. There is extensive use of pesticides and artificial fertilizers for animal feed	"Poor" The societal benefits from the ecosystem are degrading for most of the residents
	Fisheries	29% of fish around the Bay and watershed exceed the EPA mercury criteria. The data show that mercury contamination is widespread in the watershed, and concentrations in fish are frequently high enough to risk human health, wildlife, and other fish	
	Drinking water	Recent studies found that 21–60% of the drinking water wells tested in Pennsylvania's lower Susquehanna River Basin had nitrate levels exceeding public drinking water standards	
	Clean air	The damage cost of human morbidity and mortality in the Chesapeake Bay is 3.9 billion dollars	

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TABLE 4 (Continued)

Category	Indicator	Data	Score
Demographic	Population growth	Between 2010 and 2025, the population increased from 17.3 million to 19.4 million. 12% increase. There is no regulation on population growth because it is seen as a necessity for the economic model	"Poor" The population is growing without regulation or control and approaching the ecosystem's carrying capacity
	Population structure	According to the 2020 USA Census, the Northeast has the largest adult population at 77.5% and the lowest young population at 22.5%	
	Diversity	In the Watershed, 35% identify as people of color. This considers mainly people who do not consider themselves white, such as Native, Asian, black, Hispanic, or others	
	Migration/Immigration	Immigration is responsible for 66% of the population growth in the region	
	Distribution	Two-thirds of the population in the region live close to tidal water in major rivers or 2 km near the shoreline. It is estimated that 80% of the development will occur from 2000 to 2030, primarily through exurban sprawl (unconnected, spread-out, and low-density residential subdivisions and commercial areas outside cities and town centers)	
	Urban population	The urban population in the region has concentrated around the southwest of the mouth's Bay, mostly Washington DC	
	Rural population	The eastern shore has most of the rural population. Sprawl is a main issue in rural areas, mainly for tourism, second homes, and resort communities	
Social wellbeing	Food system	The present food system is built on making profits by focusing the standard American diet on animal-based food, refined carbohydrates, and a few fiber-rich fruits and vegetables 11.5% of Bay residents experience food insecurity, which falls most heavily on people of color and children	"Satisfactory" and "Poor" The socio-ecological system has recognized and taken action to improve most residents' social wellbeing. On the other hand, social wellbeing is based on certain cultures, physical characteristics, or socio-economic status for most residents in the country
	Health-care system	The healthcare system does not contribute to the health of US residents. The factors related include parents' education, poverty, family upbringing, language barriers, neighborhood effect, racial segregation, safety, workforce issues, social capital, and host environmental factors such as clean air and water	
	Mortality	There is a rise in mortality due to a lack of communal support in all life cycle stages (prenatal care, maternal leave, preschool care, elementary and high school education, education beyond high school, and substantial time off for noneconomic activities). There is also a rise in mortality due to obesity: The corn, soy, wheat, and sugar subsidies make high-calorie and low-nutrient foods cheaper, dominating the standard American Diet	
	Wastewater	Due to the TMDL WIP agreement, there has been an increase in the regulation of wastewater discharge facilities, such as stormwater, confined animal feeding operation discharges, and federally regulated wastewater	
	School	School systems across the USA struggle to build new schools and renovate aging ones	
	Public transport	The public transport in the CBW is concentrated in Washington, DC. In the USA, there is an idea that public transport is only for work commuters and transit dependents	
	Public access	In 2021, 237 public access sites have opened around the region. This is 79% of the current 2025 goal	
	Walkability	The indicator measures how many people can walk to a park in 10 min, with a score of 62%	
	Environmental Justice	There is a proposal to implement indicators to measure environmental justice in the region	
	Homelessness	There is an increase in homelessness in metropolitan areas. However, on average, outside of the West Coast metropolitan cities and New York City, homelessness has declined by 10% from 2009 to 2019 in the USA	

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TABLE 4 (Continued)

Category	Indicator	Data	Score
Identity	Sense of place	People feel more connected by the political boundaries than the ecological ones, mostly because of the difference in government dependency. The people who identify their identity in the ecosystem work professionally in the system	"Poor" Only a few have a sense of identity linked to the environment. The population's effort to maintain, restore, and improve the ecosystem is low
	Regional identity	Regional identity is strongly marked by a polarization mentality of "rural versus urban." The Eastern Shore regional identity has been defined by isolation; outrage is perceived from outside interference	
	Waterman	For centuries, commercial fishermen of the Chesapeake Bay (Waterman) have supported their families and communities and provided consumers with oyster, crab, shad, sturgeon, and herring. However, they do not feel the fishery regulation should apply to them due to a gap between scientific and traditional ecological knowledge	
	Sense of self	The personal actions to improve the Bay's health have a score of 38%	
	Sense of justice	The advocating for public engagement in local and regional activities scored 19% in the stewardship indicator	
	Public participating communities	According to the stewardship indicator, the portion of the public participating in communities is 23%	
	Public organization	The resident can connect to different organizations through the Chesapeake Bay Program, Chesapeake Foundation, or others	
Social resilience	Social vulnerability	60% of the population is prepared for a hazardous event	"Satisfactory" Some social groups are vulnerable to the adverse impact of natural hazards. There are actions (education, awareness, or emergency services) to address inequity
	Health Vulnerability index	The CBW obtained a score of 58%. The index identifies places where people are more vulnerable to health-related and flooding-related risks. The most vulnerable communities are related to neighborhoods with race-based housing discrimination, low-income communities, children, and the elderly	
	Environmental literacy	The knowledge and skills needed to act responsibly to protect and restore their local watershed. The results were 27% "well prepared," 52% "somewhat prepared," and 22% "not prepared"	
	Students	"Meaningful Watershed Education Experience." There has been no progress in these indicators since 2017. However, there has been at least 35% preparedness	
	Sustainable schools	In 2021, 14% of the 597 schools in the Watershed were certified sustainable. This is a 6% decrease in sustainable schools from 2019	
Security	Agriculture	Approximately 58% of workers come from Hispanic countries. Foreign workers are paid between 2 and 33% less than the average local worker	"Poor" There is no economic security for most of the population living in the system, or it can only be attained at the expense of environmental resilience or/and social inequality Economic security could be based on certain cultures, physical characteristics, or socio-economic status
	Companies	From 2005 to 2018, the number of part-time workers increased from 20 to 50%. Most grocery stores hire part-time workers to avoid paying additional benefits	
		Part-time workers need multiple jobs to have economic security	
	Poverty	The poverty wage is considered earning less than 35,000/year income	
	Population	The poverty population in the CBW is 13, and 19% for children	
	Poverty vulnerability	In the USA, 18% of the population lives in relative poverty. The population at risk of falling into poverty (forgo 3 months" salary) is 37%	
	Safety nets	There are no safety nets to protect vulnerable citizens falling into poverty. A decade is needed to recover from poverty	
	Gender Gap	The WEF found that the gap between genders in economic sectors is closing, with the economic participation opportunity score of 75.3%, with 100% representing the highest gender equality	
	People of color	Most farm laborers are men of ~39 years old and people of color	

(Continued)

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TABLE 4 (Continued)

Category	Indicator	Data	Score
Infrastructure	Energy sources	The energy infrastructure around the watershed depends on the state. The infrastructure includes petroleum, natural gas, electricity, coal, nuclear, renewable, and alternative fuels	"Satisfactory" The system recognizes the lack of or damaged infrastructure in the systems and takes action to improve it. The infrastructure is not designed to enhance efficiency and resilience of economic vitality
	Renewable energy sources	Conowingo Dam is a Hydroelectric generation station located in Maryland. The dam infrastructure is important for reducing nutrients and sediments	
	Public transport	The great availability of cars and their needed infrastructure reduce the public transport demands. Only a few cities in the country have attempted to make car ownership and use more costly, slower, and less convenient	
	Roads	In the USA, two-thirds of paved impervious surfaces are roads and related infrastructure	
	Cars	80% of the trips nationally are made by car	
	Airports	The main airports to access the CBW are Baltimore-Washington International Airport, Dulles International Airport, Philadelphia International Airport, Ronald Reagan Washington National Airport, and Harrisburg International Airport	
	Ports	There are five major North Atlantic ports and hundreds of smaller ports	
	Report Cards	The American Society of Civil Engineers issues a Report Card with grades about the country's overall infrastructure. The score is "D," which is 50 in a 0–100 score system. In recent years, the government and the private sector have supported additional funding to increase infrastructure maintenance	
Economy wellbeing	Household incomes	Median household income is highest in urban areas and lower in rural areas	"Poor" Economic wellbeing is based on certain culture, physical characteristics, or socio-economic status. There is no action to improve
	Housing affordability	Housing affordability is higher in rural areas and lower in urban areas	
	Transportation	There is no public transportation outside the main urban areas. There is a reliance on cars, which increases expenses and puts disadvantaged citizens who cannot ride a car or afford it	
	Jobs	There has been consistent net job growth across the entire watershed. There is no information available regarding the percentage of job growth that comes from part-time jobs or foreigners	
	Quality of life	Living in poverty without safety nets leads to dangerous jobs and neighborhoods, hazardous house zones, and decreased healthcare quality	
Industry	Agriculture	Minimal economic impact because most workers are not citizens of the country and earn low wages	"Good" The industry has high efficiency and resilience. The natural resources and social wellbeing are considered in the economic growth
	Fisheries	The fishing industry in Chesapeake Bay has been valued to be worth >3 billion dollars per year. In recent years, the most economically important fisheries are based on landed value: Atlantic menhaden, striped bass and blue crab	
	Energy industry	Coal, natural gas, and oil are the region's main resources for energy production	
	Touristic	In 2009, tourists spent $58 billion, which supports 600,000 jobs, contributing $14.9 billion in labor income and $9.4 billion in taxes, mainly in Maryland, Pennsylvania, Virginia, and Washington, DC	
	Sales and services	60% of jobs in the CBW are in sales and services	
	Construction and manufacturing	15% of jobs in the CBW are construction and manufacturing	
	Government	15% of jobs in the CBW are government-related	
	Environmental jobs	There has been a 43% surge in environmental industry jobs in Pennsylvania, Maryland, and Virginia over the last two decades	

(Continued)

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TABLE 4 (Continued)

Category	Indicator	Data	Score
Dependency	Fisheries	The fishing industry is an important part of the region's economy	"Good" There are economic diversifications and opportunities that consider natural capital recovery and industries (Muhamad et al., 2021)
	Recreational tourism	The tourism industry is an important part of the region's economy	
	Real State	Property value is increasing in the region. More people are buying summer houses or retiring to houses near the shoreline	
	Port operation	Port industries are important for the economy of the Maryland and Virginia region	
	Ecological restoration	The Chesapeake Bay is one of the biggest ecosystem restoration sites in terms of timescale and dollars invested	
	Agriculture	The agricultural earnings in 2003 were 8%	
	Construction and manufacturing	The earnings from construction and manufacturing in 2003 were 30%	
	Sales and services	The earnings from sales and services in 2003 was 40%	
	Government	The earnings from the government in 2003 were 22%	
Organization	Coordination	The EPA, federal government and state agencies, nonprofit organizations, and academic institutions coordinated the restoration of the Chesapeake Bay Watershed through the CBP	"Excellent" The organization has increased the health of the socio-ecological region with reforms and policy-shaping for the present and future generations
	Partnership	The Chesapeake Bay Program is a partnership that led and directed the region's restoration. The partnership includes 19 federal agencies, 40 state agencies and programs in several states, ~1,800 local governments, 20 academic institutions, and 60 non-governmental organizations. There are also businesses, nonprofits, and advocacy groups	
	Fisheries Coordination	The Magnuson–Stevens Fishery Conservation and the Management Reauthorization Act is the primary law governing marine fisheries management in the USA's federal waters	
	Organization	Overall, the MAFMC leads the governance of the management of fisheries. Meanwhile, the Atlantic State Marine Fisheries Commission's (ASFMC) main objective is to develop sustainable fish management plans on the Atlantic Coast	
Law and Justice	Environmental Protection Agency	Environmental Protection Agency settlement mandates reasonable assurances, consequences, offsets, certain dates, and tracking	"Good" The socio-ecological system's laws and justice have increased the ecosystem's health
	Agreements	The CBP has gathered input from a diversity of actors and institutions to develop the CBWA. This document is an agreement of how each jurisdiction partners with the local government to achieve and maintain water quality standards	
	Enforcement	The CBF is an organization that protects the Bay by pressuring the government to enforce laws and regulations to reduce pollution and restore vital natural habitats	
	Lawsuit	CBF and the co-plaintiff settled a lawsuit with the EPA. Pennsylvania and New York have not met the CBWA	
	Legal advice	The ASFMC has a Law Enforcement Committee, which meets twice a year to propose legal advice and guidance on management practices. The main members are represented by the Commission's participating states and the District of Columbia, members of NOAA Fisheries Service, the USA Coast Guard, and the USA Fish and Wildlife Service	

(Continued)

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TABLE 4 (Continued)

Category	Indicator	Data	Score
Representation and power	Women	The USA has increased political roles for women. According to the WEF, 2021 ranking, the USA obtained 37/156. The best is 1/number of countries. There has never been a female president	"Satisfactory" The government's decision considers the socio-ecological system. Therefore, the decision-making process considers the complexity of environmental health, social equality, and economic development
	Chesapeake Bay Program management	The CBP includes government representatives, academic institutions, and non-governmental organizations	
		The 15% of people working in the partnership identify as people of color. From this percentage, 7.7 work in leadership positions. The CBP has decided to place an emphasis on expanding racial and ethnic diversity within the partnership. The main goal is to represent the communities that are impacted by environmental injustice. By increasing inclusion, all people in the watershed can share a main goal to improve the ecosystem health of the region	
	Chesapeake Bay Foundation	The CBF represents the private-sector voice	
	Fisheries management	In the MAFMC council, there are 21 voting members and four non-voting members. Seven members represent the fish and wildlife agencies, and 13 represent private citizens with knowledge about the fishing sector or marine conservation. The four non-voting members represent organizations	
Legitimacy and accountability	Chesapeake Bay Foundation	The CBF is the main organization used as an accountability instrument for the restoration plans. Overall, the advocation of this foundation has helped with the effectiveness of restoration implementation plans. Their political involvement has stopped legislation and regulations that would dramatically set back efforts to restore the CBW. Additionally, the litigation department uses legal actions to hold accountable those who violate laws, define and drive the plans, and deliver their restoration progress query	"Satisfactory" Diverse actors with authority wield legitimacy and accountability to improve environmental health, social equality, and economic development
	Fisheries management	The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act takes accountability measures to prevent and end overfishing. The accountability measures are size limits, seasonal closures, trip limits, gear restrictions, or a combination of the three. There was no information in the literature about the consequences of breaking the measures	
	Chesapeake Progress	ChesapeakeProgress helps track the Chesapeake Bay Program progress with available, up-to-date, and accessible data on more than two dozen indicators of environmental health, restoration, and stewardship	
	Report Cards	The University of Maryland Center for Environmental Science Chesapeake Bay Environmental report cards synthesize data from scientists and volunteers to convert it into an image-rich format that is easily accessible to a broad audience. The report cards provide a transparent, timely, and geographically detailed assessment of CB Watershed health, including traditional ecosystem and social, economic, and cultural indicators. Overall, the CB watershed scored 64% in 2021	
	Corruption Perception Index	The USA is only the 25th least corrupt country, with corruption steadily increasing	
	Best Life Data	Number of public corruption convictions per 10,000 residents, reported violations by medical providers between 2020, states with Anti-Corruption Measure for Public Officials, and State Integrity Score. Between the state of the watershed, the mean corruption is 10.02/100, and the standard deviation is 18.25/100. Delaware obtained the maximum value and New York the minimum, 46.45/100 and 0.05/100, respectively	

(Continued)

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TABLE 4 (Continued)

Category	Indicator	Data	Score
Resource Management	TMDL	Total Maximum Daily Load is a federal "pollution diet" to restore water quality	"Good" Resource management has effective and measurable (indicators) environmental health, economic development, and social equality
	WIP	The WIP is a document that includes details and specific steps each jurisdiction will take to meet the goals of the TMDL by 2025	
	Chesapeake Bay Stewardship Fund	This is a project from the EPA, CBP, and NFWF. The main objective is to invest in and support networking and information sharing between partners	
	Chesapeake Decision tool	This tool promotes transparency and guides the CBP's GIT and Management Board members to explain how the outcomes will be accomplished and how the progress will be monitored, assessed, and reported	
	GIT	The Sustainable Fisheries Goal Implementation Team (GIT) consists of state fisheries managers led by the director of the NOAA CB Office. This group collaborates to facilitate the management of key species like the blue crab and oyster while also considering fish habitat and forage of menhaden, striped bass, and alosines	
	Oyster Alliance	The Chesapeake Oyster Alliance is committed to adding 10 billion oysters to the Bay by 2025	
	Chesapeake Bay Foundation	Chesapeake Bay Foundation organization pressures several levels of the government to achieve the management restoration projects	
	Report Cards	The Report Cards are part of the scientific communication management tool, as they provide ecosystem, economic, social, and cultural indicators that help the stakeholders and general public understand the system's current state	

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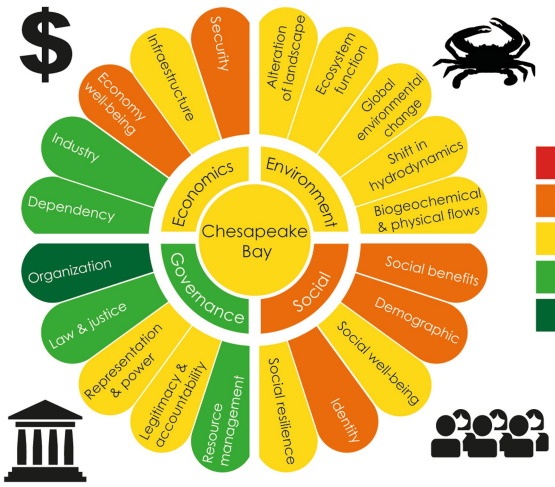

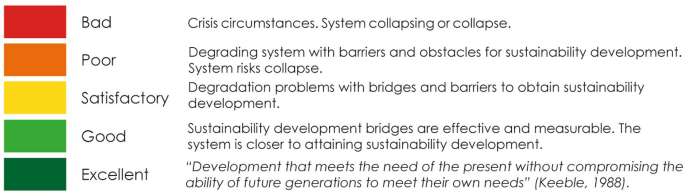

FIGURE 3
Chesapeake Bay watershed sustainability daisy.

low-nutrient food dominated by the Standard American Diet (SAD) (Cuker, 2020). The burden of an unhealthy diet falls mainly on low-income individuals in the region (Cuker, 2020). The added "Poor" score is a result of the evaluation of "Social well-being" indicators in the entire country. The "Satisfactory" score was left because the evaluation is on the region. In the context of the entire country, the main barriers are the current rise of mortality in the country due to a lack of communal support and obesity (Sterling and Platt, 2022). Communal support refers to prenatal care, maternal leave, preschool care, elementary and high school education, education beyond high school, and substantial time off for non-economic activities (Sterling and Platt, 2022). Additionally, a review of the healthcare system found that the system is not the main contributor to people's health in the country, and the main contribution is more related to social determinants (Rice et al., 2013). More research about these regional barriers is necessary to assess its sustainability.

The "Satisfactory" was also given to "Social resilience" because more than half the population is prepared for a hazardous event and have the environment literacy needed to act responsibly to protect and restore their local watershed (ReportCard_CBW, 2020; CP-ELIT, 2023). The main barriers are the vulnerable communities related to neighborhoods with race-based housing discrimination, low-income communities, children, and the elderly (Rice et al., 2013; ReportCard_CBW, 2020).

3.3 Economic

The economic domain obtained a "Satisfactory" score. This score is based on the efficient and resilient economy of the system. However, there are barriers and obstacles to economic vitality, which considers the limitation of natural resources and social wellbeing (Table 7).

The "Security" category "Poor" score is based on the high proportion of foreign workers in the region working in agriculture and an increase of part-time workers of almost 30% in larger companies that want to avoid paying additional benefits (Cuker, 2020). The 13% of the population in the region is in poverty (McKendry, 2009; Cuker, 2020), and after losing 3 months' salary, there is a 37% risk of falling into poverty in the country (OECD, 2020). There are no economic safety nets to protect the vulnerable from falling into poverty, and a decade is needed to recover (Worts et al., 2010). However, there are some bridges toward sustainability, such as a low-poverty population and a decrease in the gender gap in the economic sectors (McKendry, 2009; Cuker, 2020; WEF, 2020).

The category "Economy well-being" also obtained a "Poor" score. This score is attributed to the difference in urban and rural areas. Urban areas have higher median household incomes, while rural areas have greater house affordability (ReportCard_CBW, 2020). However, since there is no public transportation outside the main urban areas, transportation between the two regions relies on cars (Martin and Shaheen, 2011). This, in turn, increases expenses and has a negative impact on the environment (Martin and Shaheen, 2011; Zhang et al., 2023). On the other hand, while there has been a consistent net growth of jobs across the entire watershed (ReportCard_CBW, 2020), it is important to note that further information is required to determine the number of part-time positions or foreign workers within these employment opportunities.

The "Infrastructure" category "Satisfactory" score is based on the existence of the necessary infrastructure for an efficient and resilient economy, such as energy, roads, airports, and ports (Morgan and Owens, 2001; CBP-Highway, 2009; CB-Ports, 2023; eia-state, 2023). The barriers are the low availability of public transport (Garrett and Taylor, 1999; Buehler and Pucher, 2011, 2012) and limited maintenance of the existing infrastructure (ASCE, 2021). However, in recent years, the government and private sector have supported additional funding to increase infrastructure maintenance (ASCE, 2021).

Finally, the last categories obtain a "Good" score because there is a balance between economic efficiency and resilience, which, according to Table 2, considers the organization and diversity of the economy. The "Industry" category score is based on the extractive and non-extractive resources. Furthermore, in the last two decades, there has been a significant increase in environmental industry jobs, which is a positive development for the environmental resilience of the

TABLE 5 Environment score with the bridges and barriers from each category.

Domain	Score	Category	Score	Bridges	Barriers
Environment	"Satisfactory" The system has ecological degradation, and human society is trying to maintain, restore, or improve the ecosystem resilience	Alteration of landscape	"Satisfactory" The alteration of the landscape has increased ecosystem degradation. However, projects are trying to maintain, restore, or improve the landscape	• Increase in land protection • Increase in SAV restoration • Increase of bivalve tray restoration around tributaries	• Uncontrolled urban and rural development near the shoreline • Uncontrolled suburban sprawl • Increase of armored shorelines as a sea level rise response
		Ecosystem function	"Satisfactory" The ecosystem functions have degraded. There are efforts to increase ecosystem resilience to keep the ecosystem services	• Restoration of habitats that buffer nutrients and sediments • Restoration of habitats that serve as a nursery and refuge for diverse wildlife • Restoration of habitats that improve climate resiliency • Record of abundance biodiversity in the region • Open fish mitigation routes	• Restoration plans fail or lag due to habitat degradation and diseases
		Global environmental change	"Satisfactory" Global environmental change has caused ecosystem degradation. There are projects to improve ecosystem resilience to decrease the effects of global climate change. Additionally, climate change responses and adaptations protect the region's residents	• Climate monitoring, modeling, and assessment to prioritize management efforts • Climate change adaptations in Maryland • Collaboration and support to develop and fund new climate change adaptation projects	• Increase in flooding affecting shoreline habitat and flow exchange • Temperature increases, changing the biochemical concentrations • An increase in precipitation increases nutrient and sediment input into the Bay • Inadequate data, updated goals, and lack of funding for climate change adaptation
		Shift in hydrodynamic	"Satisfactory" The shift in hydrodynamics has caused ecosystem degradation. There is a commitment to decrease the impact	• Modeling system to apply and assess hydrodynamics to develop management plans	• Increase of extreme events
		Biochemical and physical flows	"Satisfactory" The biogeochemical and physical flows have changed and caused ecosystem degradation. There are actions to decrease the impact and increase ecosystem resilience	• Improvements to treatment technologies in the wastewater sector • Best Management Practice is a management tool to reduce waste from concentrated animal feeding • The nutrient reductions have made the region more resilient to warming atmospheric temperatures and higher discharges • The nutrient reductions have decreased 50–90 days of hypoxia a year	• Increase in urban runoff because of the expansion of land development • Increase of air pollutants from power plants and motor vehicles • Increase of metal pollutants from natural and industrial outputs • Increase the use of pesticides • Lack of progress in sediment load reduction in the last years

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TABLE 6 Social score with the bridges and barriers from each category.

Domain	Score	Category	Score	Bridges	Barriers
Social	"Poor" The system recognizes individual's or general society's wellbeing. However, there are no actions to address social inequity. Additionally, social conditions bring environmental destruction or/and increase in inequality	Societal benefits from the ecosystem	"Poor" The societal benefits from the ecosystem are degrading for most of the residents	• Food security	• The primary source of pollution comes from agriculture • Mercury contamination is widespread in the watershed and fish • One of the major rivers (Susquehanna) shows nitrate levels exceeding public drinking water standards • Health damage, affecting humans, due to air pollution
		Demographics	"Poor" The population is growing without regulation or control and approaching the ecosystem's carrying capacity	• Population growth helps the economic model in the region	• Lack of regulation in population growth • Development occurs close to tidal water in major rivers or shorelines • Development is estimated to increase primarily through exurban sprawl
		Social wellbeing	"Satisfactory"/"Poor" The socio-ecological system has recognized and taken action to improve most residents' social wellbeing. On the other hand, social wellbeing is based on certain cultures, physical characteristics, or socioeconomic status for most residents in the country	• Increase in public access sites in the region • More than half the population in the region can walk to a park in 10 min • There is a proposal to implement indicators to measure environmental justice indicators • Low food insecurity • Increase regulation on wastewater discharge	• Food systems built on profit and increase health problems for residents • There is a rise in mortality around the country due to a lack of communal support in all life cycle stages • Food insecurity falls on vulnerable residents of the region • The healthcare system does not contribute to the health of US residents • There is low school system growth and a lack of maintenance of the current ones in the country
		Identity	"Poor" Only a few have a sense of identity linked to the environment. The population's effort to maintain, restore, and improve the ecosystem is low	• Professionals that work on the system link their identity to the ecosystem • The residents can connect to different organizations through the Chesapeake Bay Program, Chesapeake Foundation, or others	• Traditional commercial fishermen (waterman) do not feel the fisheries regulation should apply to them • People in the region feel more connected by the political boundaries • Less than half of the residents have no sense of responsibility to maintain, restore, and/or improve the ecosystem
		Social resilience	"Satisfactory" Some social groups are vulnerable to the adverse impact of natural hazards. There are actions (education, awareness, or emergency services) to address the inequity	• More than half the population is prepared for hazardous events • 27% of the population is well-prepared, and 52% is somewhat prepared in environmental literacy • 14% of schools in the watershed are certified as sustainable	• Half the population is not prepared for hazardous events • The health-related and flooding risks fall mostly on vulnerable communities • 22% of the population is not prepared for environmental literacy • Half of the students do not have a meaningful watershed education experience

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TABLE 7 Economics score with the bridges and barriers from each category.

Domain	Score	Category	Score	Bridges	Barriers
Economics	"Satisfactory" The system economy is efficient (the network capacity to perform in a sufficiently organized and efficient manner) or/and resilience (diversity of actions that can be used to develop the economy). However, there are no actions to reach economic vitality, which considers the limitation of natural resources and social wellbeing	Security	"Poor" There is no economic security for most of the population living in the system, or it can only be attained at the expense of environmental resilience or/and social inequality Economic security could be based on certain cultures, physical characteristics, or socio-economic status	• The poverty population is low • The gender gap in the economic sectors is decreasing	• Most workers in the region are foreigners or part-timers • Most part-timers need multiple jobs to have economic security • 37% of the population in the USA is at risk of falling into poverty • There are no safety nets to protect vulnerable citizens from falling into poverty • A decade is needed to recover from poverty
		Infrastructure	"Satisfactory" The system recognizes the lack of or damaged infrastructure in the systems and takes action to improve it. The infrastructure is not designed to enhance efficiency and resilience of economic vitality	• The region has the required infrastructure for economic development • The government and the private sector have supported funding to increase infrastructure maintenance in upcoming years • Conowingo Dam infrastructure is important for reducing nutrient and sediment pollution	• Most infrastructure is made to accommodate cars • Limited availability of public transportation • Few cities in the country have attempted to make car ownership use more costly, slower, and less convenient
		Economy wellbeing	"Poor" Economic wellbeing is based on certain culture, physical characteristics, or socio-economic status. There is no action to improve	• Consistent net job growth across the watershed • Median household income is highest in urban areas • Availability of public transport inside main urban areas • House affordability is higher in rural areas	• Lower median household income in rural areas • Public transport is absent outside of main urban areas • Lack of data on the proportion of job growth attributed to part-time or foreign employment • Living in poverty exacerbates adverse outcomes that impact the overall quality of life
		Industry	"Good" The industry has high efficiency and resilience. The natural resources and social wellbeing are considered in the economic growth	• Extractive and non-extractive industries are essential for the region's economy • Increase (60%) environmental industry jobs over the last two decades	• Agriculture has minimal impact on the economy • Lack of clear indicators to assess the development and effectiveness of the environmental industry in mitigating pollution
		Dependency	"Good" There are economic diversifications and opportunities that consider natural capital recovery and industries	• Economic diversification • Medium dependency on natural resources • Ecological restoration is one of the biggest in the country	• Insufficient reliance on environmental jobs to improve natural resource resiliency

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TABLE 8 Governance score with the bridges and barriers from each category.

Domain	Score	Category	Score	Bridges	Barriers
Governance	"Good" The system's government reforms and policy-shaping have improved and transitioned to governance effectiveness. Governance effectiveness is defined as the successful decision-making process by configuring state, private, and non-governmental organizations and institutional arrangements to achieve desirable outcomes for the environment, social, and economic	Organization	"Excellent" The organization has increased the health of the socio-ecological region with reforms and policy-shaping for the present and future generations	• Coordination between the different levels of government, non-profit organizations, and academic institutions • There are partnerships between different levels of government, academic institutions, non-governmental organizations, businesses, non-profits, and advocacy groups • Fisheries organization and coordination for sustainable fish management on the different levels of government	
		Law and Justice	"Good" The socio-ecological system's laws and justice have increased the ecosystem's health	• The EPA settlement mandates reasonable assurances, consequences, offsets, goals, and tracking • Agreements on how each jurisdiction partners with the local government to achieve and maintain water quality • CBF pressures the government to enforce laws and regulations to reduce pollution and restore vital natural habitats • Lawsuits with the EPA for not meeting the agreements • Fisheries organization has a Law Enforcement Committee to propose legal advice and guidance on management practices	• Lack of information on law and justice application
		Representation and power	"Satisfactory" The government's decision considers the socio-ecological system. Therefore, the decision-making process considers the complexity of environmental health, social equality, and economic development	• The CBP includes government representatives, academic institutions, and non-governmental organizations • The CBP has emphasized expanding racial and ethnic diversity within the partnership • The CBF represents the private-sector voice in the region • The fisheries organization has members representing wildlife agencies and private citizens with knowledge about the fishing sector or marine conservation • The USA has increased political roles for women	• The diversity of the CBP partnership is 15% • Some communities are not represented in the management of the region
		Legitimacy and accountability	"Satisfactory" Diverse actors with authority wield legitimacy and accountability to improve environmental health, social equality, and economic development	• The CBF organization is the main accountability tool of the system, helping fund restoration plans and their implementation • The CBF has political influence with the capacity to stop legislation and regulation that would hinder the restoration plans • The fisheries management has the Magnuson–Stevens Fishery Conservation and the Management Reauthorization Act that develops measures to prevent overfishing • CBP has accessible data on more than two dozen indicators of environmental health, restoration, and stewardship • Report cards developed in the region can inform a broad audience (residents, politicians, or stakeholders) about its current state • The corruption in the system is low	• Additional information about the consequences of breaking laws and agreements or corruption in the region is needed
		Resource Management	"Good" Resource management has effective and measurable (indicators) environmental health, economic development, and social equality	• The management has projects and goals to restore water quality in the region • There are investments to increase collaboration in the management • There are tools to promote transparency and guides to monitor, assess, and report the management • There is fisheries management to protect key species • The CBF organization pressures several levels of government to achieve management restoration progress	• The management has not achieved ecosystem resilience

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region (Phillips and McGee, 2016; CBF-Economy, 2023). The "Dependency" category is based on the diverse economic activities. The population does not depend only on coastal resources, although coastal resources are important to the economy (McKendry, 2009; Phillips and McGee, 2016; Maryland Port Administration, 2023; PortVirginia, 2023). To achieve economic vitality, the region could establish an economic foundation that depends on "green jobs" or "sustainable jobs."

3.4 Governance

The governance domain obtained the highest score in the system. The "Good" reflects the local government, higher-level reforms, and policy-shaping projects that have improved the region's environmental health. Enhancing the ecosystem's health leads to improvements in both the economic and social domains. The governance domain has yet to achieve effectiveness in achieving environmental resilience (Table 8) despite substantial progress (Irby et al., 2018; Frankel et al., 2022; ReportCard_UMCES, 2023).

The "Excellent" score was given to the "Organization" category. The score acknowledges the coordination and partnerships between the federal government, state agencies, local governments, non-profit organizations, academic institutions, and others (USEPA, 2017; CBP-Who, 2023; MidAtlantic-Fisheries, 2023; MSA, 2023). The current organization works toward environmental restoration and has implemented various reforms and policies to accomplish its objectives through continuous research, implementation, and adaptation (CBP-Who, 2023).

The "Law and justice" score was "Good" because the Environmental Protection Agency (EPA) settlements require reasonable assurance, consequences, offset, goals, and tracking mechanisms of the socio-ecological system (EPA-CBW, 2010). There is also an agreement on how each jurisdiction partners with the local government to achieve and maintain water quality standards (CBP-Who, 2023). Currently, the Chesapeake Bay Foundation (CBF) serves as a non-profit organization that pressures the government to enforce laws and regulations by applying lawsuits against state governments that have not followed the agreements (CBF-Mission, 2023). Moreover, the Atlantic States Marine Fisheries Commission (ASMFC) has a law enforcement committee to guide the fisheries management plans and propose legal advice (ASMFC-Law, 2023).

The other category that scored "Good" was "Resource management." The Chesapeake Bay is an example of an institutionalized effort to develop and apply marine ecosystem management (CBP-Who, 2023). Currently, there are Watershed Implementation Plans to meet the TMDL federal "pollution diet" goals (CBP-TMDL, 2023). The Chesapeake Bay Stewardship Fund supports networking and information sharing between partners (NFWF-CBWF, 2023; NFWF-INSR, 2023). There are accountability tools, such as the Chesapeake Decision tool, that explain how the outcomes will be accomplished (ChesapeakeDecisions, 2023); the University of Maryland Center for Environmental Science (UMCES) Chesapeake Bay Report Card, which helps stakeholders and the general public understand the state of the Bay by providing ecosystem, economic, and social indicators (ReportCard_UMCES, 2023); and the CBF, which as it was stated before is a non-governmental foundation that pressures several levels of the government to achieve the management restoration projects (CBF-History, 2023). On the other hand, fisheries management comprises two basic functions: conservation and allocation (CBF-Fisheries, 2023). The accountability measures include size limits, seasonal closures, trip limits, and gear restrictions (NOAA-Fisheries, 2023).

The last two categories scored as "Satisfactory." The "Representation and power" score was based on the system's management, which has government representatives, academic institutions, non-governmental organizations, fish and wildlife agencies, and private citizens (CBP-Partners, 2023). Additionally, the political roles of women have increased in recent years (WEF, 2020, 2021). The main barrier is the lack of representation of people who identify as "non-white." Currently, in the CBP, 15% of "non-white" races work in partnership, and 7.7% are in leadership positions. The CBP is working toward increasing diversity to represent the communities suffering the most from environmental injustice (CP-Diversity, 2023).

Finally, the "Legitimacy & accountability" category "Satisfactory" score was given because there are several sources of data, assessment, and institutions to hold the management of restoration projects accountable (CBF-Mission, 2023; ChesapeakeProgress, 2023; ReportCard_UMCES, 2023). The USA is the 25th least corrupt country in the world (CPI-USA, 2021), and the watershed has generally low corruption, with the Delaware state holding the highest corruption value (BestLife, 2022). The main barrier is the lack of accountability responses. There is no information about the consequences of breaking the law and policies within literature or official government web pages.

4 Discussion

4.1 The Chesapeake Bay watershed sustainability

The score for each domain provided new information about the Chesapeake Bay as a socio-ecological system. The indicators gave an idea of "real life" sustainability, which gives a deeper understanding of the current state using available scientific information or other reliable sources. The categories, domains, and overall system used this information to evaluate the global sustainability score proposed by this article (Figure 2 and Tables 2, 3). The main bridges and barriers to sustainability for each domain are presented in Tables 5–8.

It is important to consider that this global score's main objective is to communicate the assessment at a more general level for various participatory stakeholders. Communication can become a bridge between scientists and stakeholders, which can help improve ecological and socio-economic wellbeing.

The evaluation was based on an extensive literature review of existing indicators, but the need for more measurable and verifiable indicators was apparent. Additionally, a quantitative threshold for each indicator category should be developed. The chosen indicators should be appropriate to evaluate the overall system, with a high spatial and temporal resolution, analysis methods, and holistic discussion. This kind of information requires high governmental, scientific, and local participation. This research can be the starting point for developing new information about the meaning of sustainability in the Chesapeake Bay watershed, as it starts the

conversation about the indicators, thresholds, goals, barriers, and bridges needed to achieve it. By developing this research and implementing the management, the score system could increase to a "Good" score (Figure 2).

The overall "Satisfactory" score obtained with this framework is consistent with other literature and frameworks. For instance, the 2022 Chesapeake Bay and Watershed Report Card scored 51%, with an improving trend in some areas. Furthermore, according to recent literature (Ator et al., 2020; Frankel et al., 2022; Zhang et al., 2023), there are improvements in the water quality due to the management, with some barriers to becoming a restored ecosystem.

4.1.1 Environmental

The management barriers for the environment are presented in Table 5. Most barriers are related to changes in hydrodynamics due to climate change. Increasing evidence suggests that climate change, particularly global warming, makes the coastal ecosystem more vulnerable to the effects of nutrient enrichment, one of the main issues in the Chesapeake Bay (Kemp et al., 2005; Frankel et al., 2022). This causes the management plans for the ecosystem resilience of the region to lag or fail, resulting in a lack of improvement in biochemical and physical flows (Meals et al., 2010; Du et al., 2018; Frankel et al., 2022). This could discourage actors, such as stakeholders, from trusting, applying, or investing in management plans to increase ecosystem resilience (Meals et al., 2010; Boesch, 2019; Frankel et al., 2022; Zhang et al., 2023). Boesch (2019) discusses how important it is for stakeholders to understand that models and reality differ, the recovery of an ecosystem could take decades, and there are variables that cannot be predicted. Expressing the complexity of recovering an ecosystem is not meant to discourage or criticize the management of the Chesapeake Bay but to highlight the complex process that requires much effort and resources. Understanding this could make the stakeholder more inclined to protect the environment and the ecosystem services it provides. Nevertheless, some studies have shown that the current nutrient reduction management goals (TMDL) can potentially decrease the impact of climate change on the system (Irby et al., 2018; Frankel et al., 2022).

Given the complexity of global environmental change, it is crucial to focus on developing strategies manageable inside the region, such as obtaining adequate data, regularly updating goals, and securing additional funding for coastal adaptation. Furthermore, establishing bridges to enhance ecosystem resilience can mitigate some of the effects of climate change worldwide.

One of the leading polluters that can be managed in the watershed is uncontrolled urban and suburban development (Goetz et al., 2004; Ator et al., 2020; Zhang et al., 2023). There needs to be more accountability and developed limits for the housing growth in the watershed and shoreline. Additionally, more incentives are needed to restore, conserve, and improve the forest buffers, wetlands, and SAV at a more local management level. These vital habitats could stabilize the shoreline from the SLR and mitigate the input of nutrients from the increased precipitation (Davis et al., 2006; Leyva Ollivier et al., 2023). Finally, to enhance environmental resilience, it is crucial to have clear information about the quantity of these vital habitats. Currently, the vital habitats management projects are meeting the goals with little change in the system's resilience. A clear threshold of area cover to buffer the current nutrients and sediments could be a helpful goal to increase management efforts.

Agriculture activities are another example of some barriers that can be managed in the region. The main nutrient and sediment input comes from a lack of regulation on agricultural activities. Since 2014, agriculturists have voluntarily implemented many Best Management Practices (BMPs), which are nutrient-reduction tools (Fox et al., 2021). More funding and incentives for BMPs could be applied to the system to improve water quality (Chadwick et al., 2011). According to Saacke Blunk et al. (2020), incentives can also be a bridge to build education for the best professional guidance for landowner conservation, farm and nutrient management, and water conservation.

4.1.2 Social

Table 6 presents the main barriers of this domain. The social benefits from the ecosystem, such as food and water, are degrading due to the increasing pollution of the watershed (Phillips and McGee, 2016). This has been addressed in the environmental section. Furthermore, the health of the Bay should be a main priority for the residents, who are the beneficiaries of the ecosystem services it offers. However, the main solution for residents is to move or build bigger houses outside the city (Goetz et al., 2004; CBP-Dev, 2023). Continued population growth makes this last action counter-productive because it only increases the pollution around the system with more infrastructure needed for urban or rural development. Therefore, one of the main barriers is the sprawling development around the watershed, which could be regulated.

Another consideration is the social wellbeing of the residents. According to Cuker (2020), the food system is built on making profits by focusing the standard American diet on animal-based food, refined carbohydrates, and a few fiber-rich fruits and vegetables. The result is a diet with low nutritional value and high caloric intake, which has health consequences. The same study identifies that the burden of unhealthy food falls mainly on low-income residents. Similarly, the healthcare system in the country is not the main contributor to people's health (Rice et al., 2013). Rice et al. (2013) provide a review of the healthcare system in the USA and found that the "social determinants of health" include cultural and environmental factors, such as poverty, education, racial segregation, and others. The results indicate that social wellbeing could be mainly linked to socioeconomic status and race. However, more research in the region is needed to validate this information with more quantitative indicators.

There is also a lack of identity around the ecoregion. The few people who relate to the environment work professionally in the system (Ardoin, 2014). The people feel more connected by the political boundaries than the ecological ones due to the different government dependencies on the rural and urban development on the Bay (McKendry, 2009). Allen and Schlereth (1990) argue that the regional identity is strongly marked by an "us versus them" mentality by what is called the Eastern Sharemen's regional consciousness due to the isolation and outrage at perceived outside interferences. Overall, the success and sustainability of the Chesapeake Bay restoration will ultimately depend on the actions and support of the region's residents. Therefore, a sense of identity outside the political views is needed to form a bridge.

There are some management efforts in the system to increase social sustainability. The UMCES Chesapeake Bay Report Cards have developed social indicators, such as stewardship, vulnerability, and walkability (ReportCard_CBW, 2020). These indicators were added considering the impact human communities have on the environment and the environment on human communities

(Laumann et al., 2019). The information provided by the Report Cards presents the opportunity to understand the link between the environment and social issues and to develop management actions that consider both. There are also proposals to develop environmental injustice indicators (IAN-EnvJus, 2023). This information can be helpful as a bridge to improve the residents' social wellbeing by providing environmental justice regardless of socio-economic status or race.

Education and outreach to the region's residents are some of the main bridges that require high attention. The knowledge of environmental justice, preparedness for hazards, urban sprawl issues, and ecosystem services to all the residents can increase the sense of responsibility for the ecosystem's health. Awareness of the socio-ecological system dynamic can increase social resilience to hazard events and develop a sense of belonging, which is highly needed to improve ecosystem resilience.

4.1.3 Economic

The economy in the system is highly efficient and resilient, and although some sustainability barriers exist (Table 7), these barriers are more related to economic vitality (Goerner et al., 2009; Mensah, 2019).

Security and economic wellbeing need improvements with more equitable opportunities for different communities and socioeconomic status (McKendry, 2009; Worts et al., 2010; Cuker, 2020; OECD, 2020). To improve economic sustainability, the wellbeing and security of the workers should become a priority. Currently, the main economic activities in the region purposely hire foreign or part-time workers, mainly because it reduces expenses or avoids paying additional benefits (Cuker, 2020). Furthermore, 37% of the residents of the USA are at risk of falling into poverty, and 18% live in poverty (OECD, 2020). According to Worts et al. (2010), recovering after falling into poverty takes a decade due to the absence of social safety nets in the country. Implementing regulations around part-time jobs and foreign workers is the main bridge to overcome these barriers. Another improvement would be to increase social safety nets to protect vulnerable communities from poverty.

On the other hand, economic wellbeing and security are highly linked to individual transport, which puts individuals with no financial means or access to cars at an economic disadvantage. Moreover, the well-established reliance on private automobiles for urban and rural transportation creates a unique challenge to the region's environmental resilience (Buehler and Pucher, 2011, 2012; Martin and Shaheen, 2011). Improving and increasing alternatives to public transport could become a bridge to decrease pollution from motor vehicles and improve equality in the security and economic wellbeing of the residents.

Finally, although the region's economy is highly diverse and efficient, some barriers exist. The insufficient reliance on environmental jobs leads to a decline in natural resources, reducing the economy's and environment's resilience. The main bridge could be increasing environmental industry jobs to develop a more circular and local economy, which helps increase environmental resilience and thereby improve extractive natural resources (Morseletto, 2020). There can also be incentives to improve residents' participation in the region's sustainability management plans. Additionally, another proposed bridge is the development of clear indicators about the effectiveness of the environmental industry in maintaining, restoring, and improving the ecosystem.

4.1.4 Governance

Governance was attributed the highest score due to the high capacity of governmental organizations, management plans, and transdisciplinary collaboration (Table 8). These bridges have made the region's management an example of ecosystem-based management by increasing the environmental resilience of the Bay in the last few years (Irby et al., 2018; Frankel et al., 2022; CBP-Who, 2023). The main barrier is the limited information in the literature about implementing accountability measures. Therefore, to enhance governance sustainability, the government needs to establish bridges that ensure the application of accountability measures. The consequences for polluters must be clear, and law enforcement must be robust to ensure accountability and decrease future environmental violations. Fines or subsidies could become this bridge by the principle of "polluter-pays" or by compensating those following the restoration plans.

The 2014 Agreement of the CBP contains a "Stewardship Outcome" to increase diversity (CP-Stewardship, 2023). The main objective is to increase the number of trained members of society from diverse backgrounds to enhance the ecosystem health of their local community. Similarly, this bridge could help identify bottom-up and community-led solutions that produce equitable, efficient, and effective outcomes (CBF-Sprawl, 2023). The project is relatively new; obtaining the expected results from this bridge may require more time.

4.2 Holistic management application of the Circles of Coastal Sustainability

Table 9 was developed considering the barriers obtained by the results and bridges proposed in each previous domain's discussion. Upon examination of the table, it becomes apparent that bridges are repeated or sometimes adapted accordingly to the domain or category. These repeated bridges were used as a foundation for holistic management response proposals for the Chesapeake Bay watershed.

One of the main repeated bridges is accountability and developing limits for housing growth. This bridge is considered because of the barriers in the urban and rural sprawl development, the growth close to tidal water in major rivers or shorelines, and the infrastructure made to accommodate cars for transportation. These barriers cause other problems, such as the high cost of infrastructure and social segregation (Bueno-Suárez and Coq-Huelva, 2020). A holistic response that considers these barriers is the concept of "compact city growth." The compact city growth is defined as a high-density, mixed-use city with efficient public transport and dimensions that encourage walking and cycling (Bibri et al., 2020). This concept can regulate sprawl and the growth close to tidal waters. Additionally, in the region, where car ownership is crucial for the residents' economic and social wellbeing (Buehler and Pucher, 2011, 2012; CBF-Sprawl, 2023), public transport development could become a bridge to decrease greenhouse gas emissions and reduce social exclusion from residents of different socioeconomic statuses (Kwan and Hashim, 2016; Saif et al., 2018). Some social benefits include reducing traffic injuries, noise, congestion, and physical inactivity (Kwan and Hashim, 2016).

Another repeated bridge is the funding and incentives to increase vital habitats and climate change adaptation. The proposed holistic management is the increase of natural spaces around the urban areas surrounding the Bay. The selection of natural spaces could serve as a

climate change adaptation tool by using green infrastructure. Green infrastructure is defined as green spaces that promote recreation activities, preserve biodiversity, and help regulate and manage technical problems such as stormwater (Patra et al., 2021). In the Chesapeake Bay case, the green infrastructure could increase vital habitats that serve as nutrient and sediment buffers, mitigate SLR, and attenuate indoor temperatures and heat islands (Leyva Ollivier et al., 2023).

Accessibility to nature can also improve social wellbeing by improving aesthetic and environmental injustice (Wood et al., 2017; Nieuwenhuijsen, 2021). Moreover, it can potentially decrease suburban sprawl for residents looking for green areas, providing natural areas within the cities (Bueno-Suárez and Coq-Huelva, 2020). Rural populations could collaborate by using traditional knowledge from the ecosystem to implement green infrastructure in urban areas. This collaboration could help reconcile the cultural boundary, decreasing the "us versus them" mentality (Allen and Schlereth, 1990) and increasing the economic wellbeing of rural areas while improving ecosystem resilience. The increase in natural areas has the potential to develop a sense of identity around the ecoregion and improve education in vital habitats, as it is part of the daily life of urban citizens.

The repeated bridge of obtaining adequate data and regularly updating goals is highly related to the scientific community. However, as straightforward as this action is, to be considered a holistic management response, it must be taken further by sharing this information with various actors. The research, education, and outreach of this data and goals could increase the awareness of the current socio-ecological system conditions and the sense of responsibility. The education of the residents could be focused on sustainable development, ecosystem health, climate change adaptation, societal benefits from the ecosystem, issues with sprawling, environmental justice, preparedness for hazards, public transport advantages, and others. There could also be more focused education with specific stakeholders, such as agriculturists, stakeholders investing in management restoration plans, or teachers from various academic stages. The scientific community embraces a significant role in sustainability development as it develops the information needed to achieve and share this goal.

Finally, according to this framework, the Chesapeake Bay watershed socio-ecological region has the governance effectiveness to implement holistic projects to improve sustainability development. Nevertheless, some proposed bridges could improve the effectiveness of current and future governance. The repeated bridge is that the consequences for polluters must be clear, and law enforcement must be robust to ensure accountability and decrease future environmental violations. This article proposes using financial instruments as an incentive mechanism and an accountability tool to ensure the implementation of current and future restoration plans. Fines could be employed under the 'polluter pays' principle, while subsidies could be provided to compensate those who adhere to the management plans. The additional funds from the fines can be invested in the current conservation project on climate change adaptation, vital habitat conservation, sustainable fishing technologies, and the application of BMP for low-income farms.

On the other hand, subsidies could be used as incentives for diverse actors, such as agriculturists, fishers, or residents. Agriculturists could be rewarded for following the BMPs, and the fisheries could be rewarded for the conservation and allocation of key species or for using sustainable fishing technologies. Similarly, the residents could receive subsidies for water conservation, recycling, compost practices, stewardship, and others.

These subsidies could help increase community-based management (Ostrom, 1990) around the watershed, promoting social and economic wellbeing improvements. The social benefits of working directly with land management are a sense of belonging to the local community, improving general health, both physical and psychological, feeling safer in the local community, and utility skills (Moore et al., 2007). The subsidies could also have economic benefits, such as a social safety net for citizens who risk falling into poverty from losing a job. The government could temporarily employ full-time workers who have recently lost their jobs, allowing them to use their skills to improve the region's environmental health while actively seeking permanent employment. Furthermore, part-time workers who seek economic security could participate in community management roles, simultaneously improving their economic and social capital while contributing to ecosystem resilience. Social capital is defined as the network, trust, and norms that facilitate community cooperation and cohesion (Moore et al., 2007).

4.3 Communication of science

The previous discussion about the scientific community outcome and education falls into the communications of science. The change in the graphic design for the framework was developed to communicate to a broad audience with different specialties. The UMCES Science Communicators who developed the design for the report cards also participated in the development of these new designs to communicate the framework better. According to Vargas-Nguyen (2020), the report cards have helped the residents, giving them the knowledge to improve and protect their communities, which is part of the intention of the design presented in this study. Therefore, the result is expected to enhance public awareness, understanding, literacy, and culture of the system and sustainability.

In Figure 2, daisy shapes and icons were selected because of their well-known shape around the world. The icons were used to attract stakeholders from the region with non-scientific backgrounds. According to Malamed (2009), the brain processes visual information first, as humans have an excellent capacity for picture memory. After the first viewing, our minds need to make sense of the images. Our brain scans our memory and uses what we already understand to interpret and infer meaning from the unknown. The understanding derives pleasure, satisfaction, and competence, increasing our desire for further understanding (Malamed, 2009). This design serves as a tool to capture the interest of several actors to engage and motivate them to understand its content more, thereby prompting more attention toward the accompanying explanation.

4.3.1 Propose global sustainability score

The scoring system for this article (Figure 2 and Tables 2, 3) was developed considering the same goal as the sustainability daisy: clear communication. The "Excellent" score aligns with the definition of sustainable development. The "Good" score is a system with the necessary bridges, such as tools and information, to achieve

TABLE 9 Chesapeake Bay watershed barriers and proposed bridges.

Domain	Category	Barriers	Proposed bridges
Environment	Alteration of landscape	• Uncontrolled urban and rural development near the shoreline • Uncontrolled suburban sprawl • Increase of armored shorelines as a sea level rise response	• Accountability and developing limits for housing growth • Incentives to improve and increase vital habitats and climate change adaptation
	Ecosystem function	• Restoration plans fail due to habitat degradation and diseases	• Obtain adequate data, regularly update goals, and secure additional funding for vital habitats that improve ecosystem functions • Incentives to improve and increase vital habitats for ecosystem function • Implement education about ecosystem recovery • Implement education about the difference between models and reality
	Global environmental change	• Increase in flooding affecting shoreline habitat and flow exchange • Temperature increases, changing the biochemical concentrations • An increase in precipitation increases nutrient and sediment input into the Bay • Inadequate data, updated goals, and lack of funding for climate change adaptation	• Obtain adequate data, regularly update goals, and secure additional funding for coastal adaptation • Funding and incentives to improve and increase vital habitat and climate change adaptation
	Shift in hydrodynamic	• Increase of extreme events	• Obtain adequate data, regularly update goals, and secure additional coastal adaptation funding • Incentives to improve and increase vital habitats and climate change adaptation
	Biochemical and physical flows	• Increase in urban runoff because of the expansion of land development • Increase of air pollutants from power plants and motor vehicles • Increase of metal pollutants from natural and industrial outputs • Increase the use of pesticides • Lack of progress in sediment load reduction in the last years	• Accountability and developing limits for housing growth • Implement BMPs around agriculture activities • Build education for the best professional guidance for landowners' conservation, farm and nutrient management, and/or water conservation • Funding and incentives to improve vital habitats and climate change adaptation • Obtain adequate data, regularly update goals, and secure additional coastal adaptation funding
Social	Societal benefits from the ecosystem	• The primary source of pollution comes from agriculture • Mercury contamination is widespread in the watershed and fish • One of the major rivers (Susquehanna) shows nitrate levels exceeding public drinking water standards • Health damage, affecting humans, due to air pollution	• Implement BMPs around agriculture activities • Build education for the best professional guidance for landowners' conservation, farm and nutrient management, and/or water conservation • Incentives to improve vital habitats and climate change adaptation • Education around the societal benefits of the ecosystem
	Demographics	• Lack of regulation in population growth • Development occurs close to tidal water in major rivers or shorelines • Development is estimated to increase primarily through exurban sprawl	• Sprawl regulation • Accountability and developing limits for housing growth • Incentives to improve vital habitats and climate change adaptation • Education about sprawling issues
	Social wellbeing	• Food systems built on profit and increase health problems for residents • There is a rise in mortality around the country due to a lack of communal support in all life cycle stages • Food insecurity falls on vulnerable residents in the CBW • The healthcare system does not contribute to the health of US residents • There is low school system growth and a lack of maintenance of the current ones in the country	• Obtain adequate data, develop goals, and secure additional funding to improve social wellbeing for all residents
	Identity	• Traditional commercial fishermen (waterman) do not feel the fisheries regulation should apply to them. • People in the region feel more connected by the political boundaries. • Less than half of the residents are not obligated to maintain, restore, and/or improve the ecosystem.	• Develop a sense of identity around the ecoregion
	Social resilience	• Half the population is not prepared for hazardous events • The health-related and flooding risks fall mostly on vulnerable communities • 22% of the population is not prepared for environmental literacy • Half of the students do not have a meaningful watershed education experience	• Improve education about environmental justice, preparedness for hazards, and ecosystem services

(Continued)

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TABLE 9 (Continued)

Domain	Category	Barriers	Proposed bridges
Economics	Security	• Most workers in the region are foreigners or part-timers • Most part-timers need multiple jobs to have economic security • 37% of the population in the USA is at risk of falling into poverty • There are no safety nets to protect vulnerable citizens from falling into poverty • A decade is needed to recover from poverty	• Implementing regulations around part-time jobs and foreign workers • Increase social safety nets to protect vulnerable communities from poverty • Improving and increasing alternatives to public transport
	Infrastructure	• Most infrastructure is made to accommodate cars • Limited availability of public transportation • Few cities in the country have attempted to make car ownership use more costly, slower, and less convenient	• Improving and increasing alternatives to public transport • Accountability and developing limits for housing growth
	Economy wellbeing	• Lower median household income in rural areas • Public transport is absent outside of main urban areas • Lack of data on the proportion of job growth attributed to part-time or foreign employment • Living in poverty exacerbates adverse outcomes that impact the overall quality of life	• Implementing regulations around part-time jobs and foreign workers • Increase social safety nets to protect vulnerable communities from poverty • Improving and increasing alternatives to public transport
	Industry	• Agriculture has minimal impact on the economy • Lack of clear indicators to assess the development and effectiveness of the environmental industry in mitigating pollution	• Increased environmental industry jobs • Develop a more circular and local economy • Development of clear indicators about the effectiveness of the environmental industry in maintaining, restoring, and improving the ecosystem
	Dependency	• Insufficient reliance on environmental jobs to improve natural resource resiliency	• Increased environmental industry jobs • Develop a more circular and local economy • Incentives to improve residents' participation in sustainability management plans • Development of clear indicators about the effectiveness of the environmental industry in maintaining, restoring, and improving the ecosystem
Governance	Organization	There are no barriers to sustainability	
	Law and justice	• Lack of information on law and justice application	• Consequences for polluters must be clear, and law enforcement must be robust to ensure accountability and decrease future environmental violations • Fines by the principle of "polluter-pays" • Subsidies to compensate those who are following the restoration plans
	Representation and power	• The diversity of the CBP partnership is 15% • Some communities are not represented in the management of the region	• Increase the number of trained members of society from diverse backgrounds to enhance the ecosystem health of their local community • Identify bottom-up and community-led solutions that can produce equitable, efficient, and effective outcomes
	Legitimacy and accountability	• Additional information about the consequences of breaking laws and agreements or corruption in the region is needed	• Ensure the application of accountability measures • Consequences for polluters must be clear, and law enforcement must be robust to ensure accountability and decrease future environmental violations
	Resource Management	• The management has not achieved ecosystem resilience	• Apply holistic frameworks to evaluate and improve the current management • Obtain adequate data, regularly update goals, and secure additional resource management funding • Improve education around the ecoregion

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sustainability. Therefore, this communicates that there is effective management and that the categories with these scores do not require immediate action. The "Satisfactory" score conveys the bridges and barriers for effective management toward sustainable development. Meanwhile, the score "Poor" conveys mostly the obstacles and barriers. These scores increase knowledge and awareness of the barriers to sustainable development. This increases the urgency of management actions. Finally, the "Bad" score was given to the system in a crisis. The lowest score was considered because sustainability development cannot be attained without a sustainability pillar: environment, social, economic, or government. The sustainability daisy can also represent insufficient data for assessing sustainability. In Figure 2, the presence of gray is noticeable; this color is assigned when there is insufficient data to assess a particular category or domain.

Gallo-Vélez et al. (2023) used a more quantitative score system with the goal of communicating the urgency for effective management actions. However, this scoring system may create expectations that reaching these values guarantees success, presenting a potential challenge to oversimplifying the system's barriers toward sustainable development (Boesch, 2019). What happens if the goal is reached with little progress toward sustainability? How does a change in the quantity of one indicator affect the others? Additionally, what if these goals do not consider the dynamic of diverse socio-ecological systems? These goals could potentially become static, hindering adaptive and management responses toward sustainable development.

The proposed global score system approach aims to communicate the meaning of sustainability in a more generalized manner. Then, when the main message is communicated, the barriers and bridges based on scientific methods can be taught to give policy decision-makers more specialized information. These bridges and barriers must be discussed by specialists in the different domains. Similarly, transdisciplinary participation and collaboration are required. Therefore, the proposed global score system could become a guide toward adaptive management for sustainable development within diverse coastal ecosystems.

There are some challenges to this global score system approach. The diversity of ecosystems, societies, economies, and governments makes this assessment highly general, which could cause misunderstanding compared to other systems that obtain a better score. Some policy decision-makers could misunderstand that applying identical management strategies in different regions guarantees success. Therefore, understanding the differences in socio-ecological systems and developing reliable scientific information from each region are crucial.

Appropriate management responses are urgently needed to improve sustainable development on a global scale. The framework opens the communication between diverse actors about the current indicator's threshold and the importance of transdisciplinary collaboration. Nevertheless, it is essential to clarify that this scoring system is still in development.

5 Conclusion

The sustainability of the Chesapeake Bay watershed socio-ecological system was assessed with a "Satisfactory" score. This score was given because the region has degradation problems with bridges and barriers to obtaining sustainability development. The score system on the Circles of Sustainability Framework is still in development. However, the results convey a general idea of the current status of the region.

The results of the domain, categories, and indicators assessment gave a general foundation of the management necessities. Overall, the Chesapeake Bay Program has environmental projects around the system to improve the health of the Bay. These projects have increased and protected the environmental resilience of the ecosystem. Similarly, this article proposes additional bridges, which were summarized in holistic management proposals. This proposal includes the concept of compact city growth; increased natural areas using green infrastructure; high involvement of scientists with research, education, and outreach on the socio-ecological system; and financial instruments as an incentive mechanism and an accountability tool to ensure the implementation of the restoration plans.

Specialists from each domain should discuss the results of the assessment together. The indicators were taken from different sources, so the assessment can be subject to bias if analyzed according to an individual discipline and availability of information within a timeframe. Therefore, transdisciplinary participation and collaboration are required, which is one of the framework's objectives. The framework is a tool to communicate the current sustainability development, provide a holistic system view, and find knowledge gaps in the research of a system. The framework and assessment can be complemented, adapted, refined, and improved with each application as part of an adaptive management iterative cycle.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Author contributions

ML: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. AN: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – review & editing. HK: Conceptualization, Data curation, Investigation, Methodology, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

ML was employed by Murray Foundation, c/o Brabners LLP.

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