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COAST ASSESSMENT OF THE CHESAPEAKE BAY WATERSHED IN THE UNITED STATES OF AMERICA, USING THE CIRCLES OF COASTAL SUSTAINABILITY FRAMEWORK

Thesis in:

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Abstract

The Chesapeake Bay is the largest estuary in the United States of America, with watershed drainage covering parts of six states and a Federal District. The system was the first estuary in the nation targeted by Congress after the rapid loss of wildlife and aquatic life. The Chesapeake Bay Watershed's (CBW) main socio-ecologic issues are eutrophication, overexploitation of resources, and industrial and urban development. This thesis aims to improve CBW management knowledge using holistic frameworks. The objectives are to contribute and assess the management, evaluate the sustainability of the socio-ecologic system, develop a normalized score for sustainability, and present these results using science communication techniques. The holistic frameworks used were DAPSI(W)R(M) and Circles of Coastal Sustainability (CCS). The DASPI(W)R(M) identified the CBW's structure, function, dynamics, and management. Meanwhile, CCS assessed its socio-ecologic sustainability in four domains: Environmental, Social, Economic, and Governance. To evaluate each domain, recognizable and comprehensive indicators were needed. Therefore, an independent literature review of each domain was developed to represent each score classification. The results of the DAPSI(W)R(M) framework indicate that the CBW is a complex system with conflicts between ecosystem health and social well-being. Overall, the score system gave a "Satisfactory" result in the CCS framework assessment. The grade was given because the socio-ecologic system is not healthy but is working towards sustainability. The results for each domain were "Satisfactory" in environmental, economic, and governmental and "Poor" in Social. The graphic design for the results was developed by a collaboration of experts, which aims to communicate sustainability to a broad audience with different specialties. The main discussion of the thesis was about the management recommendation for the CBW using the holistic framework results.

Keywords: Chesapeake Bay, Management, Holistic Framework, Sustainability, Indicators.

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Glossary and Acronyms

ASFMC - Atlantic State Marine Fisheries Commission
BMP - Best Management Practices
CAA - Clean Air Act
CB - Chesapeake Bay
CBF - Chesapeake Bay Foundation
CBP - Chesapeake Bay Program
CBW - Chesapeake Bay Watershed
CBWA - Chesapeake Bay Watershed Agreement
CCR - Common-pool resources
CCS - Circles of Coastal Sustainability
CWA - Clean Water Act
DAPSI(W)R(M) - Driver-Activities-Pressure-State-Impact (on human welfare)-Response (as Measures)
DPs - Design principles
DPSIR - Driver-Pressure-State-Impact-Response
EEA - European Environmental Agency
eia - Energy Information Administration
EPA - Environment Protection Agency
GIT - Goal Implementation Team
IAN - Integration and Application Network
INSR - Innovative Nutrient and Sediment Reduction Grants
ISFMP - Interstate Fisheries Management Program
MAFMC - Mid-Atlantic Fishery Management Council
MSA - Magnuson-Stevens Act
NFWF - National Fish and Wildlife Foundation
NOAA - National Oceanic and Atmospheric Administration
NPS - National Park Service
OECD - Organization for Economic Co-operation and Development
RC - Report Cards
SAV – Submerged Aquatic Vegetation
SES - Social-Ecological Systems
TMDL - Total Maximum Daily Load
USA - United States of America
USEPA - United States Environment Protection Agency
WIP - Watershed Implementation Plans

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1.1. Scope

The following thesis is one of the requirements of the Erasmus Mundus Master in Water and Coastal Management. This document is an assessment of the Chesapeake Bay management over the years. Its focus is to support and contribute the socio-ecologic sustainable management of the region.

1.1.1. Hypothesis

The working hypothesis explored in the thesis is that "the sustainability of the Chesapeake Bay Watershed (CBW) depends on integrated management based on the ecosystems approach"

1.1.2. Aim

The aim is to improve the knowledge of Chesapeake Bay Watershed to contribute to knowledge-based, holistic frameworks.

1.1.3. Objectives

- Contribute to and assess the CBW management of the marine environment with a holistic approach that recognizes the complexity of the system and accommodates the diverse range of uses and users.
- Evaluate the CBW using a holistic framework, considering ecology, economy, politics, and social sciences.
- Develop a normalized score for each sustainability domain from a global perspective.
- Present these results using science communication techniques to enhance public awareness, understanding, literacy, and culture of the system and sustainability.

1.1.4. Research Questions

- Can the assessment of the Chesapeake Bay help the management of the area?
- Can we identify locally relevant indicators?
- Can we use the Environmental Report Cards and Chesapeake Bay Program information resources of Chesapeake Bay?
- What are the difficulties and shortcomings on using holistic frameworks?
- Can we normalize the data obtained from indicators in different systems to develop a global perspective?
- What's the best way to communicate the results?
- How sustainable is the CBW in the four domains?

1.2. Introduction

Home to rich and productive ecosystems, estuaries have long been attractive places for human development and subsistence. However, after decades of overfishing, pollution, nutrient enrichment, and industrial development in the last century, estuaries and bays worldwide are in a dramatic state of decline (Rick *et al*., 2016).

The Chesapeake Bay (CB) is the largest estuary in the United Stated of America (USA) and arguably one of the most studied in the world (Arnold *et al*., 2021). The Bay is a unique and treasured natural resource, with an area of 6,100 km^2 (Goetz *et al*., 2004; Morgan and Owen, 2001). The Chesapeake Bay Watershed (CBW) drainage covers 167 000 km^2 within six states in the USA: Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia, as well as the Federal District of Columbia (Boesch *et al*., 2001; McLaughlin *et al*., 2022; Testa *et al*., 2017). Its natural resources support thousands of animal and plant species and the human population of 18 million, providing quantifiable economic goods and services (Morgan and Owen, 2001; Phillips and McGee, 2016; Delia *et al.,* 2021; Ator *et al.,* 2020).

Since the mid-1900s, increases in nutrient and sediment inputs to the Bay have led to the degradation of the overall system (Hood *et al*., 2021; CBP-Who, 2022; Phillips and McGee, 2016). The rapid loss of natural resources quality and productivity alerted the government in 1970 (CBP-Who, 2022). As a result, several written agreements have guided the efforts to reduce pollution and restore the ecosystem led by the Chesapeake Bay Program (CBP-Who, 2022; Hood *et al*., 2021; CBP-Accomplishments, 2022).

The program has made significant accomplishments in the efforts to restore the Bay, becoming a regional, national, and international leader in ecosystem science, modeling, and restorations partnership (CBP-Accomplishments, 2022). Nonetheless, many challenges remain for science to refine strategic models, management to develop effective responses, and political commitment to apply them (Boesch *et al*., 2001).

The main issue identified in the Bay has been cultural eutrophication, which is an excessive algae growth resulting from nutrient enrichment by human activities (Kemp *et al*., 2005; Boesch *et al*., 2001; Phillips and McGee, 2016; Glibert *et al*., 2005). These algae blooms produce organic matter that sinks into the deep waters, where it is decomposed in an oxygen-consuming process (Kemp *et al*., 2005). One of the results of this process is hypoxia, which occurs when dissolved oxygen is depleted to a certain low level (~$2\frac{mg\ O^2}{L}$), where an aquatic organism, especially benthic fauna, becomes stressed or dies due to the lack of oxygen (Du *et al.*, 2018). Since the early to mid-1970s, several coastal marine ecosystems have reported increasing nutrient-induced algal production and biomass, making it a global problem (Kemp *et al*., 2005).

Diverse ecological processes tend to “buffer” and regulate algal growth in coastal environments (Kemp *et al*., 2005). Nevertheless, many of these natural buffering mechanisms can be compromised by human activities (Kemp *et al*., 2005). For example, before humans-built roads, homes, and farm fields, most nutrients were trapped and absorbed by forest and wetland plants of the CBW. However, when these habitats were removed to accommodate a growing population, nutrient pollution increased (CBP-Issues, 2022). The main activity and source of nutrients (~60%) in the CBW is Agriculture, with 28% of cover in the watershed (Williams *et al*., 2009). Therefore, another issue has been the past overexploitation of natural resources in the past and the development within the Watershed currently (CBP-Dev, 2022). The last issue is also linked to the overexploitation of the natural resources, although, only considers the Bay system. The fishing industry has contributed millions of dollars to the region's economy, but its overexploitation has depleted the stocks and set the stage for decline (Orth *et al*., 2010; Jackson *et al*., 2001; Rothschild *et al*., 1994).

There are program, government, and non-governmental organizations developing a wealth of literature, web pages, studies, management plans, and assessments for the system restoration and sustainability of the overall resources (CBP-CBWA, 2022). However, no recent study considers the overall CBW system and the conflict between ecosystem health and human well-being in a holistic approach. Elliott (2014) wrote that any successful integrated marine management requires assessment of the source, causes, and consequences of problems delivery of ecosystem services and societal benefits, incorporating governance from the local to the global, and implementing the ecosystem approach. Furthermore, sustainability assessment needs to be across multiple domains and connections to achieve socially and environmentally sustainable outcomes.

Chapter 2.

2.1. State of Art

2.1.1. Chesapeake Bay history

The Chesapeake Bay took its present form about 10,000 years ago when the Susquehanna River valley was drowned by rising sea level following the last ice age (Bilkovic *et al*., 2019). Before colonial times, indigenous human populations influenced the landscape and locally affected the population of exploited marine organism without significant changes in the ecosystem (Aburto *et al*., 2012). When the Europeans migrated to this region four centuries ago, they encountered a landscape almost completely covered with temperate forest bordered by wetlands (Kemp *et al*., 2005). Since the colonization, the ecosystem has undergone substantial human-induced changes (Boesch, 2006).

The initial land change was the land clearing for agriculture; until the mid-1800s, the basin was continuously deforested (Kemp *et al*., 2005). The evolution of shoreline in post-colonial times was highly influenced by residential and commercial development in urban areas, with the rural areas mainly used for agriculture (Hardaway and Byrne, 1999). As a result, more plant nutrients began to wash down into the Bay, subtly altering its natural production and food web (Aburto *et al*., 2012).

After World War II, industrialization increased pollution, particularly by trace metals, and provided the mechanical means to exploit the abundant oyster population. These methods were effectively strip-mining reefs, which hindered the shoreline and navigation (Boesch, 2006). Before the 19^{th} century, the oyster population could filter a water volume equivalent to the upper and middle Bay in ~3.6 days, in the present this have change up to a hundred days (Kemp *et al*., 2005). Additionally, the development, industrialization and increase of pollution affected the underwater grasses in shallow water, which provided food and habitat to wildlife, add oxygen to the water and trap sediment and nutrient pollution (CBP-Grasses, 2022).

The mid-1900 marked the beginning of the petrochemical period, bringing pesticides and other manufactured organic chemicals, petroleum by-products, and industrially produced fertilizers (Aburto *et al*., 2012). Even after the agricultural land clearing started declining because of fertilizers, the pollution increased due to its input and the waste of animal farms (Kemp *et al*., 2005). Additionally, the advent of "leisure time" residential development along the shorelines increased. Cottage communities were established along upland areas with beachfront (Hardaway and Byrne, 1999).

Unfortunately, the ecosystem degradation went unnoticed until the later part of the 20^{th} century, when the Bay experienced a state change characterized by an increase in algal production and biomass (Boesch, 2006; Kemp *et al*., 2005; Arnold *et al*., 2021). The degradation also affected commercial fisheries, by changing the life states ecosystem of several wildlife (Aburto *et al*., 2012; Richards and Rago *et al.*, 1999; Boesch, 2006). Although the decline of oysters was of the biggest concern due to the economic value and ecosystem services, it provided to the Bay (Wilberg *et al.,* 2011). Additionally, the shoreline rural/urban development added pressure to upland banks that were prone to erosion and began to alter the geomorphic patterns (Hardaway and Byrne, 1999).

In 1970, tropical storm Agnes runoff dumped a historic amount of pollution into the already stressed ecosystem (Arnold *et al*., 2021). The pollution was primarily due to the increase in human population, agricultural fertilizers, sediment, animal waste, and atmospheric nitrogen deposition resulting from fossil fuel combustion (Boesch, 2006). In addition, the population growth occurred close to tidal water and the two most significant rivers, the Susquehanna and the Potomac (Aburto *et al*., 2012; CBF-Population, 2022; Hardaway and Byrne, 1999). By the mid-1980s, the Bay received about seven times more nitrogen and 16 times more phosphorus than when the English colonist arrived (Boesch, 2006).

At the start of the 21 century, public concern, scientific research, natural resource policies, and concern management started the agreements for ecosystem restoration (Boesch, 2006; Aburto *et al*., 2012). As a result, the concentration of nutrients and other potentially toxic substances in sediment and organisms decline, increasing the ecosystem restoration (Boesch, 2006). On the other hand, oysters have had difficulty because of the degraded reef habitat and diseases (Boesch, 2006). Nevertheless, some commercial fishes have started to recover due to removing barriers to upstream migration, restrictive fisheries, and the recovery of seagrasses (Boesch, 2006; Richards and Rago *et al.,* 1999).

Currently, the land is divided into forest, agricultural, wetlands, industrial uses, and urban/suburban development with an approximate population of 18 million (Williams *et al*., 2009; CBP-Who, 2022). Frankel *et al*. (2022) demonstrated that the nutrient reduction from 1985 to 2019 has improved the ecosystem and reduced pollution. Although, there is a very public debate concerning the amount of nutrient reduction and the lack of expected results, which is due to climate change (Frankel *et al*., 2022; Boesch, 2006). The impact of climate change is likely to become the most crucial factor counteracting the impact of management efforts within the CB in the future (Du *et al*., 2018).

2.1.2. Chesapeake Bay Management

2.1.2.1. Chesapeake Bay Program

The Chesapeake Bay is the nation’s largest estuary and arguably exemplifies the world’s most comprehensive, sustained, and institutionalized effort to develop and apply marine ecosystem-based management. The Bay's governance is divided by six states in the USA (Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia, and the Federal District of Columbia), making it a coordinated and collaborative governmental effort (CBP-Who, 2022; INSR, 2021). In addition, the region has played a central role in the USA's early history due to being a highly productive estuary (Aburto *et al*., 2012).

The system was the first estuary in the nation targeted by Congress after the rapid loss of wildlife and aquatic life (Arnold *et al*., 2021; CBP-Who, 2022). In 1970, a study was sponsored to analyze the source of the Bay's degradation, which helped lead to development of the clean water legislation “Clean Water act” (CWA) (CBP-Who, 2022; Boesch, 2006; Morgan and Owens, 2001). It was in 1981 that Maryland and Virginia formed the Chesapeake Commission, to advise legislators on how best manage the resources (Arnold *et al*., 2021).

By 1983, the Chesapeake Bay Agreement was signed by all the states, and the District of Columbia, USA Environmental Protection Agency (EPA), and the Chesapeake Bay Commission, to stop, and ideally reverse, the decline of the Bay (Morgan and Owens, 2001). The Agreement made improvements to the Bay by explicitly recognizing that states need to share decisions because causes and solutions to the pollution transcend the political boundaries (Morgan and Owens, 2001).

In 1987, and again in 2000, the same states, the EPA, and the Chesapeake Bay commission, renewed and expanded their commitments to the restoration of the Bay. During this period the management was focused on the nutrient management with the Clean Water Act implementation and a variety of other regulations (Morgan and Owens, 2001; CBP-Who,2022). Furthermore, it was found that air pollution has generated a separate problem adding to the pollution in water, the airshed is ~6.5 times larger than the watershed (Morgan and Owen, 2001). Some examples of major anthropogenic sources of nitrogen to the Chesapeake airshed include fossil-fuel combustion by power plants and automobiles and biomass burning, which are contribute mostly to the northwest and west of the region (Russell *et al*., 1998). The “Clean Air Act” is an instrument created to regulate air pollution; the instrument has also help regulate air pollution inside the CBW (Morgan and Owen, 2001).

In 2009, the CBP began drafting a new agreement that would accelerate restoration and align federal directives with state and local goals to create a healthy Bay. The partners gathered input from citizens, stakeholders, academic institutions, local governments and more to draft an inclusive, goal-oriented document that addresses current and emerging environmental concern; the Chesapeake Bay Watershed Agreement (CBWA) (CBP-Who,2022). The initiative to incorporate, consult, and lead new stakeholders to participate in the management has been rising for the benefit of the system's well-being. The result was the creation of the Total Maximum Daily Load (TMDL) a federal “pollution diet” to restore the water quality (CBP-TMDL, 2022).

To implement the TMDL, each watershed jurisdiction created the “Watershed Implementation Plans”, often called a WIPs (CBP-WIP, 2022). The WIPs is a document that includes details and specific steps each jurisdiction will take to meet the goals of the TMDL by 2025. Additionally, the document has the plan of how to partner from a local government to the federal project (CBP-WIP, 2022).

To achieve consistent assessment over time and among jurisdictions, a multimeric indicator was proposed by the CBP partnership to provide a means for measuring progress toward attainment of water quality standards (USEPA, 2017). The information is available on ChesapeakeProgress (https://www.chesapeakeprogress.com/), which includes information on more than two dozen indicators of environmental health, restoration, and stewardship. The data and information are drawn from diverse sources, including government agencies, academic institutions, nongovernmental organizations and direct demographics and behavior surveys (CP, 2022).

2.1.2.2. Chesapeake Bay Foundation

The Chesapeake Bay Foundation, founded in 1967, worked on the agreement urging effort, offering expertise and services to conduct to the public. Today it remains as one of the premier environmental organizations in the Chesapeake Bay Watershed (Powledge, 2005). The organization is one example of the CBP partnership, which serves as an accountability instrument for the restoration plans (CBP-Who, 2022; CBF-History, 2022).

The organization's primary goals are to educate, advocate, litigate, and restore the CBW. For more than 40 years, the environmental education provided by the CBF has helped monitor the system and develop goals and legislation for its recovery (CBF-Education, 2022; CBF-Restore, 2022). Its scientific study has provided much of the scientific basis for the broad interstate effort that continues today. Additionally, the advocation 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 (CBF-Advocate, 2022). Additionally, the litigation department uses legal actions as a tool to hold accountable those who violate laws, define, and drive the plans, and to deliver their restoration progress query (CBF-Litigate, 2022).

The CBF has operate through the years with the simple idea that the ecosystem needs a private-sector voice. It is a citizen awareness of the impacts they created on the ecosystem, and the eagerness to find solutions. The foundation grows stronger every day with ~300,000 members, e-subscribers, and approximately 200 staff members (CBF-History, 2022).

In summary, the CBF works to protect natural resources by advocating strong and effective laws and regulations; and holding those accountable for their actions. In addition, it actively participated in the restoration of habitat through various hands-on projects and citizen involvement, trying to inspire stewardship and volunteers by active partners and leaders (Russo *et al*., 2008).

2.1.2.3. Fisheries management

The fisheries represent jobs and tourism in the Bay; the estuary is home to 345 species of finfish and 173 species of shellfish, many of which have been fished commercially and recreationally for generations (CBF-Fisheries, 2022). In 2016, the Fisheries Economics of the USA report by the NOAA indicates that the commercial seafood industry in Maryland and Virginia contributed 1.4 billion in sales, almost 539 million in income, and more than 30,000 jobs to the local economy (CBF-Fisheries, 2022). The main commercial fisheries are blue crabs and oysters, although there are also striped bass, menhaden, and shad (Paolisso, 2007).

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act is the primary law governing marine fisheries management in the USA federal water (MSA, 2022). Since 1976, the Management Act fosters long-term biological and economic sustainability. The main objectives are to prevent overfishing, rebuild overfished stock, increase long-term economic and social benefits, and ensure a safe and sustainable supply of sea food (MSA, 2022). To develop the limits scientific data is use (MSA, 2022).

The Regional Council is a system design to allow regional, participatory governance by local people with a stake in fish management in different zones around the USA (FisheriesCouncils, 2022). The Councils are divided into eight regions, which is shown in the Figure 1. The Chesapeake Bay is inside the Mid-Atlantic Fishery Management Council (MAFMC), which develops fishery management plans and management measures, such as fishing seasons quotas and closed areas, for fifteen species of fish and shellfish. Furthermore, the Council is also responsible to manage an additional 50+ species as “ecosystem components”, meaning that it can set possession and landing limits to prevent the fisheries expansion (MidAtlantic-Fisheries, 2022).

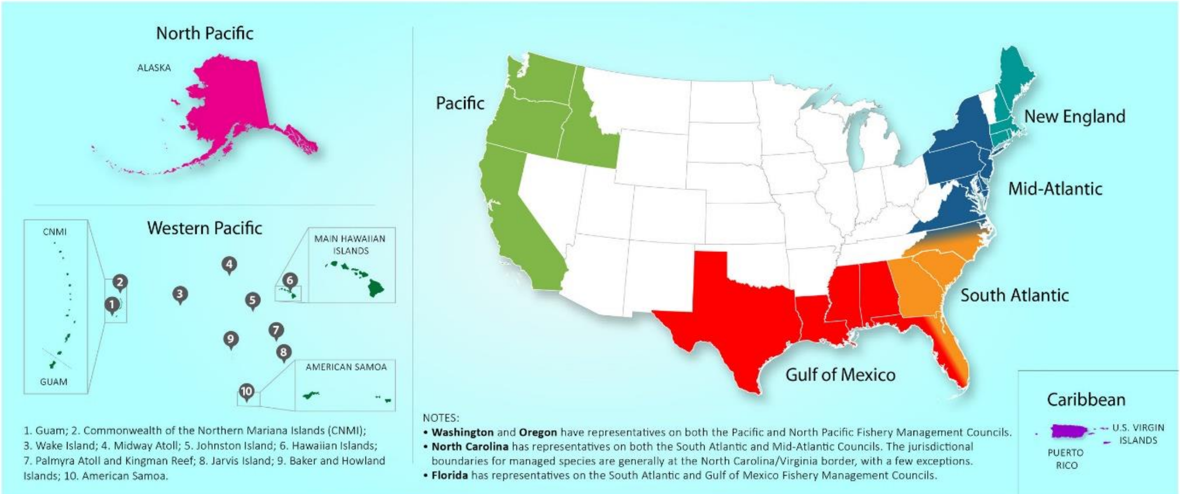

Figure 1 Regional Council for the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act in the USA, the image comes from FisheriesCouncils (2022)

The fishing species are managed under multi-species fishery management plans because they are found in the same geographic region or have similar life history. The Council manage the species within the federal 200-mile limit of the Atlantic off coasts of New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, and North Carolina (MidAtlantic-Fisheries, 2022). The Council is made up of 21 voting members and four non-voting members. Seven of the voting members represent the constituent state fish and wildlife agencies. Thirteen voting are private citizens knowledgeable about recreation fishing, commercial fishing, or marine conservation, and four non-voting members represent organizations (MidAtlantic-Fisheries, 2022).

Overall, the MAFMC leads the governance of the management fisheries. Meanwhile, the Atlantic State Marine Fisheries Commission (ASFMC) main objective is to develop sustainable fish management plans in the Atlantic Coast. To achieve this goal, the Commission strives to meet eight goals, contained within the Five-Year Strategic Plan (ASMFC, 2022). The following goals are from the five-period planning of 2019 to 2023 (ASMFC-SP,2022):

1. Rebuild, maintain, fairly allocate, and promote sustainable Atlantic coast fisheries
2. Provide sound, actionable science to support informed management actions
3. Produce dependable and timely marine fishery statistics for Atlantic coast fisheries
4. Protect and enhance fish habitat and ecosystem health through partnership and education.
5. Promote compliance with fishery management plans to ensure sustainable use of Atlantic coast fisheries
6. Strengthen stakeholder and public support for the Commission
7. Advance Commission and member states' priorities through a proactive legislative police agenda
8. Ensure the fiscal stability and efficient administration of the Commission

The decision-making occurs though the Interstate Fisheries Management Program (ISFMP). The species management boards determine management strategies that the states need to implement. The Figure 2 shows the decision-making, with the Commission being the highest level, advisory panels, technical committees, plan development and review teams prove support to the species management boards and sections (ASMFC, 2022).

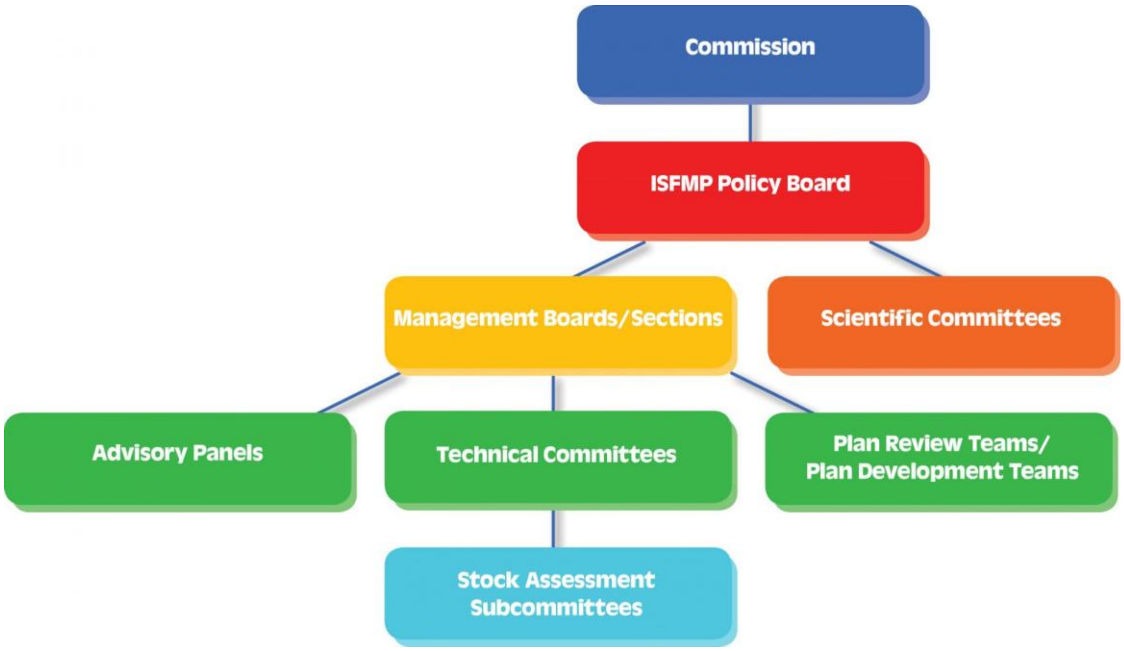

Figure 2. Atlantic State Marine Fisheries Commission decision-making conceptual map from the ASMFC (2022).

The ASMFC has several science programs, which strive to produce sound, actionable science through technically rigorous, independently peer-review stock assessment process (ASMFC-Program, 2022). Some of the program overviews are in survey, research, stock assessment, climate change, multispecies and ecosystem approaches, and economic and social science (ASMFC-Program, 2022).

Furthermore, there is also a Law Enforcement Committee, which meets twice a year to propose legal advice and guidance on the management practices. The main members are represented by the Commission's participating states and the District of Columbia, members of NOAA Fisheries Service, USA Coast guard, and the USA Fish and Wildlife Service (ASMFC-Law, 2022).

2.1.2.4. Report Cards

The academic report card serves as a communication tool that has broad appeal to and can be easily understood by the general public (Williams *et al*., 2009). Traditionally, it is used as a tool for assessing and communicating a system condition, as it provides accessible synthesized information to wider audiences (Vargas-Nguyen, 2020). To synthesis, the report cards use indicators to assemble coherent and representative scientific information about a system performance and convert them into an image-rich format (Logan *et al*., 2020; RC, 2022). The indicators must be complex, dynamic, and measurable (Logan *et al*., 2020).

Since 2006 the Integration and Application Network, University of Maryland Center for Environmental Science, has produced Chesapeake Bay Watershed Report Cards to communicate the system's overall health (RC-Publications, 2022). The report cards started with environment indicators but evolved to socio-economic indicators by 2022, representing the social-ecological system health (RC-Publications, 2022). Overall, the Chesapeake Bay and Watershed scored 64% and 50%, respectively, in 2022.

Vargas-Nguyen's (2020) thesis investigated the effect of report cards on science communication and their influence on the decision-making process. The result found there was no clear evidence that the report cards have been useful in discussing specific types of decision-making at the management policy levels. Although, the information proves helpful to local residents, giving them the knowledge to improve and protect their communities. Nevertheless, the assessment has helped identify issues through transdisciplinary collaboration involving all stakeholders of the system, which creates an atmosphere of trust, collaboration, and partnership for collective action and collective impact (Vargas-Nguyen *et al*., 2020).

Chapter 3.

3.1. Study site

3.1.1. Chesapeake Bay Watershed natural system

Located in the middle of the USA Atlantic coast, the Chesapeake Bay is one of the world's largest mixed estuaries (Figure 3) (Bilkovic *et al*., 2019; Garzon *et al*., 2018). The Bay is approximately 315 km long, with the central axis running in a north-south direction. The width of the bay varies from 20 km in its mouth to 45 km in the middle and a few km in the upper Bay (Garzon *et al*., 2018). The mean tidal amplitude varies from 0.9 m at the mouth, 0.6 at the middle, and 0.7 on the upper bay (Garzon *et al*., 2018). The tidal water covers ~11,603 km^2, which are part of the ~166,000km^2 watershed (Bilkovic *et al*., 2019). The watershed climate region is generally considered temperate-humid (Modi *et al*., 2021).

The Bay took its current form after the rising sea level when a glacier melted and flooded the Susquehanna River valley (Hardaway and Byrne, 1999). Therefore, most of the area is shallow, with 6 m in more than 50% of the system and 8% deeper than 18 m (Garzon *et al*., 2018; Boesch, 2006; Kemp *et al*., 2005). The deepest part is 53 m and is located in the middle of the Bay, in a north-south direction, which is believed to be the remnants of the ancient Susquehanna River (Hardaway and Byrne, 1999; Lin *et al*., 2002; CBP-Facts, 2022).

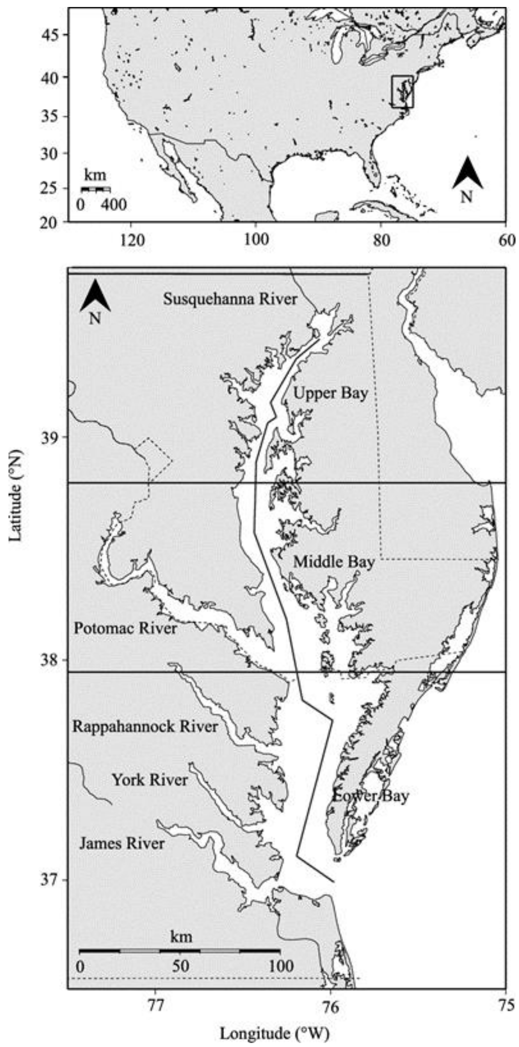

Figure 3 (Up)Chesapeake Bay location in the USA. (Down) Chesapeake Bay divisions and main rivers by Zhang et al. (2006).

Five major rivers cover the watershed: Susquehanna, Potomac, Rappahannock, York, and James, which contribute about 90% of the total freshwater to the CB (Du and Shen, 2017). An average of 2,300 m3/s of freshwater flows from the Bay's watershed into its 74.4 km3 water volume, with the Susquehanna proving ~50% of the flow (Kemp *et al*., 2005). The Susquehanna River significantly affects the stratification, sedimentation, nutrient levels, dissolved oxygen, and pollution in the region (Du and Shen, 2017).

The water input from the rivers and the Atlantic Ocean set up a strong stratification, which is characterized by a lower layer counterflow that acts to retain particulate and dissolved material (Kemp *et al*., 2005). The stratification creates long resident times for fresh water and nutrients (Kemp *et al*., 2005). The Bay has a very long, narrow, and dendritic geometry (Kemp *et al*., 2005). The combination of the later points makes this a productive system, with efficient nutrient use and a tendency for oxygen depletion from deep waters (Kemp *et al*., 2005).

The circulation dynamic of the Bay's mid- and upper- is generated by local winds, which dominate the wave climate. Ocean swell from the Atlantic Ocean can only affect the wave climate near the

Bay mouth. Swell entering the Bay mouth is either dissipated or refracted and will seldom reach mid-Bay (Boon *et al*., 1996). Although waves are generally small in the CB, they have several significant effects on the Bay's physical environment and ecosystem. For example, waves are a driving force for sediment transport shoreline erosion, and the extreme wind contributes to destratification (Lin *et al*., 2002; Kemp *et al*., 2005).

3.1.2. Chesapeake Bay Watershed socio-economic system

The Bay is located between the North American mainland to the west and the Delmarva Peninsula to the east (Orth *et al*., 2010; Garzon *et al*., 2018). The southern part of the Bay is bordered by Virginia and its northern part by Maryland. Its entrance from the Atlantic is flanked by Cape Charles to the north and Cape Henry to the south (Figure 4) (CBP-Facts, 2022).

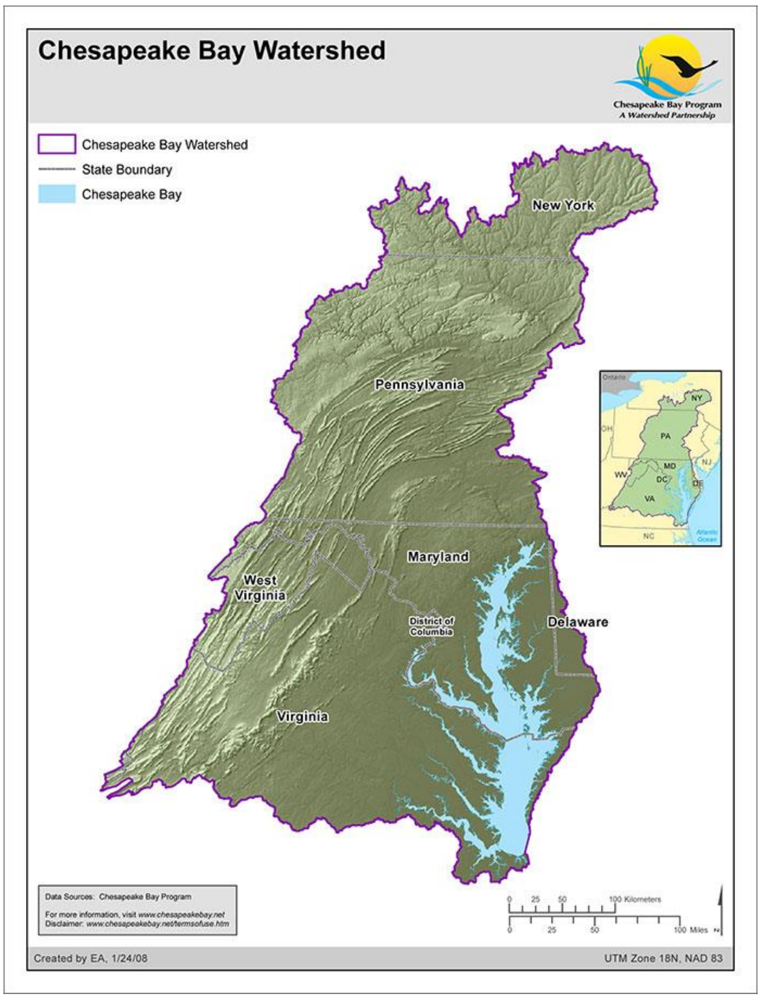

Figure 4. Chesapeake Bay Watershed with the geopolitical divisions of state by the CBP.

The Chesapeake Bay Watershed extends into New York State, contains half of Pennsylvania, the majority of Virginia and Maryland, all of the District of Columbia, and includes portions of Delaware and West Virginia (Arnold, 2021).

Currently, the land use within the watershed is diverse, which is shown in the Figure 5. Industrial and high-density urban development is concentrated on the bay's western shore near Baltimore, Maryland, and Portsmouth, Virginia. Other areas of the bay's western shore are primarily composed of oak-tulip poplar forest, urban/suburban development, and low-density agriculture. Commercial agriculture dominates the bay's eastern shore and consists of row crops, chicken farms, and pasture (DeLuca *et al.,* 2004).

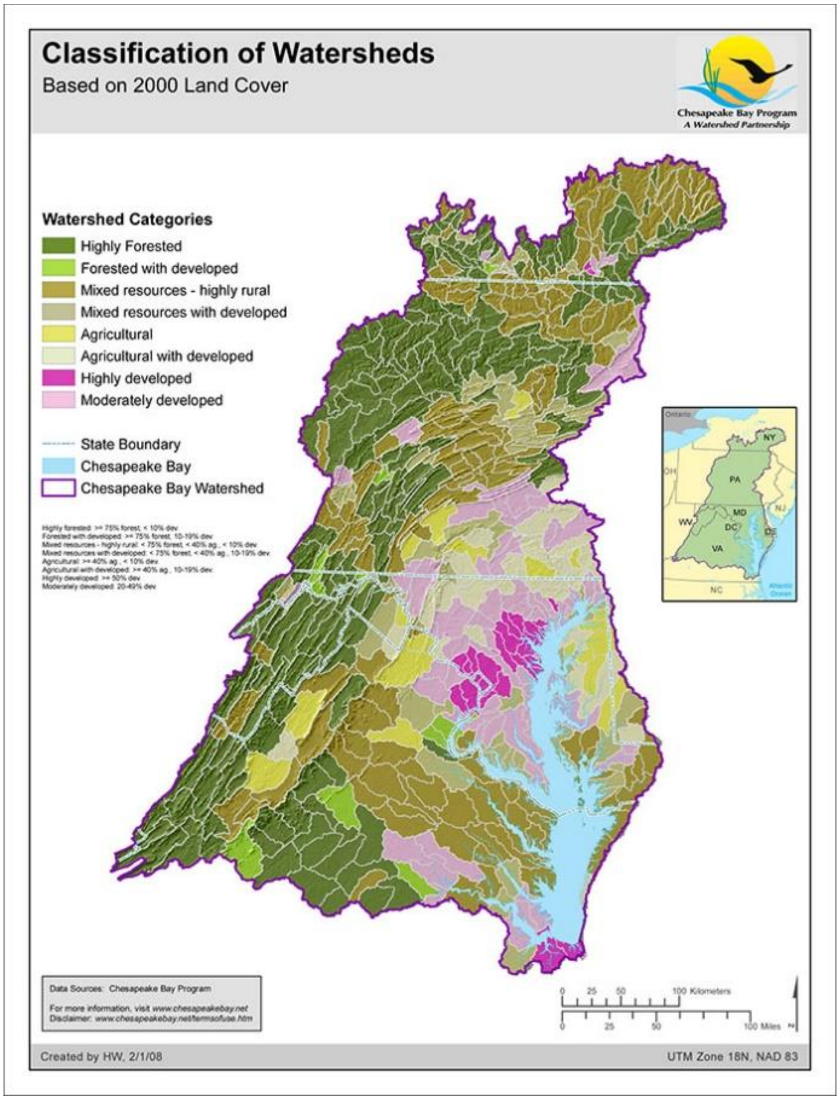

Figure 5. Chesapeake Bay Watershed land cover of 2000 by the CBP.

Chapter 4.

4.1. Method

Many holistic frameworks could be applied to the CBW, e.g., System Approach Framework, DPSIR, DAPSI(W)R(M), Ostrom, and CCS. For this thesis, the frameworks chosen were DAPSI(W)R(M), and CCS. The DAPSI(W)R(M) was chosen because it concentrated the system's information, identified the structure, and considered the socio-ecologic system. On the other hand, the CCS was chosen because it takes relevant indicators and assesses sustainability in four domains: environment, social, economic, and government. Finally, for the scoring system a literature review was developed.

4.1.1. DAPSI(W)R(M) framework

The intense and diverse use of the marine environment has led to human-induced changes in marine habitats and the ecosystem servers for human development. These problems have created a need for the development of marine policy that recognizes and considers the different communities affected (Atkins *et al.*, 2011). One of the tools used to tackle these environmental issues is the Driver- Pressure-State-Impact-Response (DPSIR) framework; this was developed by the Organization of Economic Cooperation and Development (OECD, 1993) and the European Environmental Agency (EEA, 1995) for the adaptive management of Social-Ecological Systems (SES) (Gari *et al.,* 2015).

Some problems were identified when using the framework. Elliott (2014) and Smyth *et al*. (2015) modified the framework to address them. In 2017 the DPSIR became DAPSI(W)R(M); the change made the link between different environmental problems easier to identify and develop better management strategies (Elliott *et al*., 2017). This is the methodology adopted in this study.

Therefore, the first step of this thesis was to identify the structure, function, and dynamics of the Chesapeake Bay to find the links between the Ecological, Social, Economic, and Government components. The framework links to the source of the causes and consequences of the human activities, in which Drivers (Human necessities) require Activities (by the users and developers) that create Pressures that change the State (physical, chemical, and biological) environment. A significant amount of change creates an Impact (on human welfare) that will need a Response (as Measure) (Elliott *et al*., 2017).

4.1.2. Circles of Coastal Sustainability framework

After the DAPSI(W)R(M) is completed, the Circles of Coastal Sustainability (CCS) framework is implemented, respecting the dynamic of the socio-economic and environmental system from the last framework. The CCS framework was developed by P de Alencar *et al*. (2020) with the support of Future Earth Coasts (https://www.futureearthcoasts.org/) to evaluate sustainability in a coastal zone with a holistic approach (Figure 6).

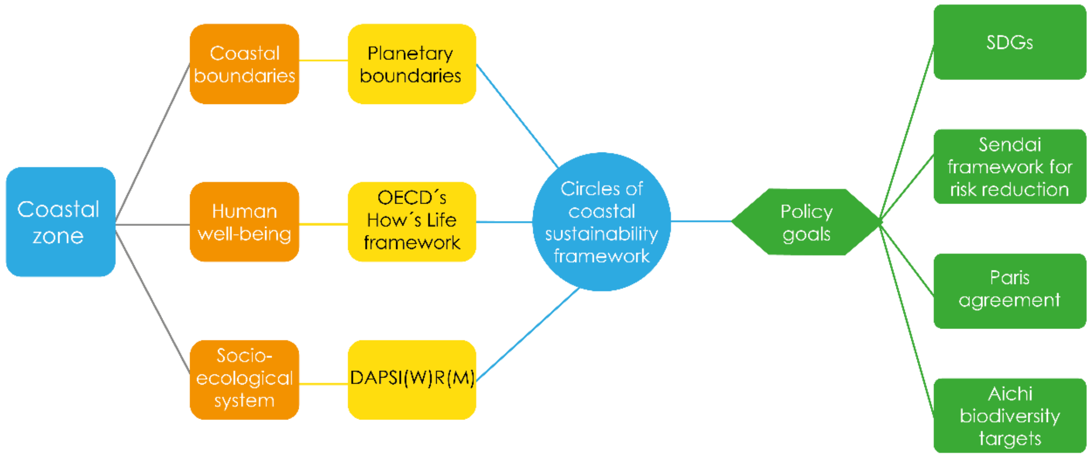

Figure 6. Adaptation of the framework organization summary of de Alencar et al. (2020). The framework is represented in the center; on the left side is the transdisciplinary content that it intends to include in the assessment, as well as the frameworks used in its creation, and on the right side is the policy goals.

The framework summarizes the ecological system's sustainability in four domains: Environmental and Ecology, Social and Cultural, Economics, and Governance and Policy. Each domain has categories that help to define the status of different coastal zones (Figure 9).

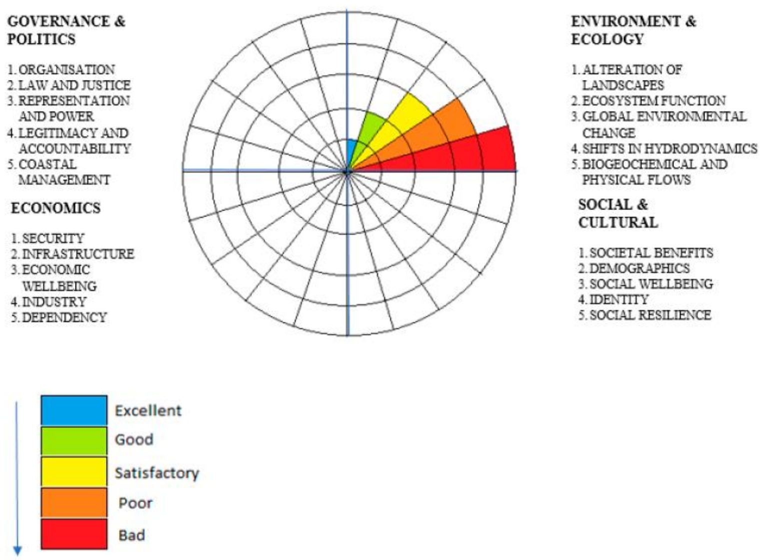

Figure 7. Example of the graphic representation of the CCS framework by P de Alencar et al. (2020). The goal of sustainability is at the center of the circle, the "bull's eye".

The graphic design to represent the CCS from P de Alencar *et al*. (2020) is shown in Figure 7. In this thesis, the design was improved to facilitate its understanding for future stakeholders. The "bulls' eye" concept was discarded for divided slides of the same size. Additionally, at the center of the design is the ecosystem name with the four domains, each of which can also have an evaluation. Finally, the last significant change was the color scheme representing the score system. P de Alencar *et al*. (2020) were inspired by the blue to red of the European Union Water Framework Directive.

However, for the new design, a more universal, globally recognized traffic light, red-orange-green, was used (Figure 8).

Figure 8. The CCS framework score system's new color scale inspired by traffic lights (red-orange-green).

Furthermore, on the outside of the wheel, there are IAN symbols (https://ian.umces.edu/media-library/symbols/), which were painted black and used as a representation of each domain division. The symbols will be respected in all domains but the environment. Due to the diversity of environments, the representation of this symbol must be chosen according to the system fauna or flora. For example, the Chesapeake Bay is known for the blue crab, which is the one chosen for this system. The symbol must be simple and give a general representation of the ecosystem.

The author of this thesis developed the final design (Figure 9) with the help of the science communication from IAN, general scientists, design experts, and the public; the public is defined by members of the society without scientific or design knowledge. The program chosen to develop the design was Adobe Illustrator 2022.

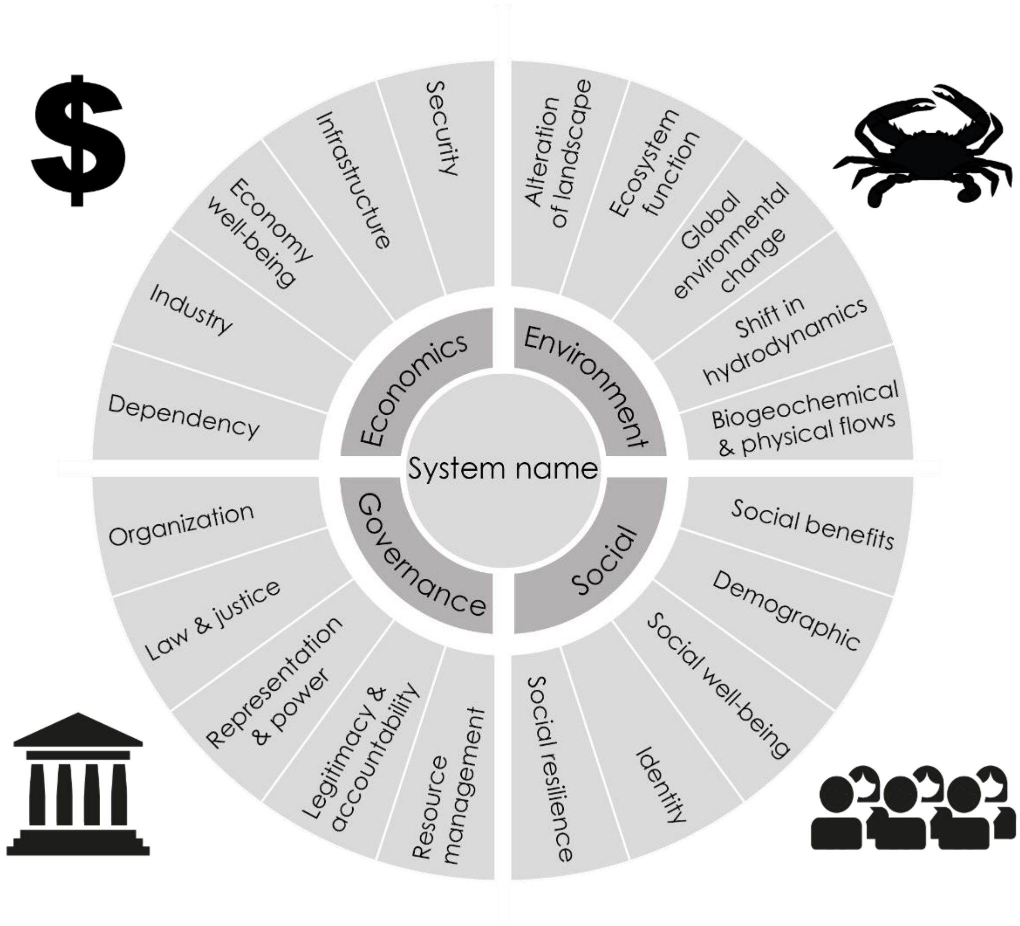

Figure 9. Graphical representation of the Circles of Coastal Sustainable (CCS) showing the domains division and categories for each assessment.

Each of the domain's categories shown on Figure 9 has what we called sub-categories, this change depending on the coastal zone, environment, economic, government, social and cultural system. The Figure 10 to Figure 13, show the sub-categories and indicators that were used for the Chesapeake Bay system.

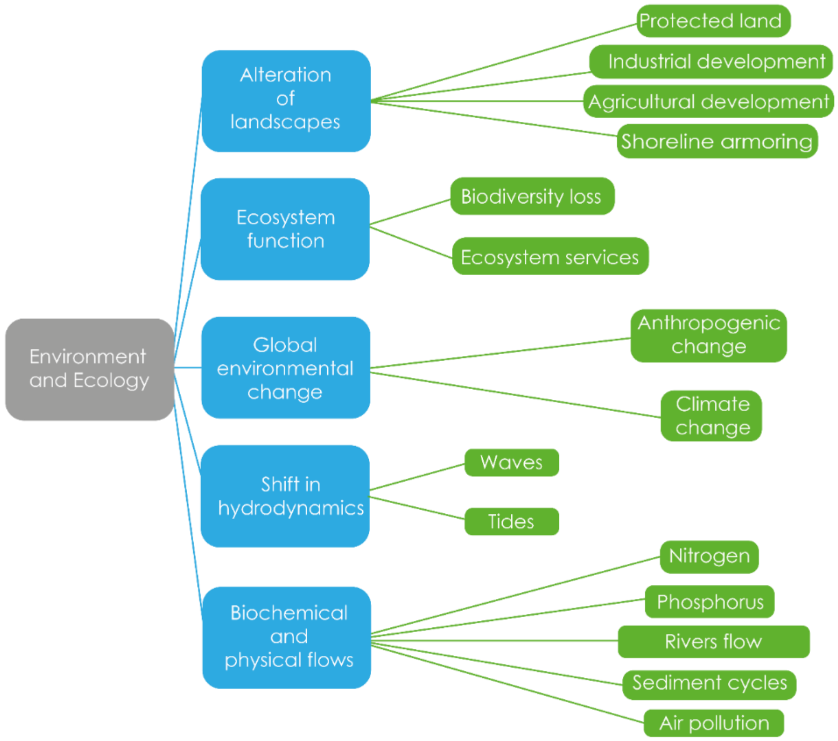

Figure 10. Environment domain with the categories in blue and the sub-categories in green (adaptation from P de Alencar et al., 2020).

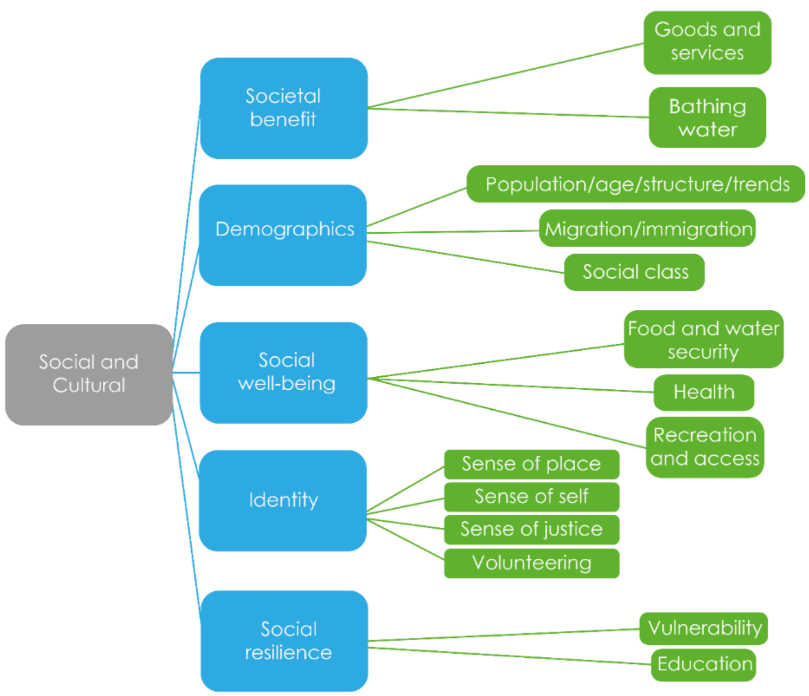

Figure 11. Social domain with the categories in blue and the sub-categories in green (adaptation from P de Alencar et al., 2020).

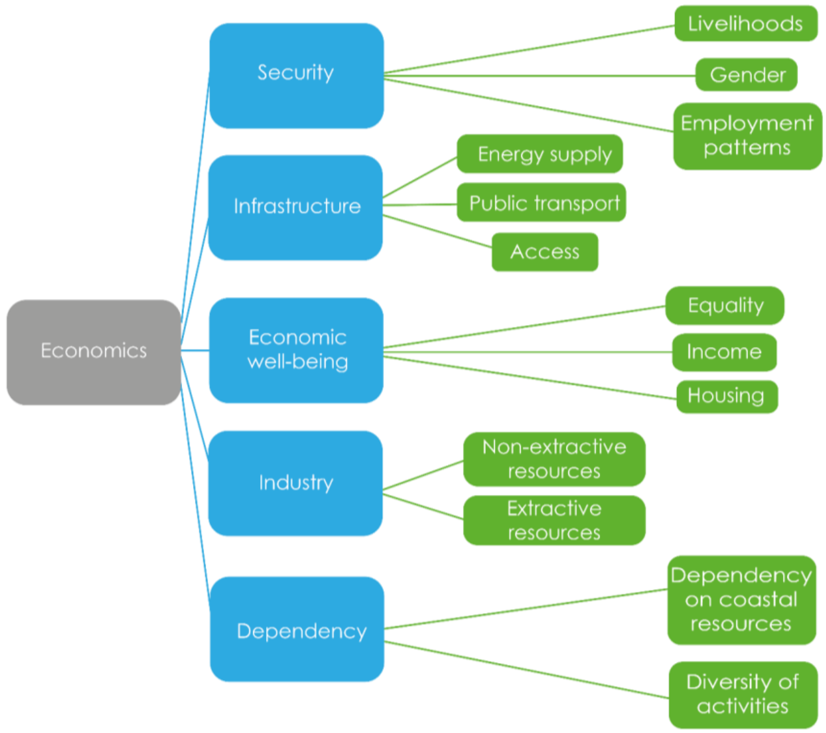

Figure 12. Economic domain with the categories in blue and the sub-categories in green (adaptation from P de Alencar et al., 2020).

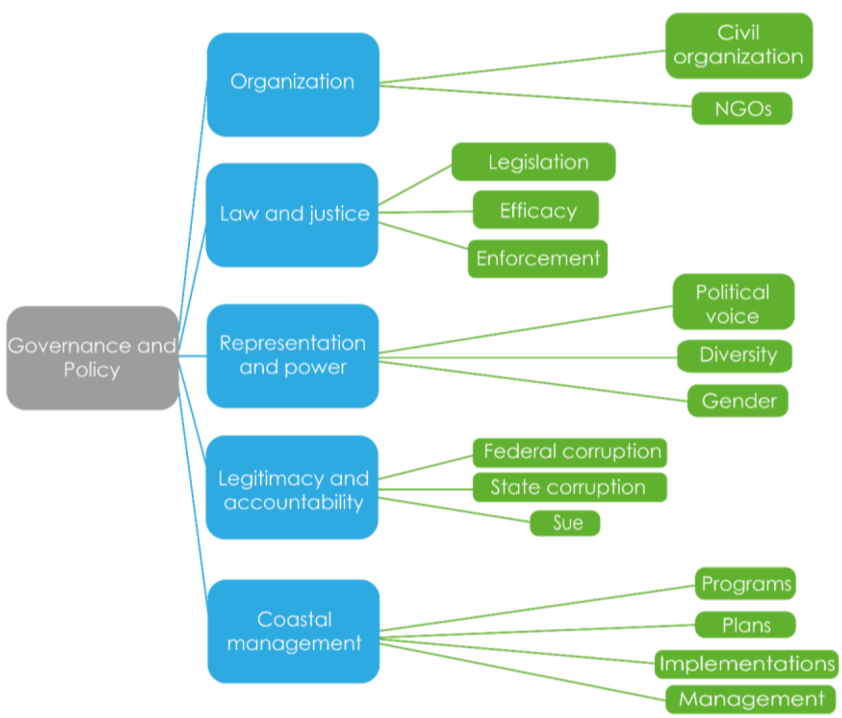

Figure 13. Governance domain with the categories in blue and the sub-categories in green (adaptation from P de Alencar et al., 2020).

For each sub-category, recognizable and comprehensive indicators are needed. The choice of indicators was made by identify measurables variables that reflect the system situation and interconnect the relationship that describes the Chesapeake Bay socio-ecological system (P de Alencar *et al.*, 2020). The indicators lead to a holistic and integrated assessment for meaningful sustainability management actions.

4.1.3. Score system

A scoring system on a scale of 1 to 5 was used to rate the sustainability levels for each domain category. Each number are represented with color labels: 1=Red for "Bad", 2= Orange for "Poor", 3=Yellow for "Satisfactory", 4=Light green for "Good", and 5=Dark green for "Excellent". The Figure 14 shows an example of the graphical representation of the scoring system evaluation, with only the environment categories graded.

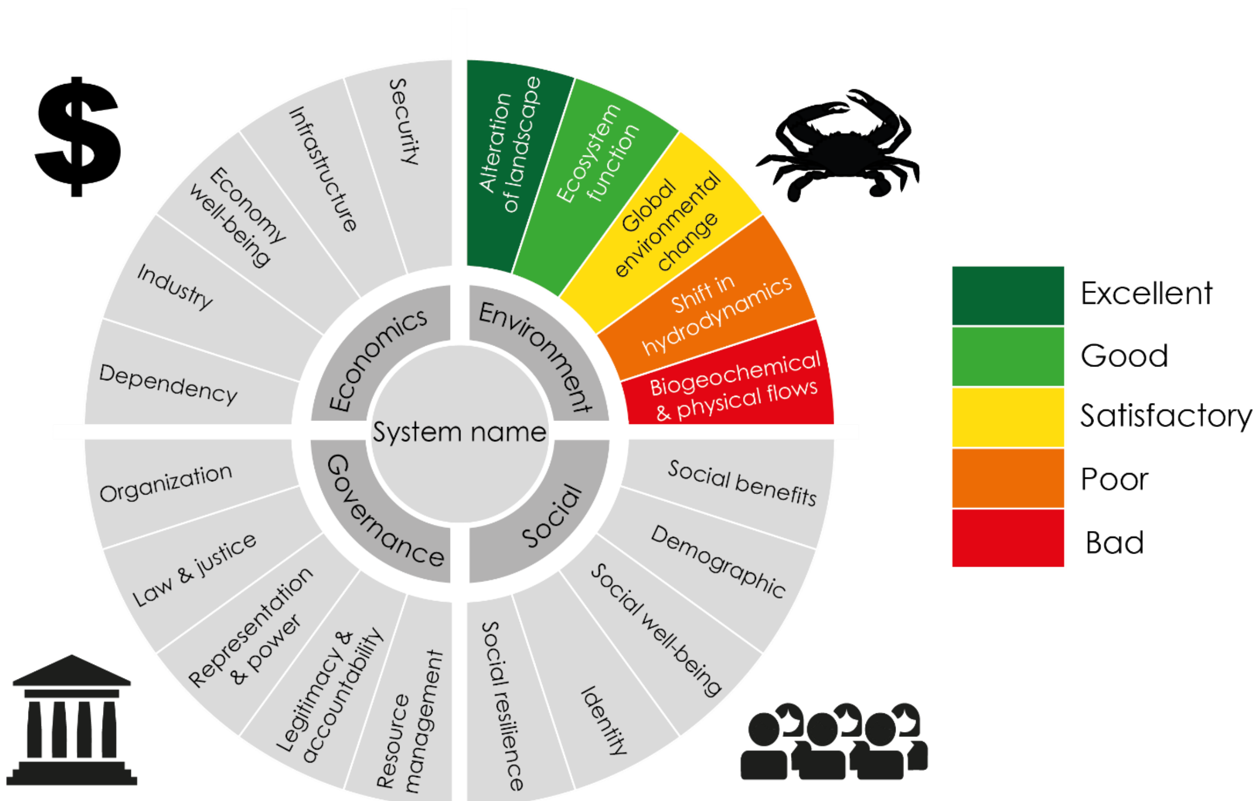

Figure 14. Example of the score system assessment application in the environment domain categories.

Most sustainability indicators are derived from a separate analysis of each domain and are not bound to measurable data; they can be descriptive, related to performance, efficiency, policy effectiveness, or overall welfare (P de Alencar *et al.,* 2020). The evaluation of sustainability for each domain was based on review of the different variables to make an informed judgment for each indicator, sub-category, and category of the system.

Therefore, an independent literature review of each domain was developed to represent each score classification. The literature review started with the definitions of "Bad" and "Excellent" scores due to the accessibility of this information. The "Excellent" score was based on Borowy (2013) definition of sustainability "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" for each domain. Furthermore, the definition of "Satisfactory" was developed aiming for the middle ground between the best and worst thresholds but always working towards sustainability. The last two scores ("Good" and "Poor") were defined using the other definitions thresholds. The "Good" score is based on the ability to improve and change over the years. Meanwhile, "Poor" is mainly defined by the resistance to acting.

Furthermore, a definition for each score rating was developed for each domain, with a graphic representation of the variables considered for their sustainability. This definition was applied to each indicator, sub-category, and category of the system to make an informed decision about the overall sustainability of the system. Finally, an overall and domain score was obtained by arithmetic average with the number assign for each score assessment for each category.

Chapter 5.

5.1. Results

5.1.1. DAPSI(W)R(M) framework apply to Chesapeake Bay Watershed

The table has three divisions: on the right, there is the DAPSI(W)R(M) framework, and each line represents a component with a parenthesis description of the same. The second column is the Chesapeake Bay watershed and coastal system management issues. The number on the left is a way of representing the link between each component. Finally, the last columns are the sources where each data was collected.

Table 1. Application of DAPSI(W)R(M) in Chesapeake Bay Watershed.

DAPSI(W)R(M) Framework	**Chesapeake Bay Watershed Coastal System**		**Source/Citation**
1. Drivers (basic human needs)	[1.1]	Population growth	Kemp *et al*. (2005) ; CBF-Population (2022) ; McConnell (1995)
	[1.2]	Food security	Phillips and McGee (2016);
	[1.3]	Commercial Development	NPS-CB (2022)
	[1.4]	Recreation	Phillips and McGee (2016);
	[1.5]	Energy	eia (2022)
2. Activities (human intervention to get the basic human needs)	[2.1]	Land change for agriculture **[1.2] [1.3]**	Roberts and Prince (2010); CBP-Issues (2022)
	[2.2]	Coastline changes for development **[1.1] [1.3] [1.4]**	Patrick *et al*. (2016); Hardaway and Byrne (1999)
	[2.3]	Coastline change due to industrial fisheries **[1.2] [1.3]**	Jackson *et al*. (2001)
	[2.4]	Fishing **[1.2] [1.3] [1.4]**	CBF-Fisheries (2022)
	[2.5]	Agriculture fertilization **[1.2] [1.3]**	Ator *et al*. (2020)
	[2.6]	Burning fossil fuel **[1.1] [1.2] [1.3] [1.4] [1.5]**	NPS-CB (2022)
	[2.7]	Urban/Suburban development **[1.1] [1.3] [1.4]**	CBP-Dev (2022); CBF-Sprawl (2022)
	[2.8]	Ports activities **[1.3]**	Gottschalk (1945)
	[2.9]	Dam constructions **[1.5]**	Cooper (1995); Palinkas *et al*. (2019)
	[2.10]	Fracking **[1.5]**	George (2019); Wells and Mueller (2014)

3. Pressures (mechanism of change from Activities)	[3.1]	Increased suspended sediment flux **[2.1]**	Ator *et al*. (2020)
	[3.2]	Decrease of tidal vegetation **[2.2] [2.3]**	Patrick *et al*. (2016); Hardaway and Byrne (1999); Jackson *et al*. (2001)
	[3.3]	Overfishing of key economic species **[2.4]**	Orth *et al*. (2010) ; Jackson *et al*. (2001)
	[3.4]	Overfishing filter feeders **[2.4]**	Rothschild *et al*. (1994)
	[3.5]	Excess nutrient runoff **[2.5] [2.6] [2.7]**	Frankel *et al*. (2022); McConnell (1995)
	[3.6]	Atmospheric deposition **[2.6] [2.7] [2.9]**	Da *et al*. (2018); CBP-AirPollution (2022)
	[3.7]	Increased wastewater **[2.7] [2.8]**	Tango and Batiuk (2013)
	[3.8]	Introduction of invasive species **[2.8]**	CBP-InvasiveSpecies (2022); Fabrizio *et al*. (2021)
	[3.9]	Block of fish passage **[2.8]**	Cooper (1995)
	[3.10]	Enhance earth permeability **[2.9]**	Pusch, *et al*. (2016)
4. State Changes (alteration of the natural system due to the Pressures)	[4.1]	Increased time and area of hypoxia **[3.1] [3.2] [3.4] [3.5] [3.6] [3.7]**	Frankel *et al*. (2022)
	[4.2]	Increased turbidity **[3.1] [3.2] [3.4] [3.5]**	Zhang *et al*. (2018)
	[4.3]	Decrease of wildlife diversity **[3.2] [3.3] [3.4] [3.8] [3.9]**	Zhang *et al*. (2018); Cooper (1995)
	[4.4]	Increased pollution on the tributaries **[3.1] [3.2] [3.4] [3.5] [3.6] [3.7] [3.10]**	Kaufan *et al*. (2021)
	[4.5]	Increased air pollution **[3.6]**	Sheeder *et al*. (2002); AirPollution (2022); Srebotnjak and Rotkin-Ellman (2014)
	[4.6]	Increased groundwater pollution **[3.10]**	Hagström and Adam (2012);
	[4.7]	Increased of earthquake **[3.10]**	Hagström and Adam (2012);

5. Impacts (con society welfare)	[5.1]	Water quality **[4.1] [4.5]**	Kemp *et al*. (2005)
	[5.2]	Sustainable Economy **[4.1] [4.2] [4.3] [4.4]**	Phillips and McGee (2016)
	[5.3]	Human health **[4.4]**	Birch *et al*. (2011)
	[5.4]	Environmental justice for local communities **[4.1] [4.2] [4.4] [4.5] [4.6] [4.6] [4.7]**	Steinzor *et al*. (2012); George (2019)
	[5.5]	Aesthetic **[4.2] [4.3] [4.4] [4.5]**	Walsh *et al*. (2017)
	[5.6]	Environmental resilience **[4.1] [4.2] [4.3] [4.4] [4.5] [4.6]**	Kenney and Gerst (2021); Miller Hesed *et al*. (2020)
	[5.7]	Ecosystem services **[4.1] [4.2] [4.3] [4.4] [4.5] [4.6] [4.6] [4.7]**	Phillips and McGee (2016)
6. Responses (Measures)		Chesapeake Bay Watershed Agreement **[5.1] [5.2] [5.3] [5.5] [5.6] [5.7]**	CBP-CBWA (2014)
		Watershed Implementation Plan **[5.1] [5.2] [5.3] [5.5] [5.6] [5.7]**	EPA-WIP (2022)
		Total Maximum Daily Load **[5.1] [5.2] [5.3] [5.5] [5.6] [5.7]**	CBP-TMDL (2022)
		Clean Water act **[5.1] [5.2] [5.3] [5.7]**	EPA-CWA (2022)
		Clean Air Act **[5.1] [5.3] [5.4] [5.7]**	EPA-CAA (2022)
		Fish Management **[5.2] [5.7]**	MAFMC (2022); CBF-ASMFC (2022)
		Best Management Practices **[5.1] [5.2] [5.3] [5.5] [5.6] [5.7]**	BMP (2022)
		Chesapeake Bay Program **[5.1] [5.2] [5.3] [5.5] [5.6] [5.7]**	https://www.chesapeakebay.net/
		Chesapeake Bay Foundation **[5.1] [5.2] [5.3] [5.5] [5.6] [5.7]**	https://www.cbf.org/index.html

		ChesapeakeProgress **[5.1] [5.2] [5.3] [5.5] [5.6] [5.7]**	https://www.chesapeakeprogress.com
		Eco Health/Report Cards **[5.1] [5.2] [5.3] [5.5] [5.6] [5.7]**	https://ecoreportcard.org/report-cards/chesapeake-bay/

5.1.2. Score system

The results of the literature review started with the definitions of "Bad" and "Excellent" scores. The "Excellent" score was based on Borowy (2013) definition of sustainability "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" for each domain. Meanwhile, the score "Bad" was developed taken crisis circumstances. On the other hand, "Satisfactory" score is defined as a discontinuity system aiming toward sustainability. Furthermore, the score "Good" is defined due to the improvement and changes over the years toward sustainability have been effective and measure. Finally, the "Poor" score is mostly defined as a decay system with high resistance to take actions.

5.1.2.1. Environment

The environmental sustainability is defined by World Wildlife Fund as "Improvement in the quality of human life within the carrying capacity of supporting ecosystems" (Goodland, 1995). The carrying capacity defined by Del Monte-Luna *et al.* (2004) is "The limit growth or development of each and all hierarchical levels of biological integration, beginning with the population, and shaped by processes and interdependent relationships between finite resources and the consumers of those resources". Therefore, when the human development keeps increasing unchecked eventually will lead to unsustainable degradation and change in the ecosystem dynamics (Del Monte-Luna *et al*., 2004; Groffman *et al*., 2006). According to Groffman *et al*. (2006) and Johnson (2013), an ecological threshold is when there is an abrupt change in the ecosystem quality, property, or phenomenon, which is associated with the limits of human development where multiple activities may interact on an ecological system.

On the other hand, Olsen's (2003) article defined a resilient sustainable system as sustainable over a long period of time, while maintaining resources use for human necessities. According to Johnson (2013), resilience is the capability of an ecological system to absorb disturbance or environmental variation and maintain structure and function. Therefore, the definition for the ecological score were classified as:

- **Bad** when there is an abrupt change in the ecosystem quality, property, or phenomenon, which is associated with the limits of human development where multiple activities may interact on an ecological system (Borowy, 2013).
- **Poor** score will be given to the system with ecological discontinuities, defined as sudden changes in any property, with no human intervention trying to improve the critical values that going towards the ecological threshold (Muradian, 2001).
- **Satisfactory** score is a system with ecological discontinuities that the human society is trying to maintain, restore or improve (Olsen, 2003; Muradian, 2001).

- **Good** score is defined as the transition from the ecological discontinuities to the ecological resilience from climate change (Olsen, 2003).
- **Excellent** is a resilient system, sustainable over a long period of time, while maintaining resources use for human necessities (Olsen, 2003).

Furthermore, Selkoe *et al*. (2015) made a graph representing the ecological threshold depending on the ecosystem conditions and impacts. The Figure 15 is an adaptation of the graph with the scores on the top representing the definition made by the literature review. The colors represent the management targets depending on the ecosystem demeanor. The confidence interval is the moment the ecosystem degradation is starting to be noticeable for the regional population. Although most of the assessment and management projects start during this interval, the risk of crossing to a degraded system is greater. Therefore, the precautionary buffer is the management best moment to set the targets toward to a safe operating state, before getting close to the ecosystem threshold. Finally, the safe operating place main management objective is to maintain a desire ecosystem.

Although, the image represents tipping point of management targets, the score is not aligned with them. The reason is because the management targets were used to help defined the score, but they are not the definition of ecosystem sustainability, which is the main objective.

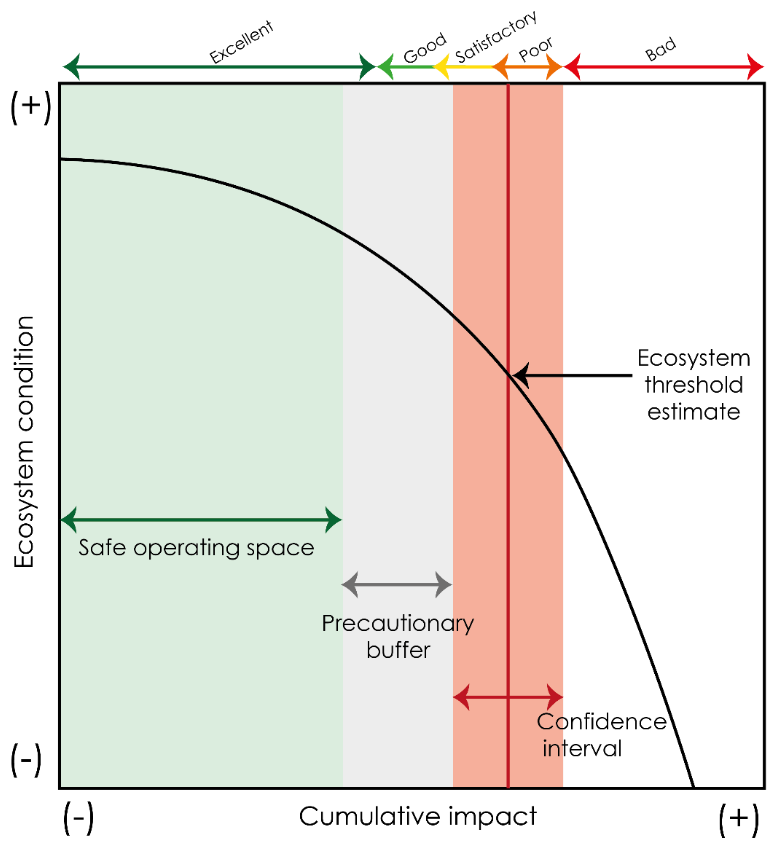

Figure 15. Graphic representation of the environment domain score system. Adaptation of the Selkoe et al. (2015) conceptial model of addressing tipping point with management targets. According to Selkoe et al. (2015), the colors inside the graph are a representation of a conceptual model to address tipping points of management targets.

5.1.2.2. Social and Cultural

The score for this particular domain was challenging as it required two different literature reviews. Nevertheless, it was merged into one, considering the two reviews. Overall, there are two significant thresholds at a societal level: individualism and collectivism (Hofstede, 1980). According to Triandis (1995), individualism is defined as a social pattern that consists of loosely linked individuals who view themselves as independent of collectives. Meanwhile, in collectivism societies, people are interdependent within their groups, shape the behavior primarily based on in-group's norms, and behave in a communal way (Mills and Clark, 1982).

However, in recent decades, globalization has been a powerful force of society and cultural change (Chiu *et al*., 2011). Globalization is defined by Arnett (2002) as a process by which culture influences one another and becomes more alike through trade, immigration, and the exchange of information and ideas. Since the post-industrial revolution, globalization has raised a new culture called "Industrial culture" (Harfst *et al*., 2018; Birkeland, 2008). For this thesis, "Industrial Culture" was defined as a society with subjects and objects valued as a profit mechanism; subjects were the humans and objects the system's natural resources.

On the other hand, there is the local culture, with the patterns, norms, creation, and rules that human communities develop that divide the human societies; the definition used in this thesis (Soini and Birkeland, 2014). Although sometimes the culture and environmental conservation are related is not always the case, and sometimes it can cause direct harm. Nevertheless, the culture and society that brought the culture were linked with environmental diversity; therefore, locals have essential knowledge of the ecosystem (Soini and Birkeland, 2014; Nazarea, 2006). Considering all the information above, the score developed for this thesis considers these thresholds to develop a score:

- **Bad** was given to a system that does not consider the individual's well-being or the general society. It can be a culture used as an instrument of economic growth (industrialism) or a conformity society with no place for any development (Soini and Birkeland; Triandis, 2001; Birkeland, 2008).
- **Poor** recognized the local culture and the need for development as an instrument to address social poverty and inequity, considering the diversity of perceptions, values, and lifestyles (Soini and Birkeland; Triandis, 2001; Vallance *et al*., 2011).
- **Satisfactory** recognized the local culture and the need for development as an instrument to address social poverty and inequity, considering the diversity of perceptions, values, and lifestyles. The society is concerned with the changes in behavior by education and society cohesion between each other with nature; meanwhile protecting the individual and cultural identities (Amberg, 2010; Kong, 2009; Soini and Birkeland; Triandis, 2001; Vallance *et al*., 2011).
- **Good** is the transformation of the culture and society identity with the sustainability of the environment, preserving the socio-cultural patterns and practices in the context of social-economic development; as well as the individual well-being (Vallance *et al*., 2011; Soini and Birkeland, 2014; Birkeland, 2008; OECD-WB, 2014).
- **Excellent** was given to a cultural vitality system that is founded on sustainable development, a society that actively supports the capacity of current and future generations to create

healthy and livable communities (McKenzie, 2004; Soini and Birkeland, 2014). According to Amberg (2010), cultural vitality is defined as proving a sense of belonging, shared meaning of recognition of identity, respect for society, creativity, and education.

The Figure 16 shows the representation of the literature review; the goal of sustainability is at the center of the circle as a "bull's eye". The graphic represents that every extreme creates no sustainable cultures and societies. For example, collectivism emphasizes conformity, obedience, security, and reliability; it creates conformity or authoritarian societies without a sense of independence and individual well-being pursuits (Triandis, 2001). The difference between the authoritarian and conformity societies is the goal they are pursuing; one is more related to the local culture and the other to the economic value (Birkeland, 2008; Soini and Birkeland, 2014).

On the other hand, individualism creates competitive environments with high social awareness and no sense of belonging (Triandis, 2001). The individualism in an "Industrial culture" creates competitive environments with high social anxiety among individuals that focus their value on personal achievement at the cost of interpersonal relationships (Ogihara and Uchida, 2014). In more local culture, the individualism develops more into an envious society that tries to put themselves down, which is often described as the "Crab mentality" with the analogy of the behavior of crabs in a basket that tries to climb out and, in the process drag each other down so that none of them manage to get out (Lasquety-Reyes, 2016). Overall, the western society is located more in an industrial and individualistic society were the score are visible in the Figure (Ogihara and Uchida, 2014).

Nevertheless, each variable defined in the graph has positive influences if not taken to an extreme. The individualistic system has positive influences by giving independency and autonomously decisions and high social mobility, such as being able to choose desirable persons to interact with, which tends to increase happiness (Ogihara and Uchida, 2014). Collectivism gives a set of instrumental values that can help to think more holistically, with a cooperative and duty mindset, social security, reliability in others, a sense of self and place that can change to adapt to the social environment expected from them (Triandis, 2001). The middle ground between the two is where people are independent of each other but actively seek an interpersonal relationship with the local society they choose to be part of (Ogihara and Uchida, 2014).

Likewise, the industrial culture has developed globalization, with the experience of welfare, economic growth, and a change in value systems (Birkeland, 2008; Ogihara and Uchida, 2014). The exchange of information between local cultures and social values has been so robust that a global mono-culture is rising, challenging the set values of societies to pursue cultural vitality considering the best of each culture (Arnett, 2002; Amberg, 2010).

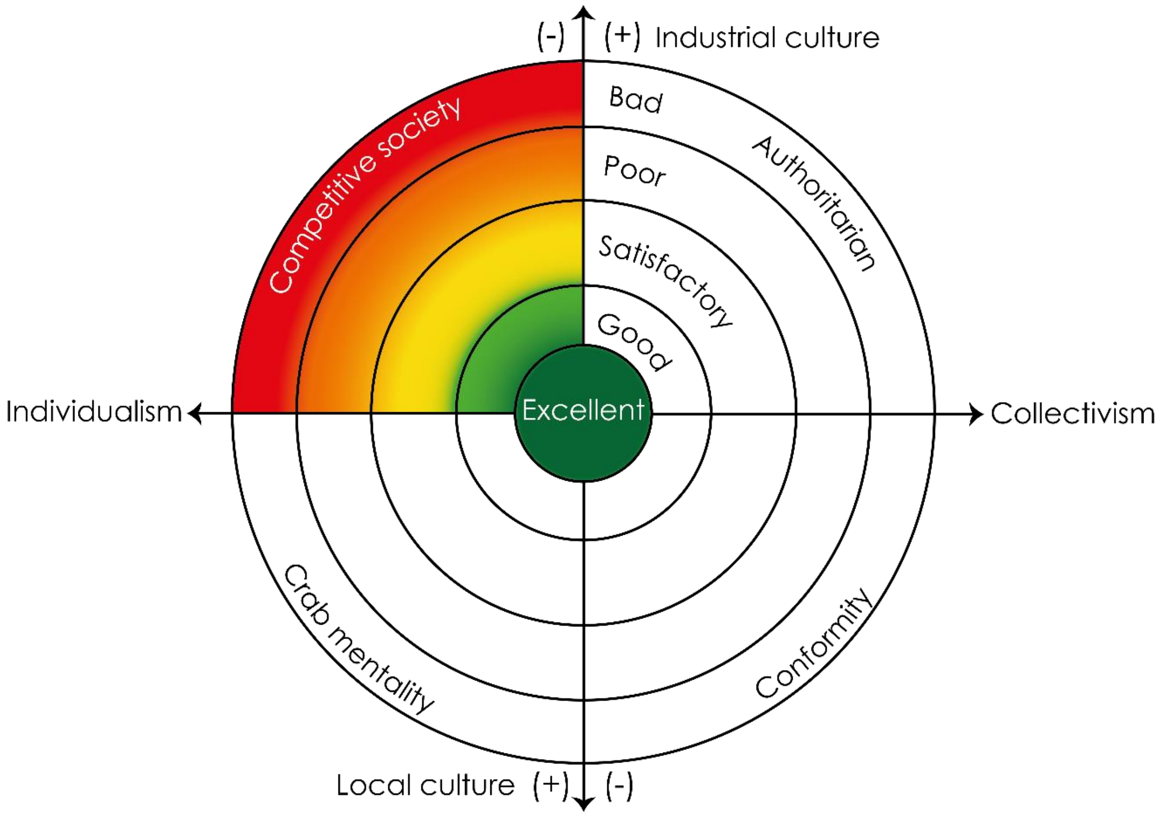

Figure 16. Graphic representation of the social domain score system.

5.1.2.3. Governance and Policy

For the scores in government, the Ostrom (1990) article was used; this study has been broadly used to diagnose the functionality of common-pool resources (CPR) dependent upon different types of natural resources across the world (Gari *et al.*, 2017). Ostrom (1990) developed eight design principles (DP) and defined them as essential elements or conditions for the success of sustainable government.

1. **Clearly defined boundaries** Who are the people that are entitled to the resources in a physical boundary.
2. **Congruence between appropriation/provision rules and local conditions** Rules are congruent with the time, place, technology, and/or quantity of resource units to local conditions.
3. **Collective-choice arrangements** Individuals affected by the rules can participate in their modification.
4. **Monitoring** There is always extensive data available about the resource.
5. **Graduated sanctions** Appropriate sanctions and accountability for the rule violators.
6. **Conflict-resolution mechanisms** Access among the individuals affected to low-cost conflict resolution processes.
7. **Minimal recognition of rights to organize** Resources management institutions are recognized by government authorities.
8. **Nested enterprises** Appropriate multi-layers organization for enterprises.

The Ostrom principle has been tested in many situations evaluating the common-pool resources sustainable management by the robustness or lack of robustness according to the presence/absence of design principles. Gari *et al*. (2017) wrote an article about the application of this method to determine the institutional performance of case studies in different countries and continents. The choice of the literature was concentrated on three aspects:

- The application of the design principles within common-pool resources institutions
- The time the common-pool resources institution had been in place
- The performance of the common-pool resources institutions and the main factors that contributed to the outcome.

The evaluation was divided into "Absent", "Rarely Present", "Sometimes Present", "Mostly Present", and "Present". The article found several points of discussion from the results that depending on the number of institutions diagnosed as either Weak/Fragile or Robust. It was noticed that relatively young institutions could improve over time, and most of them are highly time dependent. Furthermore, there is also the uncertainty of the relationship between robustness and success, as it can have a poor implementation of the design principles and does not consider efficiency of effectiveness. Although, it also shows that the institutions with "Present" or "Mostly Present" exhibit more successful community-based resource management.

After considering the Ostrom design principles applications and the two discussions from Gari *et al*. (2017), the scores were developed. The scores development for this thesis considered the time that evaluation is made and if it is aiming to improve with objectives measured with time.

- **Bad** was developed considering the governments with crisis-related vulnerabilities and short-term crisis management capabilities (Stiftung, 2011). An example of this could be a country or place at war or an economic crisis.
- **Poor** is given to governments invested in the consumption/exploitation of resources and are only held accountable by specific individuals and collective actors (Stiftung, 2011).
- **Satisfactory** was given to a political system with the fundamental capacity to act/implement on several key issues and be held accountable with transdisciplinary collaboration (Stiftung, 2011.)
- **Good** was given to a system that has the government capacity to act and held accountability to governmental and non-governmental actors or institutions (Stiftung, 2011). The aim is to make governance more economically efficient, socially productive, and environmentally protected.
- **Excellent** was given to a system that has the government capacity to act and held accountability to governmental and non-governmental actors or institutions with participatory competence (Stiftung, 2011). The actors include citizens, legislatures, parties, associations, and the media that monitor the government activities to improve the quality of government (Stiftung, 2011). The aim is to make governance more economically efficient, socially productive, and environmentally protected.

The Figure 17 represents the scoring system; it was developed considering the literature review. The first variables in the vertical and horizontal are the capacity of the government to act and be accountable. After the two of them have at least a middle capacity, another two variables are taken into consideration, the transdisciplinary collaboration and holistic management.

Assuming the executive capacity was the only variable considered, the government actor's decision would only be beneficial to specific individuals, which is the economic or government actors in most cases. Therefore, holistic management (defined by Savory and Butterfield, 1999) adds diversity into the decision-making process by considering the complexity of the environment and culture of the system, which links to Ostrom DP.

The horizontal axis has executive accountability and transdisciplinary collaboration. The actions made by the government must have accountability inside and outside its system, with different disciplines evaluation from different actors. The transdisciplinary collaboration focuses on solving new, highly complex concerns in many areas concerning science, technology, social problems and policy, education, and the arts (Bernstein, 2015). If only one discipline is taken into consideration, the accountability will be centered on one result and not on the sustainability of the whole system. Therefore, the accountability must collaborate on different science for the score to improve.

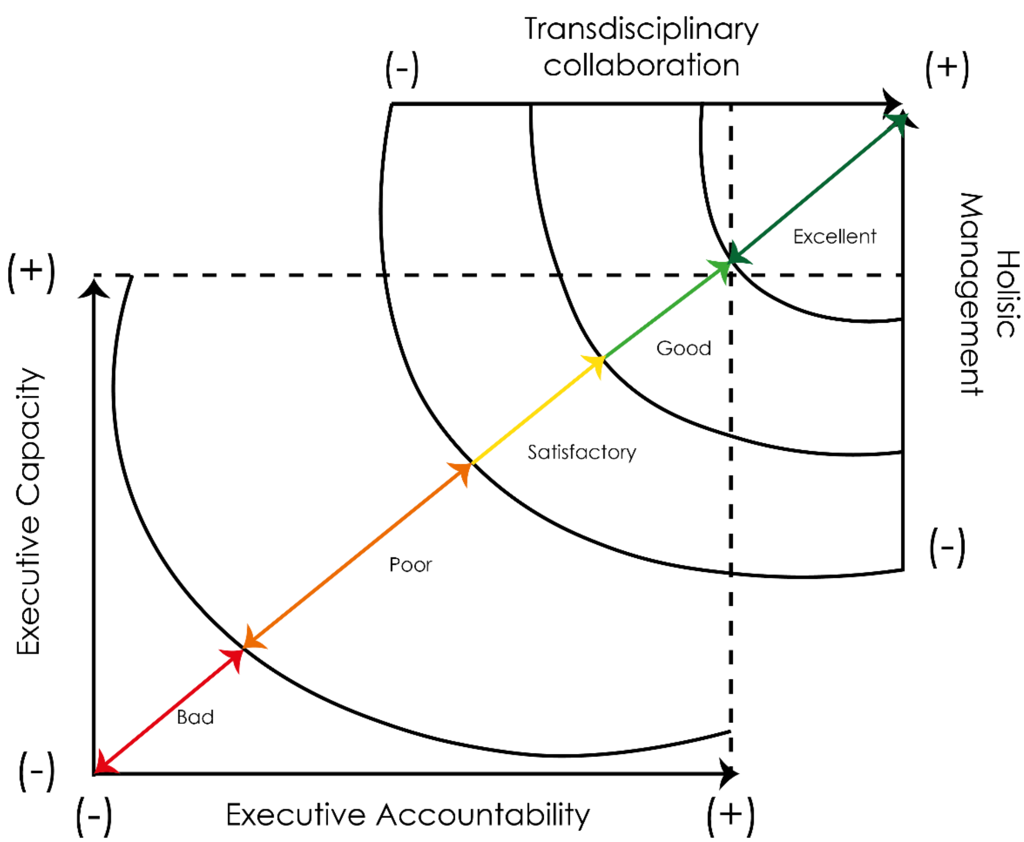

Figure 17. Graphic representation of the government domain score system.

5.1.2.4. Economic

Most of the definitions for the economy were taken from Goerner *et al*. (2009) article, which combined thermodynamic, network, and information-theoretic measures with research on real-life for any complex matter/ energy flow ecosystem, to create a new narrative for long-term economic health and sustainability.

- **Bad** was given to a system that heavily depends on a resource or it is overexploiting it in a very inefficient way (Anand and Sen, 2000; Goerner *et al*., 2009).
- **Poor** was given by Goerner *et al*. (2009) and Foy (1990) as the obsession with Gross Domestic Product growth, efficiency, and maximizing profit for owners regardless of the cost of environmental degradation assets.
- **Satisfactory** is given to a system that has the most significant amount that can be consumed in the current period without reducing the prospect for the future (Anand and Sen, 2000). The focus must be on developing the local economy like small-business, micro-credits, local network facilitation groups, and small enterprise incubators (Goerner *et al*., 2009).
- **Good** is a system that is going to be more focused on resilience during economic growth. This economic vitality requires the exchange of diverse alternatives and efficient performance that produce long-term vitality in all flow systems (Goerner *et al*., 2009).
- **Excellent** the economic system is resilient, diverse, and efficient by maintaining and improving the assets base so the following generations can live better or equally (Anand and Sen, 2000; Goerner *et al*., 2009). Although, Goerner *et al*. (2009) found that sustainability is situated toward environmental resilience.

The Figure 18 is a graph adapted from Goerner *et al*. (2009), with the two variables dependent on economic sustainability, economic efficiency and environmental resilience. According to Goerner *et al*. (2009), efficiency is the network's capacity to perform in an organized and efficient manner to maintain its integrity over time. On the other hand, resilience is the diversity of actions that can be made to meet the necessities of novel disturbances with the novelty needed for the ongoing development and evolution of an environmental system.

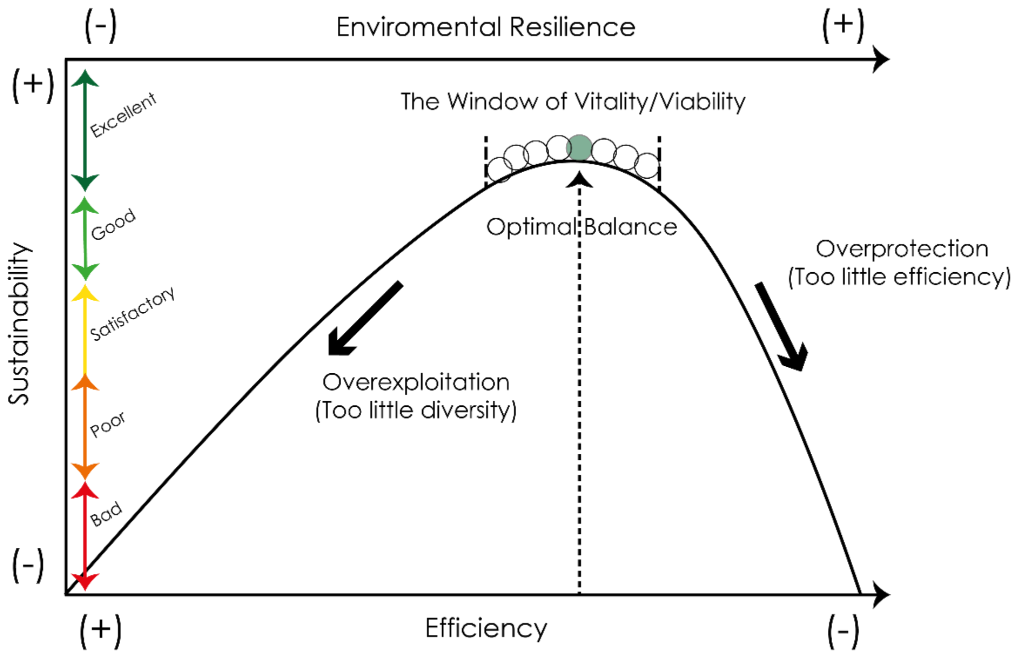

Figure 18. Graphic representation of the economic domain score system. Adaptation from the sustainability as a function of effiency and resilience from Goerner et al. (2009).

5.1.3. Circles of Coastal Sustainability application to Chesapeake Bay Watershed

The results of the Chesapeake Bay Watershed using the CCS framework are present in the Figure 19. Overall, the CBW got a "Satisfactory" score. The environment, economic, and governance results are "Satisfactory," and the social domain obtain a "Poor" score.

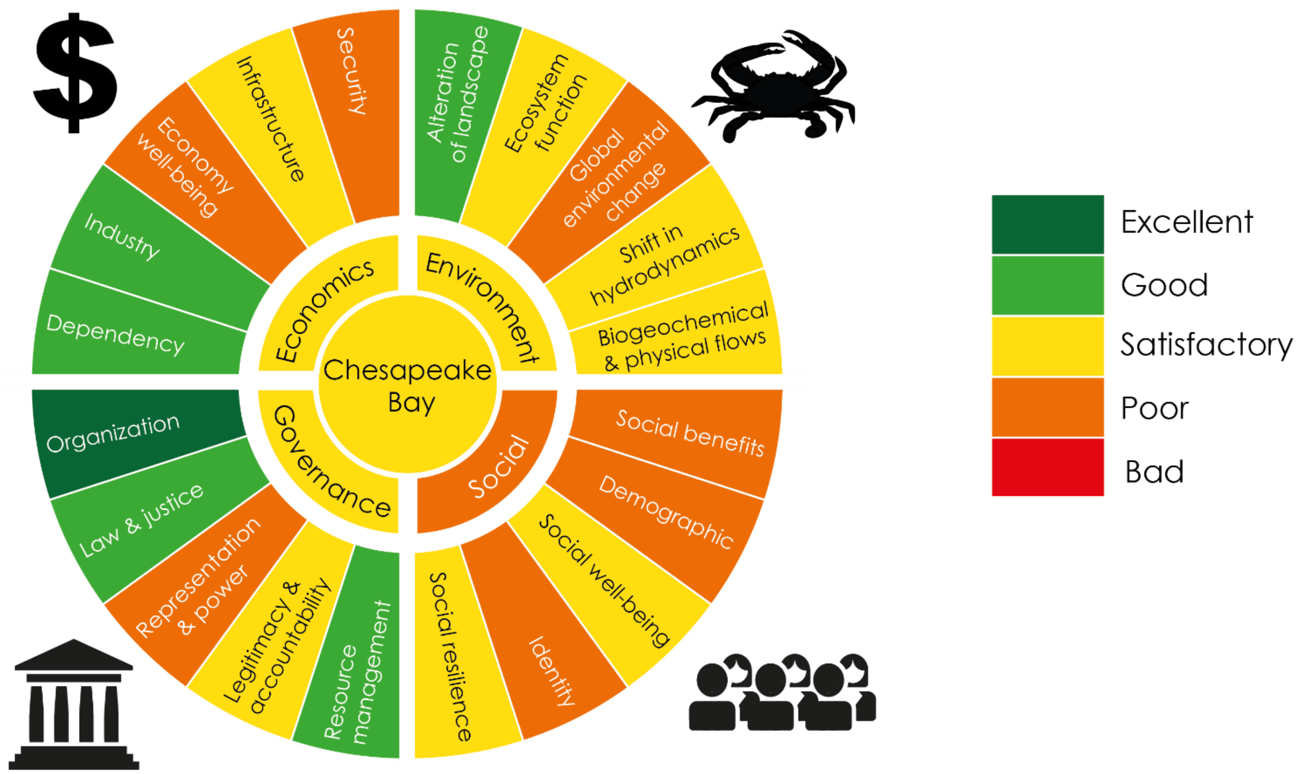

Figure 19. The CCS results from the Chesapeake Bay Watershed.

5.1.3.1. *Environment and Ecology*

- Alteration of landscape – Good

The score "Good" was given because land protection is high and increasing, the shoreline armoring is moderating and stopping, and the submerged aquatic vegetation (SAV) restoration is relatively high overall.

According to data collected through early 2019, nearly 22% of the total land in the region is protected, which is 69% of the conservation goal adopted in the WIP agreement (CP-ProtectedLand, 2022). State agencies are the most significant contributions to land protection: they own approximately 44% of the protected acres in the Watershed. However, private organizations, non-governmental organizations, local governments, and other entities have also been highly active in land conservation and remain critical partners in land protection efforts (CP-ProtectedLand, 2022).

Another essential alteration of landscape is on the shoreline. Eight sub estuaries on the Bay are 50% armored, and 23% more are between 30% and 50% armored (Patrick *et al.*, 2016). Shoreline armoring is another potential driver of SAV loss. According to CP-SAV (2022), 48% of SAV vegetation has been restored; the target is to achieve 130,000 acres by 2025. There has been a decrease in SAV acres restoration in the last two years (CP-SAV, 2022).

- Ecosystem function – Satisfactory

The score "Satisfactory" was given because the oyster restoration projects are increasing, the wetland restoration is starting, forest buffer is moderated restore and increasing, the SAV restoration is relatively high, and the fish passages are completely open. Nevertheless, invasive species have put in danger local diversity and there is no overall information about the recovery of the ecosystems by the projects implemented.

Oyster, SAV, wetland, and forest buffer provide vital services for the wildlife and human settlements; each of these indicators were used to evaluate the ecosystem function of the Bay (Jackson *et al*., 2001; Kemp *et al*., 2005). By 2020, ten selected tributaries were selected for oyster restoration, three of them have been restored, and an eleven tributary have been added (CP-Oysters, 2022). On the other hand, the wetland has been restored to 10% of the target put by the Chesapeake Bay Program; and the forest buffer has gone 55% of restoration; rivers will not be protected until at least 70% of their edges are buffer (CP-Wetland, 2022; CP-Forest, 2022). SAV has already been mentioned in the "Alteration of Landscape".

The abundance of biodiversity is an indicator of ecosystem health (Gamfeldt *et al*., 2008), and most of the species in the Chesapeake Bay are increasing, according to the CP-AbundantLife (2022). However, the introduction of invasive species in the CBW has put more than 40% of the nations at risk and further decline, according to the Center for Invasive Species and Ecosystem Health (CBP-InvasiveSpecies, 2022). Furthermore, the fish migration routes for reproduction have been open and reached their 2025 goal (CP-Fish, 2022). This indicator can help with the consistent presence of fish diversity for economic value species (CP-Fish, 2022).

- Global environmental change – Poor

The score "Poor" was given because the Bay physical and geochemical condition is changing and there is no climate change adaptation project, although it's in the making.

Some of the projected changes to the physical dynamics by the end of the 21st century within the Bay due to climate change are changes in wind patterns, large-scale increases in temperature (+4.5°C) and precipitation (10%) (Frankel *et al*., 2022; Modi *et al*., 2021). This will increase the coastal flooding submerging the wetland, increase the salinity, increase the time and area of hypoxia, reduce SAV vegetation, and alter interaction among trophic levels (Najjar *et al*., 2010). However, there is no climate change adaptation to enhance the resiliency of the Bay and the aquatic ecosystem due to limited progress on the Climate Monitoring and Assessment Outcome, which will provide information to guide adaptive actions (CP-ClimateChange, 2022). Although the 2014 Agreement explicitly addresses climate change goals and outcomes related to climate resiliency, monitoring, assessment, and adaptation (Hood *et al*., 2021).

- Shift in hydrodynamics – Satisfactory

The score "Satisfactory" was given because the management efforts have been able to model the hydrodynamic shift of the Bay and use it as a tool for the future changes.

Globally climate change is affecting the hydrodynamic of the Bay (Hood *et al*., 2021; Bigalbal *et al*., 2018). The Bay has an increased wave height of 0.1 m from 1979 to 2015 and a continued increase in extreme waves, such as hurricanes and tropical storms (Bigalbal *et al*., 2018). Additionally, the tidal amplitude has a predicted increase prediction of 0.75 cm/ century (Ross *et al*., 2017); with an SLR of 1 m, Zhong and Foreman (2008) found that the amplitude will increase 15 to 20% on the upper Bay.

According to Hong and Shen (2012), the SLR will strengthen exchange flow, even though the downstream transport of freshwater will be slower. In addition, the water residence time in the Bay will increase due to the increased volume and circulation change. Finally, the vertical transport will be weakened, which will increase the stratification.

The management efforts of the CBP have developed a modeling system to apply and assess the hydrodynamic of the Bay (CBP-Modeling, 2022). The prediction of locally relevant restoration outcomes from the shift in hydrodynamic may helped identify issues in the coastline and motivate further investment on management actions relevant to local communities and stakeholders (Hood *et al*., 2021).

- Biochemical and physical flows – Satisfactory

The score "Satisfactory" was given because there are studies, evaluations, and management plans about the biochemical and physical flows. Nevertheless, there are still high discontinuities in the system.

The changes in the hydrodynamics in estuaries are essential to understand the changes of biochemical processes coupled with the physical processes (Niroomandi *et al*., 2018). In 1976 a decline in natural resources forced the Government to respond to the Bay's degradation, which developed a series of models for hypoxia, one of the most characteristic features of the Bay (Frankel *et al*., 2022; CBP-Who, 2022).

The study of Frankel *et al.* (2022) has demonstrated that the nutrient and sediment reductions from 1985 to 2019 have made the CB more resilient to warming atmospheric temperatures and high discharge years by preventing additional hypoxia from developing. The same study developed a realistic numerical model hindcast, which was used to estimate the impact of the watershed nitrogen reduction on hypoxia. The results indicate that if nutrient reductions did not occur, 50-90 days of additional hypoxia would have occurred at specific locations in the oligohaline and southern mesohaline portions of the CB for the threshold of $O^2 < 3\frac{mg\ O^2}{L}$ and $O^2 < 1\ \frac{mg\ O^2}{L}$.

At the locations where oxygen remains above $3\ \frac{mg\ O^2}{L}$ threshold, a large portion of the summer due to nutrient reductions, demersal fish had greater habitat availability (Buchheister *et al.,* 2013). Within the benthic community itself, a decrease in the number of days with $O^2 < 1\ \frac{mg\ O^2}{L}$ can be the difference between life and death, as most microbenthic species experience mortality when conditions are below this threshold for only a few days (Seitz *et al.,* 2009).

5.1.3.2. Social and Cultural

- Societal benefits – Poor

The score "Poor" was given because the social benefits are link to social-status and race, and there is a reduce sense of community or identity as being part of the Bay Watershed.

The social benefits of the CBW are the food security due to the agriculture and food industry, the aesthetics and housing, and the job security; due to all of this, its economic importance in the USA is notable (Kemp *et al*., 2005; Walsh *et al*., 2017; Bilkovic *et al*., 2019).

Since the CBP, water quality has improved, and now 33.1% of the CB and its tributaries have clean water for bathing (CP-WQSA, 2022). Nevertheless, these benefits are degrading with the increasing pollution of the Watershed (Phillips and McGee, 2016). The polluted runoff that causes "Dead zones" on the CB can also contaminate the groundwater on the CBW (CBF-HH, 2022). Recent studies found that between 21-60% of the drinking water wells tested in Pennsylvania's lower Susquehanna River Basin had nitrate levels exceeding public drinking water standards. In 2001, the standard for EPA for nitrate, arsenic, and phosphate levels was set lower than 10 $\frac{\mu g}{L}$ (CBF-HH, 2022; IAN-EnvJus, 2022). The forest loss in the region is related to groundwater contamination; the forest protects and filters water for 75% of the watershed residents (CBF-HH, 2022). In Maryland, private well water makes up 20% of the water supply, further studies need to evaluate if minorities communities have more community water supply contamination (IAN-EnvJus, 2022). Drinking water high in nitrates can raise the risk of cancer, nervous system deformities in infants, hemorrhaging of the spleen, and other problems (CBF-HH, 2022; IAN).

Concerning food, the Government found mercury on all the lakes and rivers in Pennsylvania, Maryland, and Virginia, issuing a statewide fish consumption advisory (CBF-HH, 2022). Mercury pollutes waterways and contaminates fish; consumption can potentially damage human intelligence (CBF-HH, 2022). Oysters are also polluted by the runoff from the land (CBF-HH, 2022).

The contamination of air has also been a problem in the Bay. CBF-HH (2022) estimated that 20,000 heart attacks and 13,200 premature deaths per year are caused by fine particle pollution from coal-fired plants, which can also cause asthma and other lung diseases. The annual cost of illnesses and death has been estimated between 62-100 billion dollars, with the toll falling heaviest on children and the elderly.

It is important to consider the environmental justice of the region. IAN-EnvJus (2022) proposed several indicators to contribute to the evaluation of the environmental disamenities and burdens of minority communities in the CBW. The injustices includes health disparities, housing differences, hazardous waste, climate change, and accessibility to clean water (IAN-EnvJus, 2022).

- Demographics – Poor

The score “Poor” was given because the bay watershed is approaching the carrying capacity with the human population still increasing. There is also no governmental regulation as the economic growth will continue increasing with more residents.

The human population in the CBW is projected to increase from 17.3 million to 19.4 million from 2010 to 2025, about a 12% increase (Hood *et al*., 2021). The population growth in the Watershed is occurring close to tidal water and in major rivers, like the Susquehanna and Potomac, with almost two-thirds of the region residents living within approximately two km of the Bay's tidal waters (CBF-Population, 2022; Walsh *et al*., 2019). The urban population on the region has concentrated around Washington DC and the southwest of the mouth’s Bay. Meanwhile, the rural population is mostly on the eastern shore of the Bay and sprawl around the watershed (McKendry, 2009).

There is also a concern that the residents are moving to bigger houses outside the city, creating a sprawl; this means unconnected, spread-out, low-density residential subdivisions and commercial areas are developing outside cities and town centers (CBP-Dev, 2022). Goetz and Jantz (2004) estimate an increase of developed land area over the next 30 years (2000-2030) of 80%, primarily through suburban sprawl. The sprawl in rural areas will develop mainly for tourism, second homes, and resort communities, although the sprawl near urban areas is also increasing in the market (Goetz and Jantz, 2004).

The 2020 Census shows that the Northeast had the largest proportion of the adult population (77.5%) and the smallest proportion of the young population (22.5%) (Census-USA, 2022). In the Watershed, 35% identify as people of color (Native American or Alaskan Native, Asian/Asian American, Black/African American, Hispanic/Latino/Latina, Other or Multi-racial/multi-ethnic) (CP-Diversity, 2022).

Between 2000 and 2009, immigration directly accounted for 66% of the population growth, considering the children born in the USA to immigrants (Ruark, 2010). Maryland experienced the most immigration-related population growth counting 98% of the state's growth; DC followed it with 41%, Virginia with 58%, Pennsylvania with 48%, Delaware with 18%, and West Virginia with 10% (Ruark, 2010). New York experienced a decrease in population; however, the immigrant population is still increasing (Ruark, 2010).

Finally, according to Ruark (2010) the population of the CBW has already grown beyond the ecosystem's carrying capacity and is on pace to exceed 23 million residents by 2050. Overpopulation is symptomatic of the impact of immigration-driven population growth and the lack of action from the federal Government to see the problem on the premise that it is a necessity for the economic model (Ruark, 2010).

- Social well-being – Satisfactory

The score “Satisfactory” was given because although the basic services are mostly provided and the Bay provides natural resources, most of them are linked to socio-status and race. Additionally, the social system is overall built on making profit without facilitation of social security from the government.

The Bay provides countless valuable and quantifiable economic services, e.g., food, beautiful scenery that promotes recreation, tourism, some of the country's highest property values, and shipping industries (Phillips and McGee, 2016). Although, several sources (Assari, 2018; Cuker and Davis, 2020; Hardy *et al*., 2018) have proven that these benefits are linked to the socio-economic status and race of the individual.

The drinking water on the Bay comes from the rivers and groundwater in the Bay's Watershed. However, increasing pollution studies have found that between 21 and 60% of wells tested in Pennsylvania and 20% in Maryland have exceeded the standard (CBF-HH, 2022; IAN-EnvJus). More studies about the water system and minorities must be conducted. Furthermore, IAN-EnvJus (2022) has talked of possible indicators about housing segregation in minority communities and its proximity to hazardous waste sites, leading to more health issues.

Furthermore, the food system is built on making a profit with the aid of government subsidies focused on the production of health-damaging animal agriculture. As a result, about 10% of the Bay's residents face regular food insecurity, and 14% receive subsidized nutrition benefits from the Government (Cuker and Davis, 2020). The Standard American Diet (SAD) is based on expensive animal-based foods, refined carbohydrates, and few fiber-rich fruits and vegetables. The burden of unhealthy and cheap food has fallen most heavily on people with a lower-income and people of color (Cuker and Davis, 2020).

Nevertheless, the USA National Academy of Science report a rising mortality for the USA adults for White adults with secondary education or less. The rise is largely attributable to death of despair and obesity due to the lack of communal support in all stages of the life cycle. Without the support, difficulties accumulate until there seems to be no way forward. The study also measures other wealthy nations and found thus facilitating diverse paths forwards and protecting individuals and families the mortality decreases (Sterling and Platt, 2022).

On the other hand, in 2020, 12 new public access sites were added around the CBW, which brings the total to 206, marking 69% achievement of the CBP goal to add 300 new access by 2025 (CP-PublicAccess, 2022). Public access and outdoor nature are associated with mental well-being, and there is evidence of a link between nature access and mental health with a place of belonging (Wood *et al*., 2017). Another improvement has been walkability, with a score of 62%; this indicator measures how many people can walk to a park in ten minutes (RC-CBI, 2022). There are two other indicators in the making by IAN-EnvJus (2022), access to recreational fishing and access to marine mammals; both of these indicators are more related to socio-economic status because of the lack of funds to obtain these services.

- Identity – Poor

The score “Poor” was given because there is only a reduce group of people that feel an ecoregion identity with no local culture to the land.

With almost 18 million people living, working, and playing in the CBW, connecting the residents to nature is vital to fostering stewardship and the long-term health of the environment (CP-EC, 2020). A study conducted by Ardoin (2014) explores the sense of place related to the Chesapeake Bay environment. The study found that 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 (McKendy, 2009). The few people related to the ecological ecoregional scale worked professionally at the system (Ardoin, 2014).

However, there is a particular identity called "waterman" in the CB, who are men and women who make a living by fishing, crabbing, and oystering. Most of them are independent fisherman. The community has change little through the years, they work throughout the year in all kinds of weather have special tools and boats (The Mariner's Museum, 2002). Paolisso (2002) talked about their involvement in the management of the blue crab (Callinectes sapidus) when spawning stock was at dangerously low levels. Therefore, they are an important part of the management decision-making process (Paolisso, 2002).

On the other hand, the ChesapeakeProgress showed the engagement of the community to the environment with a series of indicators. The CP-Stewardship (2022) indicator data scored 24/ 100 on the Citizen Stewardship Index. The score was a mean between three components: the personal action taken to improve the Bay's health, the portion of public participating communities, and the advocating for public engagement in local and regional activities. Each component scored 38, 23, and 19, respectively. To score a 100, residents in the region would need to be involved in improving the watershed health (CBP-Stewardship, 2022). The long-term success and sustainability of the Chesapeake Bay restoration effort will ultimately depend on the actions and support of the resident of the region who call the watershed home.

There are many ways for residents to connect to different organizations around the Bay to actively work to restore and converse natural resources and create sustainable communities (https://www.chesapeakebay.net/action/join), although maybe it needs more exposure.

- Social resilience – Satisfactory

The score "Satisfactory" was given because an above average portion of the population are prepared for hazards, although this is mostly based on socio-economic level and race. Additionally, environmental literacy is increasing.

The ReportCards (2020) developed a social index indicator that uses data about social vulnerability and how a community can respond to hazardous events from the USA Census. Overall, it has a score of 60%, which means that a little more than half the population is prepared for a hazardous event.

The Health Vulnerability Index is another indicator taken into consideration, developed by NASA and Groundwork USA; the CBW obtained a score of 58%. This index identifies places with a greater vulnerability of people to health-related and flooding-related risks. As it has been said before, the vulnerable communities are related to neighborhoods with race-based housing discrimination, low-income communities, children, and the elderly (ReportCards, 2020; Assari, 2018; IAN-EnvJus; Cuker and Davis, 2020; Hardy *et al*., 2018).

Another social resilience significant variable is environmental literacy; this enables residents in the region to gather the knowledge and skills needed to act responsibly to protect and restore their local Watershed (CP-Literacy, 2022). The first indicator is environmental literacy planning; since 2019, 55% of education agencies have measured the degree of environmental literacy preparedness among school districts across the Watershed. The results were 27% "well prepared", 52% "somewhat prepared", and 22% "not prepared" (CP-ELIT, 2022). This indicator has increased from 2017-to 2019 with a 23% increase in preparedness (CP-ELIT, 2022).

The other two indicators for environmental literacy are Student and Sustainable Schools (CP-Literacy, 2022). The "Student" considers the age-appropriate understanding of the Watershed through educational experiences at different levels called "Meaningful Watershed Education Experience," or MWEEs. In 2019, the elementary schools reported 35% of system wide MWEE to at least one level, while 32% reported some MWEEs. Middle school lever reported 39% of system-wide MWEEs, 38% provide some MWEEs, and High school level reported 35% and 43%, respectively (CP-Student, 2022). There has been no progress in this indicator since 2017, which is of most significant importance for the future of social resilience.

Finally, the last indicator considers the number of schools in the region that reduce the impact of their buildings and grounds on their Watershed, including student-led protection and restoration projects (CP-SS, 2022). In 2019, 15% of the 634 public schools on the Watershed were certified sustainable. This is a 4% increase from 2017, and it is expected to get higher in the future (CP-SS, 2022). This increase comes mainly from the Maryland and Virginia states on the west coast, dominated by megacities (CP-SS, 2022). Stewart's (1990) article explains that the isolation of the rural zone resulted in a push of outside interferences from big cities regions; it seems that the education patterns follow this narrative.

5.1.3.3. Economics

- Security – Poor

The score “Poor” was given because although poverty is low, there is no safety net for falling into poverty, which as it has indicated in the social domain, makes you highly vulnerable to environmental injustice. In addition, most of the jobs purposefully hire part-time workers or foreigners to cut expenses and avoid paying additional benefits.

The various natural capital is the basis of the economic importance of the Bay; the major economic contributions base on natural capital are fisheries, farming, real state, and tourism (CBF-Economy, 2022). However, contamination and overexploitation of natural resources have damaged the economic benefits and the quality of life (Phillips and McGee, 2016). The CBF-Economy (2022) and Phillips and McGee (2016) showed that the clean-water plans benefit the ecosystem services on the CBW and stimulate the local economy by creating jobs and supporting livelihoods.

Agriculture and fisheries support thousands of jobs and produce food for USA citizens (Cuker and Davis, 2020). However, approximately 58% of agricultural workers come from Hispanic countries; USA citizens are 49% of farm laborers, and 81.3% of farm managers (Cuker and Davis, 2020). Foreign workers come for three years and are paid 2% and 33% (depending on their position) less than the average agricultural worker (Cuker and Davis, 2020). It is important to consider that most jobs in the CBW region pay less than 31,980 US dollars per year, which is the minimum (Cuker and Davis, 2020). Large grocery stores purposefully hire part-time workers to avoid paying additional benefits; from 2005 to 2018, the part-time workers increased from 20% to 50%, making the CBW citizens need to work multiple jobs to make ends meet (Cuker and Davis, 2020).

The poverty in CBW, less than 35,000/ year income, is 13% and 19% for children (McKendry, 2009; Cuker and Davis, 2020). Overall, in the USA, 18% of the population live in relative income poverty, and 37% would be at risk of falling into poverty if they must forgo three months of salary (OECD-USA, 2022). Worts *et al*. (2010) studied the poverty vulnerability in the USA. They found that there are no safety nets to protect vulnerable citizens falling into poverty and that to recover a decade is needed.

There is also a gender consideration, although it is not as marked as the minority groups. According to Cuker and Davis (2020), most farm laborers are men of ~39 years old and people of color, and in the management area, they are mostly male and white. However, there is a percentage of female workers of 23.7% in farm labor and 16.6% in farm managers. Furthermore, the WEF (2021) found that the gap between the genders in economic sectors is closing with an economic participation and opportunity score of 75.3%.

- Infrastructure – Satisfactory

The score "Satisfactory" was given because the CBW has the infrastructure the residents need to support economic development. Nevertheless, there is still a need for maintenance and public transport.

The energy sources around the watershed vary depending on the state. The CBW has infrastructure for petroleum, natural gas, electricity, coal, nuclear, and renewable and alternative fuels (eia-state, 2022). In eia-state (2022), each state has different energy approaches. For example, Pennsylvania is the third-largest producer of electricity in the nation with natural gas; New York is the most advance in clean energy with 9/10 of renewable energy development; Washington DC receives 98% of its electricity from power plants in surrounding states. There is also the infrastructure for the electricity and pipeline transmission around the CBW (eia-maps, 2020); because some state needs more energy than they can produce, and others produce more than they need.

Additionally, there is the Conowingo Dam, a Hydroelectric Generation Station located in Maryland. The dam infrastructure is important to the ecological condition of the CB; it helps reduce the nutrients and sediment from the Susquehanna River to the Bay (Hirsch, 2012). However, new studies found that it no longer has the long-term ability to store sediments and nutrients (CBP-Dam, 2022). In 2016, the Lower Susquehanna River Watershed Assessment (LSRWA) team released the results about the management of the Dam with the only cost-effective solution of reducing the nutrients (CBP-Dam, 2022).

There are five airports to access the CBW by air: Baltimore-Washington International Airport, Dulles International Airport, Philadelphia International Airport, Ronald Reagan Washington National Airport, and Harrisburg International Airport. Furthermore, the Bay has two of the five major North Atlantic ports in the USA (Morgan and Owens, 2001). Additionally, there are also hundreds of smaller ports, each offering diverse commercial or recreation activities (CB-News, 2022). For example, the Baltimore Port, which is recognized as one of the leading seaports of the USA, ranked first in the nation in handling automobiles, light trucks, farm, and construction machinery, as well as imported gypsum (Hille and Suelflow, 1970; Maryland-Gov, 2022). Furthermore, the Port of Virginia shelters the world's largest naval base, the largest shipbuilding and repair industrial base, a thriving export coal and bulk trade, and the 6th largest containerized operation in the USA (HamptonPort, 2022). Finally, the Annapolis port is a historic colonial port and major governmental and institutional city; it is home of the USA Naval Academy and is a regional boating center; the port activity is more focused on recreational and educational infrastructure (Craig *et al*., 2019).

Nationwide, roads and related infrastructure in the USA make up at least two-thirds of all paved impervious surfaces (CBP-Highway, 2022). The automobile is the choice for the vast majority of travels; 80% of the trips nationally are made by automobile (Garrett and Taylor, 1999). After World War II, rising personal income, greater availability of automobiles, low fuel prices, and substantial public investment in urban street and freeway systems reduced public transport demand (Garrett and Taylor, 1999; Buehler and Pucher, 2012).

There is significant variability in public transport use within the USA, where most public transport use is concentrated in a few large metropolitan areas. In 2007, New York City, Chicago, Los Angeles, Washington DC, Boston, Philadelphia, and San Francisco accounted for more than 50% of all unliked transit trips in the USA (Buehler and Pucher, 2011). The CBW only has two of these metropolitan areas. In the USA, there is an idea that public transport is only for work commuters in large older cities or low-income captive drivers without cars (Buehler and Pucher, 2012). The two principal markets that remain for the public transportation system are downtown commuter and transit dependents, people who are too young, too old, too poor, or physically unable to drive (Garret and Taylor, 1999). Only a few cities have attempted to make car ownership and use more costly, slower, and less convenient (Buehler and Pucher, 2011).

In addition, the USA transportation consumed 96% of the energy sector in gasoline or diesel (Martin and Shaleen, 2011). The well-established reliance on the private automobile for urban transportation has placed the USA in a uniquely challenging position to shift travel in ways that lower automobile dependence (Martin and Shaleen, 2011).

In 2021 the American Society of Civil Engineers issue a Report Card with grades about the overall infrastructure of the country. Since 1998 USA had a score of “D” (50 in a 0-100 score system). However, in recent years all levels of government have recognized the critical role the infrastructure plays in the quality of life and economy. Elected officials and members of the public have improved infrastructure policy and support additional funding. There is a benefit of this action in drinking water, inland waterways, and airports. The private sector has invested in the electric grid, freight, rail, and more (ReportCard-USA, 2022).

- Economic well-being – Poor

The score “Poor” was given because economic well-being is linked to mobility and there is no public transportation outside the main urban areas. The efficiency of individual transport comes with the cost of environment resilience.

The indicators for the economic well-being in the USA using the OECD Well-being framework from 2020 gave an overall score of 18% of the population living in relative income poverty, and 37% would be at risk of falling into poverty if they must forgo three months of salary (OECD-USA, 2022). Worts *et al*. (2010) studied poverty vulnerability in the USA; they found that there are no safety nets to protect vulnerable citizens falling into poverty and for those that do fall into poverty a decade is needed to recover.

In the CBW, median household incomes are highest in urban areas and housing affordability is higher in the rural areas (RC-CBW, 2022). Therefore, to have high economic well-being, the watershed population must work in an urban city and live in a rural area. Without public transportation in rural and to urban areas, the reliance on the private automobile increases, which increase the expenses that this entails (Martin and Shaleen, 2011).

On the other hand, there has been a consistent net job growth across the entire watershed (RP, 2022), although the increase of jobs could be related to more part-time job or migratory workers (Cuker and Davis, 2020). The poverty level is 13% (McKendry, 2009; Cuker and Davis, 2020) and there is data of the risk of falling into poverty, which can be by loss of job or increase of overall expenses.

- Industry – Good

The score “Good” was given because there is high diversity in the industrial development in the extractive and non- extractive. To achieve an “Excellent” score the industry need to consider the environmental resilience of the system.

Agriculture and Fisheries are the most predominant extractive industries on the Bay (Kemp *et al*., 2005; CBF-Fisheries, 2022). In 2016, the NOAA's Fisheries Economics of the US report indicates that the commercial seafood industry in Maryland and Virginia contributed 1.4 billion in sales, almost 539 million in income, and more than 30,000 jobs to the local economy (CBF-Fisheries, 2022). However, the agricultural industry has less impact on the economy because most workers earn low wages and are likely not citizens of the country (Cuker and Davis, 2020).

In the extractive resources, there is also the energy industry; it is essential to clarify that each state has different extractive resources. The CBW has coal, natural gas, and oil as the most significant electricity production from extractive sources (eia-USA, 2022). For example, Pennsylvania has a natural gas production and is the 3rd largest net energy supplier to other states (eia-Pennsylvania, 2022). On the other hand, West Virginia is the nation's second-largest coal producer (eia-WestVirginia, 2022). The last example is Virginia, where natural gas accounted for 61% of utility-scale electricity generation and an oil reserve (eia-Virginia, 2022).

The predominant non extractive industries in the CBW are touristic recreation, sales and services, construction and manufacturing, and Government (Phillips and McGee, 2016; McKendry, 2009). According to McKendry (2009), industrial employment in the CBW is 15% in construction and manufacturing, 60% in sales and services, and 15% in Government.

A growing new industry is clean-water technologies and science; the USA environmental industry is worth $312 billion yearly (CBF-Economy, 2022). The number of environmental industry jobs in Pennsylvania, Maryland, and Virginia has surged by 43% over the last two decades. For each wastewater project an approximate of 20, 000 construction jobs are created, and $1 billion is invested with earning in ecosystem services (CBF-Economy, 2022; Phillips and McGee, 2016).

- Dependency – Good

The score “Good” was given because there is a diversity in economic activities, dependent and independent from the natural resources it offers. To achieve an “Excellent” score the industry need to consider the environmental resilience of the system.

The dependency on coastal resources in the CB constitutes the fisheries, recreational tourism, real state, and port operations (CBF-Fisheries, 2022; Phillips and McGee, 2016; CBF-Economic, 2022). In 2016, the NOAA's Fisheries Economics of the US report indicated that the commercial seafood industry in Maryland and Virginia contributed 1.4 billion in sales, almost 539 million in income, and more than 30,000 jobs to the local economy (CBF-Fisheries, 2022). Furthermore, citizens of the USA spend ~ $44 billion on trips to coastal areas for recreation activities (boating, fishing, wildlife watchers, etc.) (CBF-Economic, 2022). In 2009, tourists spent $58 billion in Maryland, Pennsylvania, Virginia, and Washington DC, supporting 600,000 jobs, contributing $14.9 billion in labor income and $9.4 billion in taxes (Phillips and McGee, 2016). There is also an increase in property value as more people have retirement or summer houses near the shoreline in CBW (Hardaway and Byrne, 1999). Lastly, the port of Baltimore 37, 300 jobs in Maryland are generated by port activities, and Virginia port generated $23 billion in paychecks for the Port of Virginia (EI-Maryland, 2022; HamptonPort, 2022).

The diversity of other activities not related to the coast are agriculture, construction and manufacturing, sales and services, and Government. According to McKendry (2009), the earnings of each industry indicate the size and importance of each activity in the system. The earnings of agriculture in 2003 were 8%, 30% for construction and manufacturing, 40% for sales and services, and 22% for Government. It is important to clarify that agriculture also considers natural resources like fishing; even with 22% of the CBW based on agriculture, it seems that the most critical economic sector is sales and services (USEPA, 2017; McKendry, 2009; Phillips and McGee, 2016).

5.1.3.4. Governance and Policy

- Organizations – Excellent

The score “Excellent” was given because there are numerous organizations working towards the restoration of the Bay.

The Environmental Protection Agency (EPA) works with the federal government and state agencies, nonprofit organizations, and academic institutions to coordinate the restoration of the Chesapeake Bay and its Watershed through the CBP (EPA-RCB, 2022). The CBP 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, including businesses, nonprofits, and advocacy groups (CBP-Who, 2022).

- Law and justice – Good

The score “Good” was given because there is evidence of legal accountability for restoration.

This category takes into consideration that the Bay's Governance is divided by six states of the USA. Since 2009, the CBP has gathered input from citizens, stakeholders, academic institutions, and local Government to develop the Chesapeake Bay Watershed Agreement, which establishes goals and outcomes for the restoration of the Bay (CBWA) (CBP-Who, 2022). Each watershed jurisdiction has created a Watershed Implementation Plan, often called a WIP; the documents describe how the jurisdiction partner with federal and local governments to achieve and maintain water quality standards.

The CBF work at local, state, and federal levels to protect the Bay by pressuring the government to enforce laws and regulations to reduce pollution, restore vital natural systems (CBF-Mission, 2022). In 2010, CBF and the co-plaintiff settled a lawsuit with EPA. The historic settlement is a legally binding, enforceable document requiring the EPA to take specific actions by dates certain to ensure the pollution reduction in the watershed (CBF-Courtroom, 2022). The settlement mandates: reasonable assurances, consequences, offsets, dates certain and tracking (CBF-Courtroom, 2022). Nevertheless, EPA has failed to hold Pennsylvania and New York accountable for not meeting the Clean Water Act obligation in 2020. As a result, the CBF and its partners filed a complaint suing the federal EPA for abdicating its responsibilities under the Clean Water Act (CBF-Sue, 2022).

- Representation and power – Poor

The score “Poor” was given because although there are several projects to increase the diversity of the organizations managers, there is still a low diversity in the management representation.

The 2014 Agreement of the CBP contained a Stewardship Outcome to "Increase the number and diversity of trained and mobilized resident volunteers with knowledge and skills needed to enhance the health of their local watershed" (CBP-Stewardship, 2022).

The diversity of the watershed representation of power for this thesis will consider two groups as indicators, people of color and women; this was considered due to their minority status in the country (Morrison and Von Glinow, 1990). According to the WEF (2021), the USA has increased political roles for women; it went from ranking 86/153 in 2020 to 37/156 in 2021 (WEF, 2020; WEF, 2021). However, it is vital to consider that there has never been a female president (WEF, 2021). It is important to consider that this is a generalization of the political representation in the USA, and more research is needed to consider the CBW political representation.

On the other hand, the CBP diversity survey, which takes into consideration the people that work for or with the partnership, indicates an increase in the percentage of workers who self-identified as people of color (Native American, Asian, Black, Hispanic, etc.) from 13.7% in 2016 to 14.6% in 2019, the goal is to arrive at 25% by 2015 (CBP-Diversity, 2022). Furthermore, the CBP increased the number of people of color in leadership positions from 9.1% to 10.3% in 2019; the goal is to meet 15% by 2025 (CBP-Diversity, 2022).

- Legitimacy and accountability – Satisfactory

The score “Satisfactory” was given because there are several sources of data, assessment, and institutions to hold accountable the progress of the CBW restoration with generally low corruption. Although there is no instrument that hold accountable the responsibilities under the CWA (CBF-Sue, 2022).

To achieve consistent assessment over time and among state jurisdictions, the CBP partnership proposed a multimeric indicator to measure progress toward attainment of water quality standards (USEPA, 2017). The information is open on ChesapeakeProgress (https://www.chesapeakeprogress.com/), which includes information on more than two dozen indicators of environmental health, restoration, and stewardship. The data and information are drawn from diverse sources, including government agencies, academic institutions, non-governmental organizations, and direct demographics and behavior surveys (CP, 2022).

Furthermore, 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, which includes traditional ecosystem indicators and social, economic, and cultural indicators. Overall, the CB watershed scored a 64% in 2021 (RC, 2022).

Although the information for the CB is transparent, government corruption still must be taken into consideration. According to the Corruption Perception Index (CPI), the USA is only the 25th least corrupt country, with corruption steadily increasing (CPI-USA, 2022). To measure corruption in

Chesapeake Bay governance, we used the Best Life data collection. Best life looks at the number of public corruption convictions per 10,000 residents, the number of reported violations by medical providers between 2020, states with Anti-Corruption Measure for Public Officials, and State Integrity Score. The mean corruption between all the watershed states is 10.02/100 with a standard deviation of 18.25/100, Delaware has the maximum value of 46.45/100, and New York has the minimum with a grade of 0.05/100 (BestLife, 2022).

- Resource management – Good

The score "Good" was given because there is a substantial amount of management projects around the CBW and easy access to the data, reports, and stewardship. However, the management in some resources, especially oysters, has not necessarily resulted in substantial improvement in the overall ecosystem.

The current management applies the WIPs to the Bay, which uses the BMP to reduce the pollution on the Bay with 2025 goals. According to the Chesapeake Assessment Scenario Tool (CAST), between 2009 and 2020, there has been a reduction in nitrogen and phosphorus loads due to wastewater facilities (CP-WIPs, 2022). On the other hand, the sediment reduction has been 4%, primarily from the natural and agricultural sectors (CP-WIPs, 2022). Furthermore, there is an important proposal under a new program called "Innovative Nutrient and Sediment Reduction Grants" and "SMALL Watershed Grant Program" that will grant $8 million to $18 million dollars per year though (NFWF-CBS, 2022). The Chesapeake Bay Stewardship Fund will also make target investment that support networking and information to share between its partners (NFWF-CBS, 2022). The project will partner with EPA, CBP, and NFWF (INSR, 2021).

On the other hand, the Sustainable Fisheries Goal Implementation Team (GIT) is composed of state fisheries managers chaired by the director of the NOAA CB Office. The group of managers and scientists coordinate and 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 (CBP-GIT1, 2022). There is also the Chesapeake Oyster Alliance with the commitment to add 10 billion oysters to the Bay by 2025 (COA, 2022).

Finally, the CBP is working on a ChesapeakeDecision tool, like ChesapeakeProgress, that promotes transparency and guides the CBP's GIT and Management Board members to explain how the outcomes are to be accomplished and how the progress will be monitored, assessed, and reported (CD, 2022).

Chapter 6.

6.1. Discussion

6.1.1. Holistic frameworks

The results of the DAPSI(W)R(M) holistic framework gave an overall idea of the human-induced changes that the Chesapeake Bay ecosystem has been gone through over time. The land use of the CWB supports human necessities by providing food security, commercial development, recreation, and energy. The activities that have resulted from these necessities (agriculture, fisheries, industrial, urban/suburban development, and burning fossil) have developed a mechanism of change, which led to depleted fisheries, eutrophication, hypoxia, and the overall change of ecosystem services it provided. The impacts on society have been in the environmental sector as the water quality, aesthetics, and ecosystem health has been degraded. There is also an impact on the economic sector with the reduction of visibility and fisheries, the increase of poor human health, and a loss in agriculture productivity and touristic value.

As a response to the ecosystem degradation, the federal, state, and local government have participated in the CBP, implementing several regulations to meet water quality standards for a healthy bay. On the other hand, the fisheries around the CB have developed a substantial management regulation, with the objective of sustainability. The results have been partially successful with ecosystem health discontinues. There have been some outside pressures, like climate change and political agendas, that have slowed down the recovery process. Nevertheless, the studies have shown that if the reduction of nutrients and fisheries management have not been made, the bay would be more degraded. For example, the hypoxia would have been in a larger area for longer periods and the fisheries would been depleted.

The CCS framework score for each domain gave new information about the priorities of the main issues identified with the DAPSI(W)R(M) framework. Three of the four domains gave a “Satisfactory” score. The governmental domain obtain the score due to the high governmental organization capacity, high management plans, high transdisciplinary collaboration, medium accountability, and low diversity. To improve, the accountability most be strongly implemented with a diversity representation of power (Figure 20).

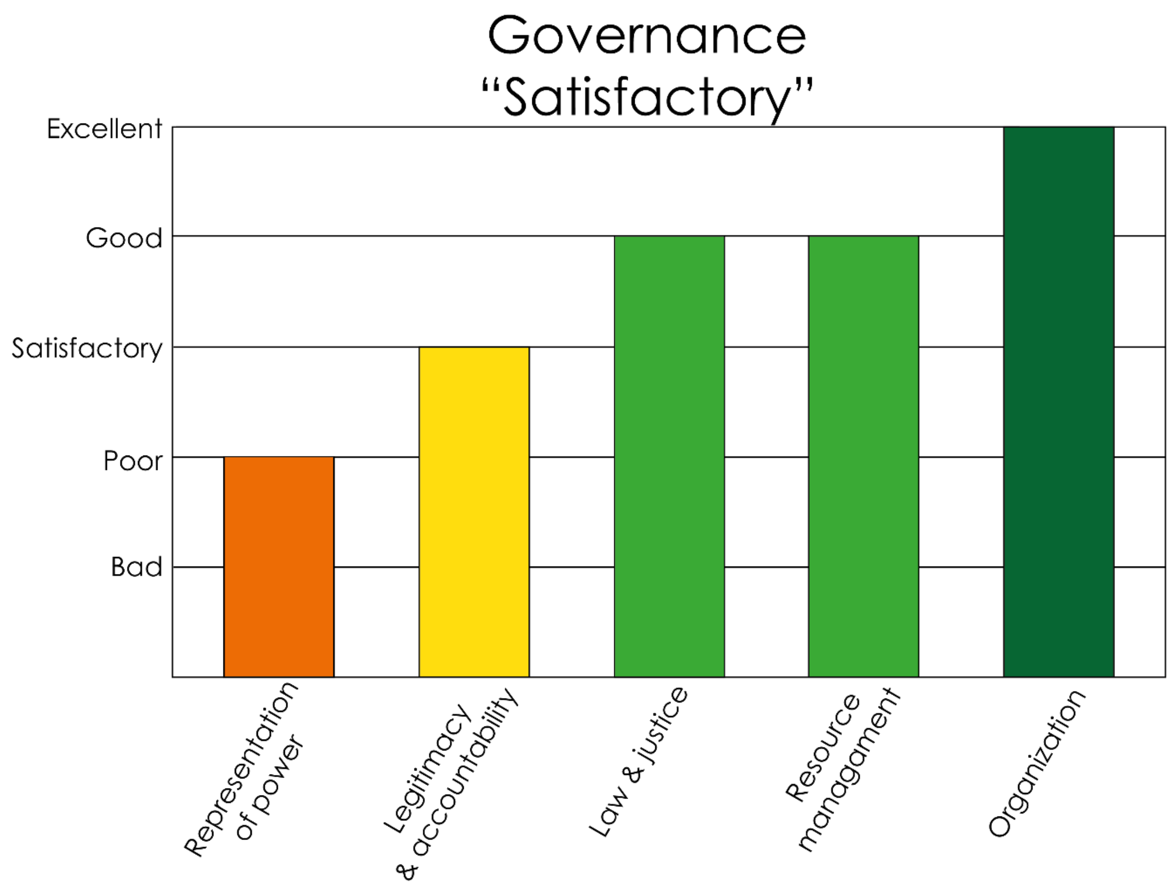

Figure 20. Government domain categories score results in the Chesapeake Bay Watershed in order from high needs of management to least.

The environmental score was given due to the high ecological discontinuities. The main concerns are the change in hydrodynamics due to climate change and the lack of adaptation to it (Figure 21). Furthermore, there is increasing evidence suggesting that climate change, particularly global warming, makes the coastal ecosystem more vulnerable to the effects of nutrient enrichment (Kemp *et al*., 2005; Frankel *et al*., 2022). Therefore, the management plans for eutrophication fail or lag, which results in a lack of improvement in biochemical and physical flows (Meals *et al*. 2010; Du *et al*., 2018; Frankel *et al.,* 2022).

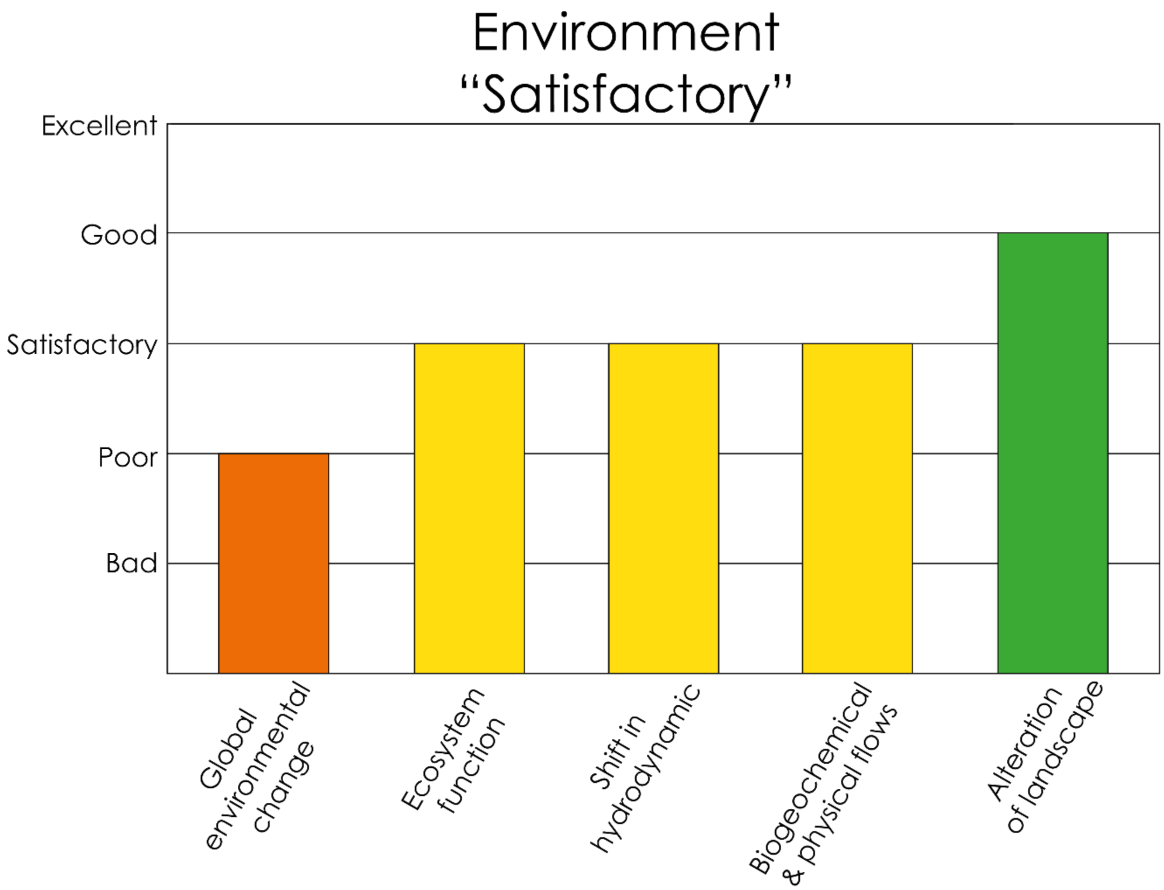

Figure 21. Environment domain categories score results in the Chesapeake Bay Watershed in order from high needs of management to least.

The economic domain score "Satisfactory" because the economy in the watershed is linked to high efficiency and medium to low environmental resilience. The security, economic well-being, and infrastructure need improvement with more equitable opportunities for different communities and social-economic statuses. In addition, there is a low dependency due to the high diversity of resources and industries in the Bay (Figure 22). To improve, it needs to be more focused on environmental resilience and local economy efficiency (Goerner *et al*., 2009).

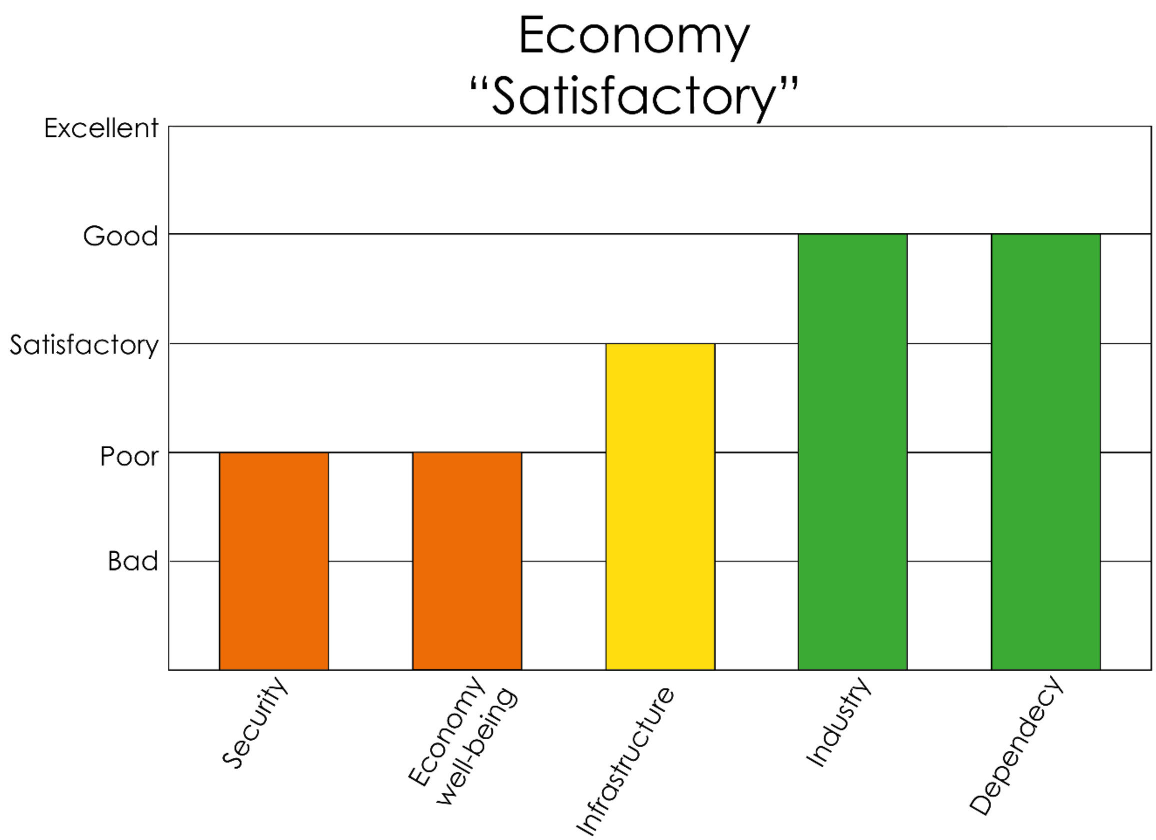

Figure 22. Economic domain categories score results in the Chesapeake Bay Watershed in order from high needs of management to least.

Finally, the social domain score “Poor” because there is a high individualistic society and high industrial culture (Figure 23). Stewart (1990) argues that the regional identity is strongly marked by an "us versus them" mentality by what are called the Eastern Shoremen's regional consciousness, due to the isolation and outrage at perceived outsides interference. Additionally, according to several sources, social benefits, resilience, and well-being are strongly linked to socio-economic status and race (Assari, 2018; IAN-EnvJus; Cuker and Davis, 2020; Hardy *et al*., 2018). Therefore, a sense of identity outside the socio-economic status and race is needed. Additionally, demographic growth centralizes in the system's economic growth and not ecological capacity.

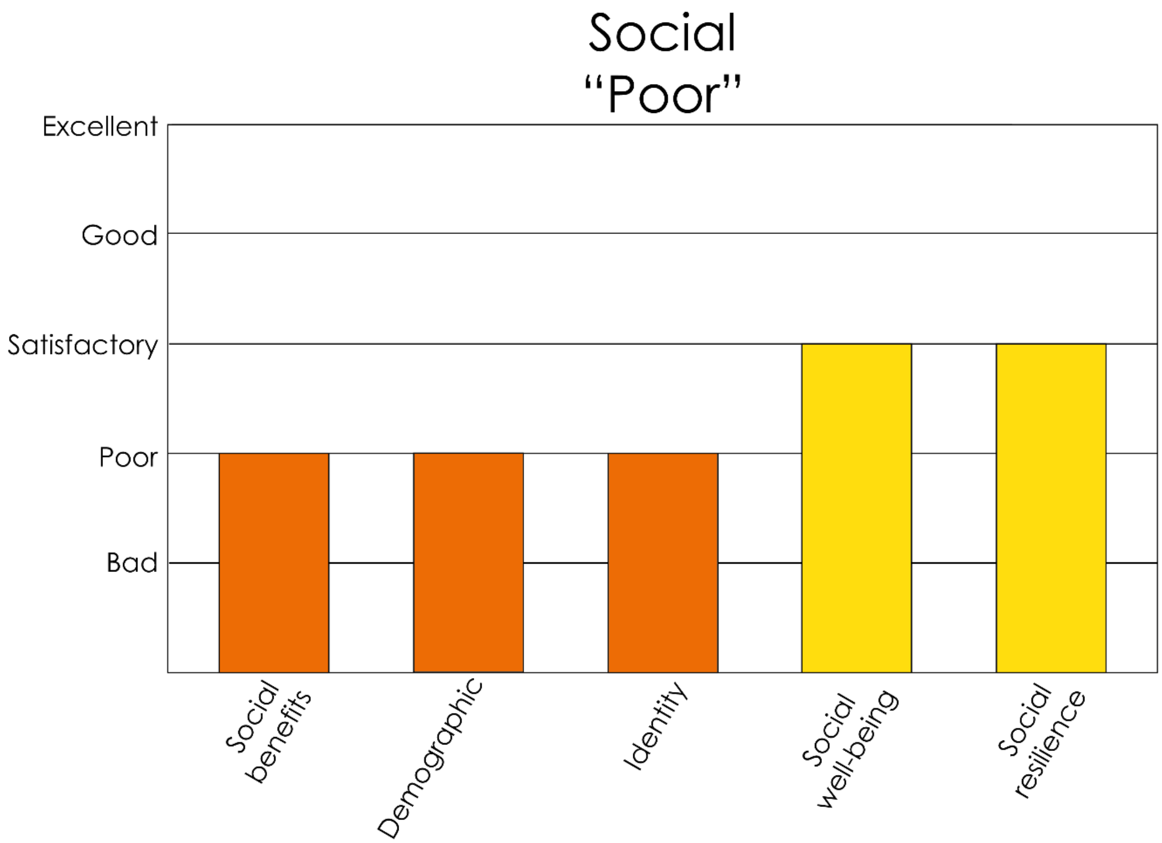

Figure 23. Social domain categories score results in the Chesapeake Bay Watershed in order from high needs of management to least.

Furthermore, it is important to consider that the evaluation was made from a general literature review of sustainability in each domain and available indicators. Therefore, studies need to be conducted to develop a more objective judgment. Additionally, more systems must be evaluated to improve the global score system implementation.

The indicators scores also must be developed by a consensus with knowledgeable stakeholders to develop quantitative thresholds for each system evaluated. Furthermore, the data must be appropriate to evaluate the overall system, with a high spatial and temporal resolution, analysis methods, and holistic discussions. This kind of information requires high governmental, scientific, and local participation. Overall, evaluating different indicators from the system's stakeholders would help improve the ecological and socio-economic well-being.

Finally, the graphic design for the score systems graphics and the CCS framework was developed to communicate to a broad audience with different specialties. The IAN scientific communicators that developed the design for the report cards participated personally in the development of these new designs to better communicate the sustainability score system and the CCS framework. According to Vargas-Nguyen's (2020) thesis, 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 thesis. Therefore, the result is expected to enhance public awareness, understanding, literacy, and culture of the system and sustainability.

6.1.2. Management applications

The merging of the holistic framework of DAPSI(W)R(M) and CCS helped to understand and evaluate the Chesapeake Bay Watershed socio-ecological system. The main issues and categories scores develop a foundation for the management necessities. For example, the governance needs accountability, which can be obtained through financial instruments. The money collected can later fund environmental science and technology or restoration and conservation projects.

On the other hand, society sustainability scored the lowest grade in the system, which can also be addressed with environmental justice governance. Environmental justice addresses the problem with minorities and the link with low health, social benefits, and risk (Mohai *et al*., 2009). The financial instrument that can improve the public good could be progressive taxation, as it can invest in education and public transport (Oishi *et al*., 2012). In this case, the technology and research need to be more focused in the overall social well-being, and the restoration and conservation in their maintenance.

Table 2 was developed considering general solutions for particular or general issues. The different responses and management are divided in governance, financial instrument, technology and research, restoration and conservation, and education and outreach, which were considered as the main management responses.

Table 2. Responses and management needed for each Chesapeake Bay Watershed issue.

Governance													
	Accountability	Transparency	Parks and recreation	Environmental justice	Green economy	Manure management	Support Best Management Practices	Public transport	Development limits for housing	Initiation of projects	Adaptive governance	Blue economy	Holistic management
Eutrophication	✓	✓	✓	✓	✓	✓	✓						
Industrial and Urban development	✓	✓	✓	✓	✓			✓	✓				
Overexploitation of resources	✓	✓	✓	✓	✓					✓	✓	✓	✓

Financial instruments						
	Fines	Incentives	Investment	Progressive taxation	Fines corporation	Fee individual consumers (Plastic and cars)
Eutrophication	✓	✓	✓	✓	✓	
Industrial and Urban development	✓	✓	✓	✓	✓	✓
Overexploitation of resources	✓	✓	✓	✓	✓	

Technology and Research																
	Living shorelines	Water quality	Environmental justice	Climate change effect	Green infrastructure	Wastewater management	Integrated nutrient management	Improve Best Management Practices	Water conservation	Green energy	Improve harvest methods	Stock assessment	Effectiveness of restoration and conservation projects	Population dynamics	Blue growth	Intrusive species stock and dynamic
Eutrophication	✓	✓	✓	✓	✓	✓	✓	✓								
Industrial and Urban development	✓	✓	✓	✓	✓	✓			✓	✓						
Overexploitation of resources	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓

Restoration and conservation							
	Coastal wetland	Oyster	SAV	Implement Best Management Practices	Connected forest	Viewshed	Improving migration corridors
Eutrophication	✓	✓	✓	✓			
Industrial and Urban development	✓	✓	✓		✓	✓	
Overexploitation of resources	✓	✓	✓				✓

Education and outreach														
	Sense of identity	Ecosystem services	Environmental justice	Climate change effect	Stewardship	Nutrient management	Livestock management	Water conservation	Sprawl development	Public transport	Recycle	Compost	Life cycle	Fish management
Eutrophication	✓	✓	✓	✓	✓	✓	✓							
Industrial and Urban development	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Overexploitation of resources	✓	✓	✓	✓									✓	✓

6.1.2.1. Eutrophication

The main socio-ecologic issue in the Chesapeake Bay Watershed is eutrophication, mainly for the Bay's high agricultural activities. Since 2014, agriculturists have voluntarily implemented many Best Management Practices (BMP) (Fox *et al*., 2021). Fox *et al*. (2021) found that the farmers consider themselves responsible for the water quality but lack the financial support to implement the BMP needed to improve the ecosystem's health. Therefore, the higher-income farms can have progressive taxation that can be invested in smaller farms to help them implement the BMP (Fox *et al*., 2021; Oishi *et al*., 2012).

Additionally, no literature addresses fines implementation for lack of responsibility in the nutrient and pollution source; therefore, it is vital to develop it. The money can be invested in management or responses project developing a green economy and growth (OECD-GreenEconomy, 2022; Eikeset *et al*., 2018). The green economy improves resource use efficiency, reducing environmental impact, focusing on the ecosystem, and encouraging and improving new technologies for resource use productivity (OECD-GreenEconomy, 2022). There is already some green economy application in the CBW agriculture practice, although it requires more funding and incentives (Chadwick *et al*., 2011). Furthermore, according to Saacke Blunk (2020), incentives could help farm resiliency and education for best professional guidance for landowner conservation, farm and nutrient management, and water conservation.

On the other hand, the CBP partners have a strong government foundation to develop the technology and research. The CBWA goals include sustainable fisheries, vital habitats, water quality, toxic contaminants, healthy watershed, stewardship, land conservation, public access, environmental literacy, and climate resilience. For example, the latest Report Cards found that a significant investment should be made in the wastewater treatment plants, which, combined with better operational oversight, could improve water quality (RC-2021, 2022). The Table 2 shows some projects that can be developed for better sustainability.

However, if we consider that climate change is the main contributor to the lack of results in the management issues, an effort must be made to counter it. The project that was considered the highest impact in the eutrophication and overall issues is the living shorelines, an alternative of shoreline protection using natural habitat elements (Davis *et al*., 2006). The oyster-reef can provide protection for sea-level rise, filtration of nutrients in the Bay, and stabilization of sediment (Rodriguez *et al*., 2014; Davis *et al*., 2006). Furthermore, the existing oyster is already protected and restored as part of the CBWA with vital habitats. Another example is the poplar Island Environmental Restoration Project, a national model for wetland restoration using dredge material from the navigation routes (Derrick *et al*., 2007).

Finally, the last management response to eutrophication is to ensure education and outreach. For example, the lack of climate change education has stakeholders question the nutrient management reduction due to the lack of knowledge about its relationship with eutrophication (Meals *et al*., 2010). Additionally, considering the sense of identity is not linked to the ecoregion, another response can be the education on the ecosystem and encouraging volunteerism (Ardoin, 2014; McKendy, 2009; Davis *et al*., 2006). Therefore, another investment can be on the parks and recreation agencies to promote free activities outdoor with pay transport. Public access to green areas is associated with mental well-being, and there is evidence of a link between nature access and mental health with a place of belonging (Wood *et al*., 2017).

The Table 3 shows the general actors, approximately timeframe and cost of each of the management responses projects described for eutrophication.

Table 3. Eutrophication actors, timeframe, and cost of responses and management.

Eutrophication			
Response	**Actors**	**Timeframe**	**Cost**
Governance	❖ Local government ❖ State government ❖ Federal government	Years-decades	Minimal
Financial instruments	❖ Local government ❖ State government ❖ Federal government	Generational	Moderate
Technology and research	❖ Academia ❖ Private enterprise	Years-decades	High
Restoration and conservation	❖ Local government ❖ State government ❖ NGOs ❖ Residents	Years-decades	Very High
Education and outreach	❖ NGOs ❖ Academia ❖ Parks and recreation	Years	Minimal

6.1.2.2. Industrial and human Watershed development

Eutrophication is a consequence of high industrial and urban/suburban development in the Chesapeake Bay Watershed. Therefore, some of the management and responses already addressed in the last chapter will be complemented with a more socio-economic perspective.

As it has been said repeatedly, agriculture is the primary source of nutrients and sediment in the Bay. However, urban and suburban development around the watershed are also inputters of wastewater discharges (CBP-Dev,2022; CBP-Nutrients, 2022). There is a lack of accountability and developed limits for housing for the growth in the Watershed and shoreline. Additionally, there are no incentives for participating in a CBP project that aims to restore, conserve, improve or research the shorelines or wetland. Furthermore, there is a lack of education on the ecosystem region dynamics, management, and service, as well as wastewater management, which could explain the lack of high stewardship or landowners' project implementation. Society's lack of environmental sense of identity could also be a problem.

The sense of identity is one of the main social issues found in the watershed. The different government dependency between urban and rural areas marks a political sense of identity that divides the watershed population. The rural population has a sense of ecoregion but does not want interference from the government (Stewart, 1990). Therefore, there is a need to develop a sense of identity and belonging to the ecoregion outside the political views. Initially, the governance could start founding social safety nets, subside insurance to workers, accessible and quality education, parks and recreation projects, and incentives for green projects. Society's role could be improved with incentives by applying water conservation, recycling and compost practices, and stewardship. Moore *et al*. (2006) study found that these kinds of activities give a sense of belonging to the local community and a greater willingness to work toward improving their community; there were also health and increase of security benefits.

On the other hand, the science community must be open to sharing information with residents in simple and understandable terms. The technology must be developed considering the resident different cultures and economies. For example, Nieuwenhuijsen (2020) found that green infrastructure can give environmental services, reduce violence, and increase health. There are also links between nature access and mental health with a place of belonging (Wood *et al*., 2017). The rural population could be part of the projects, using the local knowledge to develop this green infrastructure in urban areas, which could help reconcile the cultural boundary (Stewart, 1990).

Furthermore, there is a necessity to address connectivity with cheap and reliable public transport for the different socioeconomic status resident. The CBW residents' economic well-being and social benefits are linked to car ownership due to the lack of public transport, which is another pollution source (Buehler and Pucher, 2012; CBF-Sprawl, 2022; Buehler and Pucher, 2012). To address this issue, the government must invest in infrastructure for public transport, public transport incentives, and education (Buehler and Pucher, 2012). The education must be centered around environmental justice, the benefits of public transport, and the issues with sprawling.

Finally, the industries' development in the watershed must be towards green growth, which considers the local population's environmental resilience and well-being (OECD-GreenGrowth, 2022). For example, the government could increase foundation in projects like green energy, wastewater plans, forestry, and water conservation technologies. Furthermore, financial incentives to industries could push them to develop the technology themselves.

The Table 4 shows the general actors, approximately timeframe and cost of each of the management responses projects described for industrial and urban Watershed development.

Table 4. Industrial and Urban Watershed development actors, timeframe, and cost of responses and management.

Industrial and Urban Watershed development			
Response	**Actors**	**Timeframe**	**Cost**
Governance	❖ Local government ❖ State government ❖ Agriculturist ❖ Land developers	Generational	High
Financial instruments	❖ Local government ❖ State government	Generational	Moderate
Technology and research	❖ Academia ❖ Private enterprise ❖ Federal government	Years-decades	Very High
Restoration and conservation	❖ Local government ❖ State government ❖ NGOs ❖ Residents	Years-decades	Very High
Education and outreach	❖ NGOs ❖ Academia ❖ Parks and recreation ❖ Food industry ❖ State Health Department	Years	Minimal

6.1.2.3. Overexploitation of Bay resources

The main fisher management institutions are the Atlantic State Marine Fisheries Commission (ASFMC) and the Mid-Atlantic Fishery Management Council (MAFMC), divided by the different species they manage. The overall management is comprised of two basic functions: conservation and allocation. Conservation determines how many fish, crabs, and oysters can be caught without harming the resource, and allocation determines who gets to harvest these resources. When one of the two or one of these basic functions is compromised, fisheries have depleted (CBF-Fisheries, 2022).

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act requires annual catch limits and accountability measures in federal fisheries to end and prevent overfishing. The accountability measures are usually some combination of the size limit, trip limits gear restriction, and seasonal closures (NOAA-Fisheries, 2022). However, there is no clear information about the accountability if these laws are not met by the end of the year or if they have ever been implemented in any of the Bay states.

Therefore, a clear accountability act must be implemented with a severe fine. The money could be used to develop a blue economy, defined by the World Bank as the "sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of the ocean ecosystem". For example, Menold (2021) study found the fines and punishment for oyster violations as neither severe enough nor applied early enough in a habitual violator poaching career. He proposes three solutions which are to improve incentives, courts to handle fishery violations, and fines for fishery violations, which are the solution that could be implemented in fisheries management in more than one specie.

There is also a lack of science and technology implementation as the scientific advisor representative is taken more as a recommendation. For example, the Mid-Atlantic Council is made up of 21 voting members and four non-voting members. Seven of the voting members represent the constituent state fish and wildlife agencies. Thirteen voting are private citizens knowledgeable about recreation fishing, commercial fishing, or marine conservation, and four non-voting members represent organizations (MidAtlantic-Fisheries, 2022). On the other hand, the ASFMC has the Figure 24, which represents the flow of decision-making (ASMFC-Fisheries,2022). The image has the scientific committees as a branch and not as a step to get to management, which will be more in line with a holistic approach.

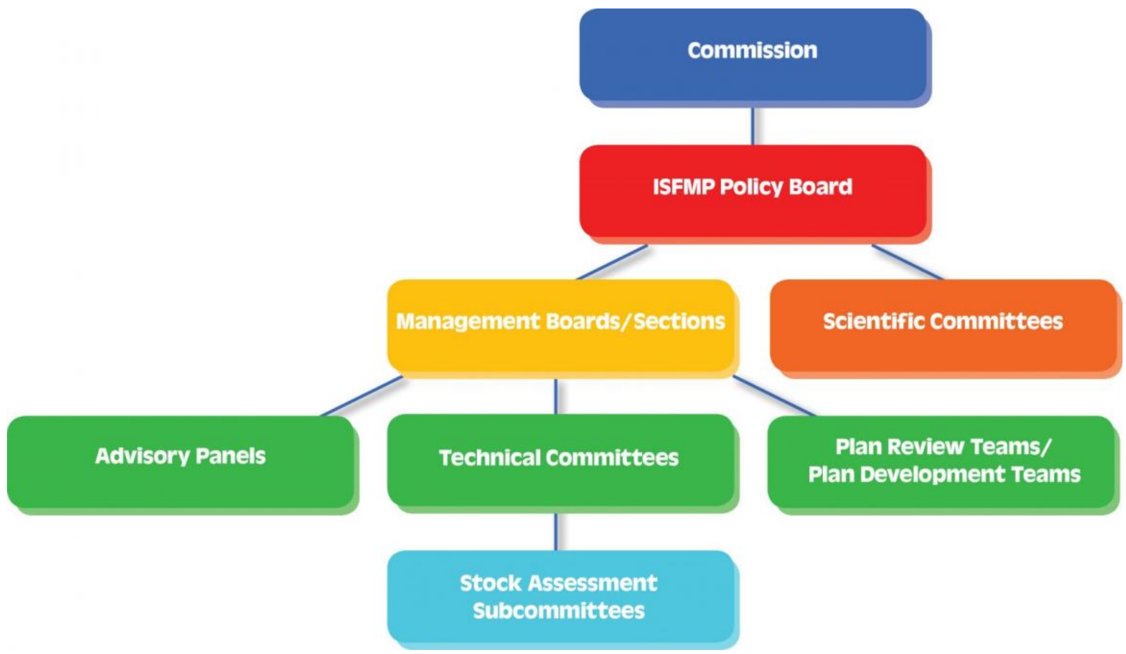

Figure 24 Atlantic State Marine Fisheries Commission decision-making conceptual map from the ASMFC (2022).

Furthermore, climate change is a factor that is not adequately taken into consideration for resource exploitation. Najjar *et al*. (2010) give some consequences of climate change on fish and shellfish. The result gave some positive results, although most impacts were negative. However, the uncertainty of the response in different trophic levels is non-linear with the organism cycles, which makes management difficult. Jesse *et al*. (2021) study talk about the increased disease on the marine organisms in CB due to climate change and the lack of important fisheries to consider in the management to modification regulation. Therefore, there is a need for adaptive governance, which is essentially environmental governance coupled with the ability to adapt to changes (Cunningham, 2018).

The technology and research must be focus on developing better harvest methods. The study of Rick *et al*. (2016) shows that the native American have a sustainable fishery, and how practices could be mimicked by reducing modern harvest levels and creating increased no-take zones. Additionally, the living shoreline project could be implemented, as well as the effectiveness of restoration, population dynamic, and population estimates.

Nevertheless, the CBP has helped the restoration of fish by continually increasing access to support the migratory fish population in the CBW rivers and streams (CP-Fish, 2022). The protection of wetlands is also increasing, although only 11% of the wetland supports the fisheries by providing critical habitat for hundreds of species (CP-Wetland, 2022; CBP-Wetlands, 2022). Therefore, the restoration and conservation projects must continue and improve these systems. Some of the challenges to reaching the goals are the lack of funding and resources to complete the project, the unwillingness of landowners to take on voluntary restoration, and conflicting state priorities (CP-Wetland; CP-Fish, 2022).

Overall, the knowledge of fisheries can help with the resistance to regulation from adaptive management, to understand of the socio-ecology of the system, and the restoration project acceptance. One example of lack of resistance is the waterman, the local most significant fisheries in the CB. Paolisso (2002) found that they resisted regulation that interfered with the natural production of crabs but supported science and regulation that improve what nature provides. They believe that the decline is by industrial wastewater, government officials, sprawl, and sewage. On the other hand, the Washington Post (2020) gave the Baywide Blue Crab Winter Dredge Survey the lowest count in three decades, with no understanding of the organism's data analysis or life cycle. Therefore, the education and outreach must be on life cycles, climate change, management, and ecosystem services open and understandable for all the residents of the CB and stakeholders.

The Table 5 shows the general actors, approximately timeframe and cost of each of the management responses projects described for the overexploitation of the Bay resources.

Table 5. Overexploitation of Bay resources actors, timeframe, and cost of responses and management.

Overexploitation of Bay resources			
Response	**Actors**	**Timeframe**	**Cost**
Governance	❖ Federal government ❖ State government ❖ Commercial and recreational fisheries	Years	Minimal
Financial instruments	❖ Federal government ❖ State government	Years-decades	Very High
Technology and research	❖ Academia ❖ State government ❖ Local culture ❖ Commercial and recreational fisheries ❖ Aquacultures	Years-decades	Very High
Restoration and conservation	❖ Federal government ❖ State government ❖ Local government ❖ Commercial and recreational fisheries ❖ NGOs	Years-decades	Very High
Education and outreach	❖ Residents ❖ Seafood industry ❖ NGOs ❖ Academia ❖ Parks and recreation ❖ Commercial and recreational fisheries ❖ State Health Department	Years	Moderate

Chapter 7.

7.1. Conclusion

(Research Q1) The results of the DAPSI(W)R(M) framework represented in Table 1 identify the Chesapeake Bay Watershed's structure, function, dynamics, and management. The CBW is a complex system with conflicts between ecosystem health and social well-being; it has a robust governmental management capacity to coordinate and collaborate between six states and Federal District. The main socio-ecologic issues identified are eutrophication, overexploitation of Bay resources, and industrial and human watershed development.

(Research Q2) Furthermore, the DAPSI(W)R(M) framework helped identify relevant indicators for the sustainability assessment and the main human activities, impacts, and responses. However, it only gives an idea of the structure, there is no assessment of the issues identified or the level of impact that each of the activities are creating. Therefore, the frameworks give an idea of the socio-ecologic system, with no priorities for the main issues identified. There is also a lack of links between the culture and the ecosystem impacts.

(Research Q3) Nevertheless, the assessment of the CBW has been consistent over time and among jurisdictions with multimeric indicators used to evaluate the traditional ecosystem indicators, as well as social, economic, and cultural indicators. The main assessment projects have been done by the Report Cards and the ChesapeakeProgress. Both projects' indicators were used to apply the CCS framework in the CBW. Although the indicators include an overall assessment, an intensive literature review was still needed to complete each domain evaluation of sustainability.

The merging of both holistic frameworks, DAPSI(W)R(M) and CCS, complemented each other in this thesis. Although both work with socio-ecologic indicators, their application is very different. One of them gives the structure of human-induced changes, and the other assesses its current sustainability. The order of putting the DAPSI(W)R(M) first was helpful in this thesis because the CBW information is extensive in literature, web pages, studies, management plans, and assessments. However, this order could not be preferred. For example, individual assessment of indicators using CCS could be helpful to start finding the connection relevant to sustainability, which will take out irrelevant data when DAPSI(W)R(M) is developed. Nevertheless, this could also lead to an incomplete DAPSI(W)R(M) that only considers sustainability, not the overall system structure.

(Research Q4) The shortcoming of using holistic frameworks in this thesis is the subjectivity of the indicators and the prejudice of the scientific evaluation of them. Therefore, knowledgeable stakeholders must discuss the indicators to develop quantitative thresholds for each system evaluated, considering the sustainability of all the domains. This kind of information requires high governmental, scientific, and local participation, which is most likely not found in most systems. Nevertheless, this thesis starts the possibility with the global score evaluation base.

(Research Q5) The score system developed by the literature review was applied to evaluate sustainability from a global perspective. The results provided a guide for each domain's sustainability goals. However, this scoring system needs to be tested globally to remove subjectivity and normalize the indicators data found in different socio-ecological systems. Furthermore, the indicators score for each system must be further developed by high knowledgeable stakeholders, governmental institutions, scientific experts of each domain, and residents of the system.

(Research Q6) The development of the new design was to improve the global and stakeholder understanding of the CCS framework. The main objective was to enhance the system's public awareness, understanding, literacy, and culture. The design was developed with the participation of communication scientists of IAN, general scientists, design experts, and the general public. The design changes were to deliver a more visual grade of each category and to add the domain and overall system evaluation. For this thesis, the last two grades were obtained by the arithmetic mean, but because each score is not a quantified value, more research needs to be developed to obtain these scores. This representation is essential because it communicates a priority management plan. The assessment of each domain gave weight to which management projects are more important to develop in the CBW. Overall, the final result is more visual than the latest (P de Alencar *et al*., 2020), with a design closer to the Report Cards. However, the report cards have different design details, indicators, and domains.

(Research Q7) Overall, the score system gave a "Satisfactory" result in the CCS framework assessment. The grade was given because the socio-ecologic system is not healthy but is working towards sustainability. The results for each domain were “Satisfactory” in environmental, economic, and governmental and “Poor” in Social. The government has a great capacity to act and accountability is relatively good, but it needs more transparency and diversity. The environment has ecologic discontinuities due to climate change and lack of incentives for local project implementation. The economy has high efficiency, but it lacks the environmental resilience for the resources; additionally, there is a lack of maintenance on the overall infrastructure. Finally, the social has a high individual and industrial society, which has resulted in low social well-being in the overall society and a lack of sense of belonging to the ecosystem.

The recommendation for the Chesapeake Bay Watershed management is to increase the social awareness of the region through education and outreach to the socio-ecological system. The government's help in social safety nets and investment in parks and recreation is essential for a sense of belonging, which is highly needed. The financial instruments can incentivize the resident to be part of the project to clean the bay, which could give a sense of responsibility to the people near the shoreline. Another financial instrument can be progressive taxation for high-earning industries to help the smaller local industries to fund the new management practices implementations. The government can also hold an accountability fine and use the money for technology, research, restoration, and conservation projects. The projects must focus mainly on adapting to climate change, oysters, wetland, and environmental justice.

7.2. Dissemination and exploitation

This thesis contains valuable information about the Chesapeake Bay Watershed management and sustainability. However, to properly reach a diverse audiences' different tools are needed. Therefore, Table 6 was developed, which describes the different future projects for the information obtained in this thesis. The primary audiences are the scientific community, managers, and the general public. The scientific community considers researchers, communication scientists, science students, and universities. Meanwhile, the managers consider the Chesapeake Bay Program, Chesapeake Bay Foundation, Mid-Atlantic Fishery Management Council, and Atlantic State Marine Fisheries Commission. Finally, the general public is to educate and reach the audiences not part of the last two about management, indicators, and sustainability.

Table 6. Dissemination and exploitation of this thesis future projects for different audiences

Audience	Dissemination and exploitation description	Status
Scientific community	Future submission of the "**Social-Ecologic analysis of the main management issues of the CBW**" article to the Ocean and Coastal Management magazine.	In preparation
	Future submission of the "**Sustainability assessment of the of the CBW**" article to the Sustainability journal.	In preparation
	Future submission of the "**Global sustainability assessment**" article to the Sustainability journal.	In preparation
Managers	Development of **pamphlet** with information about the present **management of CBW**.	In preparation
	Pamphlet with **management contribution for CBW.**	In preparation
	Development of presentation of future project management of the CBW.	In preparation
General public	**The CCS design** presentation in a **world map museum** with the **Sustainability scores in the world**.	In preparation
	Education and outreach of **indicators** using **communication science**.	In preparation

Chapter 8.

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