SCHOOL OF ECONOMICS AND MANAGEMENT

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Citizen Science: An Uncut Diamond for Marine Monitoring

- A Case Study of Marine Monitoring in Sweden-

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Abstract

The marine environment is a vital resource protecting our ecosystem and a critical part of the wellbeing of our planet. Marine Strategy Planning (MSP) is essential for conservation and protection of marine monitoring systems and governments should constantly improve their strategies and aim for increased effectiveness of these systems. This thesis focuses on marine conservation in Sweden and reviews how it could be improved using the concept of citizen science (CS). It presents CS as a promising monitoring method that has gained large momentum recently, and more specifically it describes it as a scientific research method used for monitoring where citizens contribute by collecting or reviewing data. The research investigates the effectiveness of CS by analyzing and comparing two different Swedish monitoring cases, one of which uses citizens in its methodology. Both projects survey bottom fauna and create habitat mapping for the seafloor, however, only one includes CS and the project is categorized as a traditional monitoring method. In addition, the thesis examines government reports and evaluates described suggestions in the field of marine monitoring and evaluates recommendations for potential changes in their execution. The results of the thesis indicate that CS is suitable for projects of a more simple nature where execution requires simple instructions and low marine monitoring skills. However, findings indicate that CS is not as applicable in more complex contexts and therefore it is concluded that as a method it does not complement all monitoring projects. On the contrary it indicates that CS could complicate the execution and create less reliable results in such contexts. Interestingly, findings indicate that CS drives positive complementary effects and for example it could increase awareness of marine environmental issues in areas where it is applied. Furthermore, CS could potentially contribute to innovation and streamline marine resource management in Sweden. Nonetheless, CS is a new method and it appears to require additional development to induce major benefits. To conclude, in more simple contexts where large datasets are required, there appears to be potential for CS in Sweden's marine strategy. Nonetheless, it does not illustrate effectiveness when included in all contexts of marine monitoring projects. Given today's rapid development of tech-enabling research methods, in combination with increased interest for marine environments in both the eyes of researchers and citizens, it is likely that CS methods will continue to develop and gain larger attention in the future.

Keywords: Citizen Science, Marine Monitoring, Marine Conservation, Biological Observations, Open Science, MPA, MSP, Performance Indicators.

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List of Acronyms, Abbreviations and Statistical Symbols

API	Application Programming Interface
CS	Citizen science
EQO	Environmental Quality Objectives
GDPR	The General Data Protection Regulation
HELCOM	The Baltic Marine Environment Protection Commission
KSO	Koster Seafloor Observatory
MPA	Marine Protected Area
MSP	Marine Spatial Planning
OECD	The Organisation for Economic Co-operation and Development
PIs	Performance Indicators
ROV	Remotely operated underwater vehicle
SDG	Sustainable Development Goals
STI	Science technology and innovation
SIME	The Swedish Institute for the Marine Environment or Miljöinstitutet
SwaAM	Swedish Agency for Marine and Water Management or Vatten och Havsmyndigheten
UNESCO	The United Nations Educational, Scientific and Cultural Organization

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1. Introduction

Climate change, over-pollution, and eutrophication are just a few of the threats our oceans are facing due to the human environmental footprint. The Swedish government wants to ensure and maintain conservation, restoration, and sustainable use of the water and fishing resources in order to reach the Sustainable Development Goal 14, Life below water (Regeringskansliet, 2020). Eutrophication is the most extensive threat to marine conservation in Sweden with far-reaching effects. Algal blooms, extensive oxygen depletion, and loss of biodiversity are all examples of consequences of overfishing, toxic pollutants and emissions of nutrients (Swedish Environmental Protection Agency 2021).

A growing research field within environmental studies and possibly an effective measurement to support marine conservation is citizen science, henceforth called as CS (UNESCO, 2020). CS has several purposes and can be defined, executed, and interpreted differently (UNESCO, 2020). Robinson, Cawthra, West, Bonn, and Ansine (2018) describe it as scientific work undertaken by the general public in collaboration with or under the direction of scientists. The participants facilitate the research process by collecting and reviewing large amounts of data or collecting data at places that are difficult to sample. This research method has gained momentum in the scientific field and is today frequently used in studies observing biodiversity and pollution for monitoring nature (Robinson L.D. et al. 2018).

The Swedish government has established 16 Environmental Quality Objectives (EQs) based on European directives to prevent major environmental problems for the next generation of Sweden. They were presented in the Government Proposition 1997/98:125 and the objectives most relevant to the marine environment are:

1. A balanced Marine Environment, Flourishing Coastal Areas and Archipelagos
2. Reduced Climate Impact
3. Natural Acidification Only
4. A Non-Toxic Environment
5. A Safe Radiation Environment
6. Zero Eutrophication

The Swedish Agency for Marine and Water Management (SwaAM) is an environmental authority acting on behalf of the government and in charge of the practical implementation of maritime administration in Sweden. The authority has established a strategy to reach these environmental qualitative objectives for the conservation of Sweden's marine ecosystems. This process consists of a set of detailed criteria and methodological standards to facilitate actions and reporting of the strategy. The authority collects information, analyzes the current situation and sets goals to make decisions in spatial and temporal conditions regarding the use of Sweden's marine resources and marine areas. They are also in charge of distributing responsibilities and appropriate actions to counties and municipalities, for example Naturvårdsverket. These responsibilities include measurements to support the marine environment and one essential part is to understand the outcome by monitoring marine areas (SwaAM, 2022).

The European Commission defines marine resource management as the process behind policies and decision-making for marine resources. Marine conservation is defined as the protection and conservation of ecosystems in oceans, including lakes, streams, coastal and groundwater (European Commission, 2022). The Swedish Institute for the Marine Environment (2017) also called SIME presents a strategic analysis of Sweden's marine environmental monitoring and argues that the system should extend its uniformity and that researchers, policymakers and citizens should communicate and monitor together. They argue that Sweden's methods should be more cooperative and encourage engaging monitoring methods. This research paper seeks to investigate if CS is a solution with potential to make Swedish monitoring more integrated and effective.

More specifically, this paper will investigate the effectiveness of CS in marine resource management by comparing results of two different marine monitoring projects. Both projects involve marine monitoring and marine conservation, their methods differ slightly as only one includes data analysis performed by the public. This research paper will conduct an evaluation of the projects based on eights metrics to understand their difference in outcome and in which contexts it can be concluded as an appropriate method. What is the role of citizen science and in what ways is the method preferred over traditional monitoring?

1.1 Relevance

Interaction between citizens, scientists, and policymakers is essential and relevant to enrich research and reinforce the trust of society in marine conservation. Kelly, Fleming, Pecl, Gönner and Bonn (2020) argue that there is an urgent need for improving methods within marine monitoring since environmental changes and its hazardous effects are accelerating which increases the pressure on facilitating marine monitoring and resource management. The current monitoring methods seem inadequate and Swedish monitoring and one possible solution for streamlining it is CS. CS is possibly an important change that would create innovation, facilitate data collection and make entities work more cross-disciplinary.

1.2 Aim and Research Question

The overall aim of this research is to investigate citizen science (CS) and evaluate its effectiveness to streamline marine conservation compared to traditional monitoring methods. It aims to find new methods to streamline current monitoring methods and to examine Swedish marine resource management. The results of the projects will be compared according to eight different metrics with the aim to assess the effectiveness of both projects and thereby conclude if citizen science is effective in the given context. The thesis endeavors to enrich research in the field of monitoring to understand forces necessary to obtain beneficial monitoring, and if citizen science could contribute to this. Is it beneficial to increase the usage of citizen science in SwaAM's model for marine monitoring in Sweden?

Research Question: How effective is citizen science as a policy tool to monitor marine conservation in Sweden?

Sub-question: In which contexts are citizen science complementary and a better method compared to traditional monitoring methods?

NOTE: Effectiveness is defined by eight metrics: Investment cost, monitoring cost, cost per detection (cost of the project/amount of observations), reliability, environmental impact, required expertise, spatial detection efficiency and temporal efficiency.

1.3 Delimitations

This research is limited to investigating Swedish monitoring and mainly focuses on its current status and its future potential. The government is disposed to several policy tools that can be appropriate for marine conservation and striving towards EQs. However, this research focuses on monitoring and examines traditional monitoring methods to understanding potential changes for the Swedish monitoring systems in the future. It focuses on Swedish marine conservation and excludes other types of environmental conservation. Data availability is another de-limitation, especially as data in the field is often confidential. To counteract this, the thesis is chosen to be qualitative and investigates public governmental reports and scientific reports. It also interviews experts who contribute with valuable knowledge in the marine area.

1.4 Outline of the Thesis

The following section describes marine resource management worldwide and current research in the field of marine monitoring and citizen science. The literature review section reviews existing literature and theories about marine monitoring to understand current challenges and what is being done in the marine field. Section four consists of the theoretical framework and explains effective monitoring and the development of the metrics that will be used to compare the cases. Continuously, the interviews are presented and summarized in comparison to designed performance indicators. After that, an analytical discussion will answer the research question and analyze the project's results to understand positive and negative effects of citizen science. Lastly, concluding remarks will include an assessment of using citizen science as a policy tool for Swedish monitoring.

2. Background

This section provides a brief overview of the Swedish marine conservation framework and currently used measures for striving toward sustainable development and the EQS. First, the environmental policy of Sweden and its implementation will be outlined. Then the focus will be on marine monitoring and how it is established in Sweden. Lastly, this section will describe citizen science more in detail and its recent expansion and development.

2.1 Marine Conservation in Sweden

The concept of marine conservation is important for Sweden, especially since part of the nation's environmental strategy is striving toward the Marine Strategy Framework Directive developed by the European Commission. UN (2022) presents the Marine Strategy Framework (MSF) which is a directive for marine conservation that protects the marine environment across Europe. Marine conservation or ocean conservation is the conservation and protection of marine ecosystems by managing marine resources and preventing overexploitation. It is a relatively new discipline and it is studying marine ecosystems and its response to environmental changes and biodiversity loss (UN, 2022). MSF was established by the European Commission in 2008 with the purpose of creating a sustainable and integrated approach for water bodies and producing detailed criteria and methodological standards for marine resource management and regulations of human activity (European Commission, 2022). This directive has created a guiding framework for Sweden to assess the environmental status of marine life (European Commission, 2022; UN, 2022; SwaAM, 2022).

OECD (2017) states that one defining societal challenge is to sustainably manage our oceans, seas, and marine resources. Marine ecosystems are fundamental for our survival and are under immense pressure. For example, 60 percent of the world’s major marine systems are used unsustainably even if these ecosystems and services are non-renewable and fragile for change. Marine Protected Areas (MPA) is a policy instrument used to provision marine ecosystems and marine services and make certain areas embedded in a legal framework. OECD describes some key changes for the design and implementation of MPAs, so societies can maximize the environmental and socio-economic benefits. One of the key recommendations is to develop MPA management plan with robust monitoring and strict reporting to understand approaches of compliance and enforcement. Even though specific goals of individual MPAs vary, the prime objective is to ensure sustainable use of the ecosystem and to conserve marine resources - monitoring and reporting is essential to ensure the goals are reached (OECD, 2017).

MPAs are abundant in Sweden and cornerstones for marine conservation of the country. Sveriges Vattenmiljö (2022) explains that there are three different types of protected marine areas: national parks, nature reserves and Natura 2000. National parks are under the strictest protection with the aim to conserve their natural conditions and hence remain unchanged. According to Statistics Sweden (2022) about 15 % of Sweden's total land area and inland waters are categorized as protected areas. This covers national parks, nature reserves, nature conservation areas, habitat protection areas, the National City Park and Natura 2000. In total, about 12 % of Sweden's marine areas are under protection. Given that large areas in Sweden are under protection, it is clear that the government is aware of the environmental threat (Sveriges Vattenmiljö, 2022; SCB, 2022).

2.2 Marine Spatial Planning (MSP)

The marine strategy of Sweden is based on Marine Spatial Planning (MSP) which is a strategy developed by the MSF to analyze and allocate human activities around marine resources. MSPs are used in over 50 countries worldwide, including the United States, China and Sweden (OECD, 2017). SwaAM (2022) describes Sweden's MSP and how it creates informed and coordinated decisions regarding the use of marine resources to achieve a long-term sustainable use of seas, lakes and coastal areas. They emphasize that marine species, societies, habitats, and functions should be protected and conserved along with the use of marine resources to strive for cooperation between multiple users. This long-term plan for marine resource management is a policy tool to regulate and measure Swedish waters and ensures a guiding framework for decisions in accordance with the environmental code. The purpose is to monitor the environmental status of the marine environment and ensure that industries and human activities coexist and adapt with the ecosystem. Counties in Sweden have different MSPs and each of them include detailed project-and site-specific assessments where each county administrative board has an essential role in the planning and licensing processes with monitoring and reporting (SwaAM, 2022)

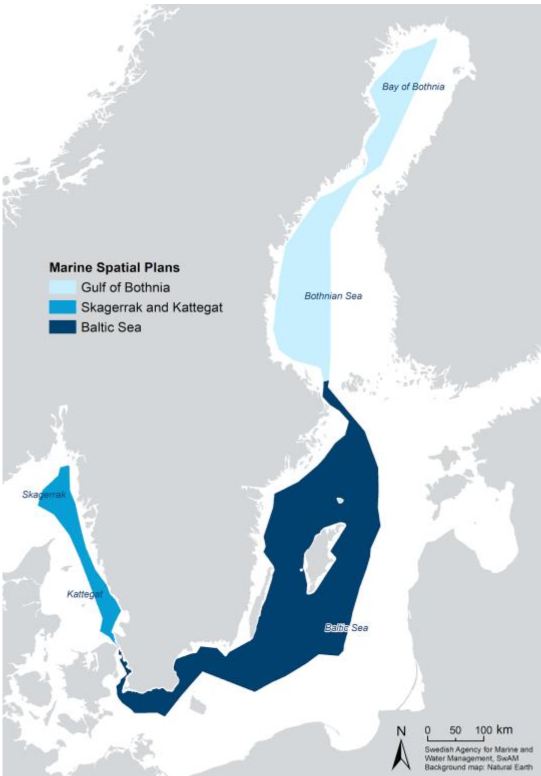

Figure 1: Mapping of MSP in Sweden (SIME, 2017)

2.3 Marine Monitoring in Sweden

The Swedish Agency for Marine and Water Management (SwaAM) was established as an independent agency in 2011 where their responsibilities previously had been under the agenda of Naturvårdsverket. However, the government decided to create SwaAM to increase the focus on MSF and to facilitate policymaking for marine ecosystems. SwaAM (2022) describe themselves as a managing authority working on behalf of the government to ensure a sustainable management of seas, water and waterways. They have the overall responsibility for protecting and developing these marine areas and are also in charge of Swedish MPAs, MSP and Swedish marine monitoring of the country.

Their main goals are:

1. Zero eutrophication
2. Flourishing lakes and streams
3. Balanced marine environment
4. Flourishing coastal areas and archipelagos

The overall objective is to work towards SDG 14 by promoting biodiversity and a sustainable use of the environmental assets to maintain water quality and its capacity. The agency continuously monitors its actions to understand the fulfillment and development of their strategies. They have a comprehensive toolbox at their disposal by working with a broad perspective and multiple collaborators, both internal and external partners. Their collected data can be divided into three geographical scales of monitoring national, regional, and local. The state finances national and regional projects whereas the local monitoring is mostly financed by municipalities or private actors. All assessments of marine areas coordinated by SwaAM are submitted to the Swedish Government which conducts an in-depth evaluation of these every fourth year with the assistance of SIME. Traditional methods for monitoring include observations by trained divers, sediment/manual water sampling from research vessels and morphological identification of sampled organisms (SwaAM, 2022).

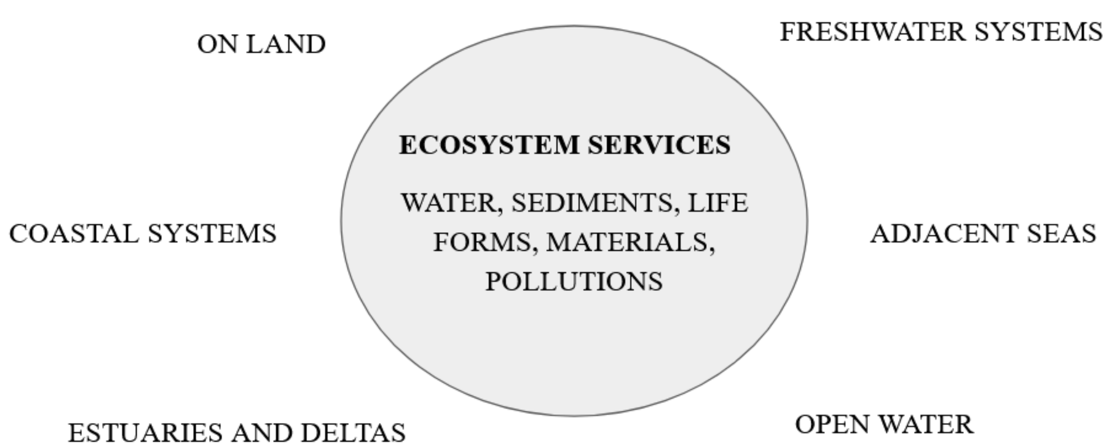

Figure 2: Holistic Approach of SwaAM (SwaAM, 2022)

The Swedish Institute for Marine Environment, SIME (2017) presents a strategic analysis of SwaAM's marine environmental monitoring to understand its practice and continuously give recommendations on possible changes. The aim is to optimize SwaAM and to ensure that its 13000 monitor stations are effective and reach the environmental objectives. SIME (2017) believes that SwaAM's strategy is lacking from not being cooperative enough and not encouraging engaging monitoring methods. They recommend Swedish marine monitoring to use more inquiry-based assessments, joint analysis of data and clarify the roles and areas between those working with the collected marine data. They argue that analytical questions linked to governmental objectives should be approached through exploration and problem-solving. Another recommendation is to extend the data by coordinating the use of data between national, regional and local monitoring (SIME, 2017).

2.4 Citizen Science (CS)

Robinson, Cawthray, West, Bonn and Ansine (2018) describe CS and how it involves the public or people who are not researchers, to help researchers by gathering data or investigating certain questions they need support with. The most common circumstance is when there is large amounts of data to be analyzed and reviewed, a time-consuming situation for a sole researcher. They mean that citizens can assist and release workload by reporting their findings or classifying images based on pre-created categories. There are several advantages with CS from speeding up the process of research but also involving people outside the research community. Aside from saving time, CS can increase societies' confidence in science and increase their connection to research. CS has been increasingly used and approved in marine monitoring, it seems to be a new method with a positive future forecast (Robinson et al. 2018).

Pocock, Chapman, Sheppard, and Roy (2014) explain that CS has expanded and gained potential during the last ten years due to new digital solutions that facilitate data collection and make CS more precise and effective. The digital transformation has facilitated sharing and receiving of data which facilitates communication between researchers and volunteers through for example websites or smart devices. This online integration facilitates crowdsourcing and is a cost-efficient approach for collecting data. (Earp & Liconti, 2019; Pocock, Chapman, Sheppard & Roy, 2014).

3. Literature Review

The following section presents previous research in the field of marine conservation, marine resource management and marine monitoring to understand what type of monitoring that is effective. It begins with describing the challenges in marine resource management and monitoring types that need improvement. Moreover, it presents an overview of the possibilities in marine resource management and methods and strategies that seem to work for monitoring. The aim of the section is to outline relevant solutions and theories for marine conservation to understand its current agenda and areas for improvement to produce effective monitoring outcomes.

3.1 Challenges in Marine Monitoring

Benedetti-Cecchi et al. (2018) working for the European Marine Board emphasize the importance of biological observations to prevent environmental threats and describe how European countries should improve their monitoring with more integrating methods. They mean that monitoring of ecosystems captures nature's development and essential actions for preserving and conserving its biodiversity and complexity. The report's general finding is that current monitoring is is disintegrated across disciplines and that integrated monitoring is a cornerstone to create multidisciplinary hypotheses and a strategic vision with the right approach. They encourage a collaborative monitoring system where methodologies are standardized to make researchers work together to better understand marine changes and implement the most effective management strategies and policies (Bendetti-Cecchi et al. 2018)

There is an urgent need for improving methods within marine monitoring and much criticism is directed to its unnecessary costs. Kelly et al. (2020) argue that the biggest problem with monitoring is that many systems are based on observational surveys and morphological identification which are costly, time consuming, and offer low ability to create change. These on site specific methods should be exchanged by in situ which means over wide spatial and temporal scales. They emphasize that new technology has created low and standardized cost tools that should be further implemented in monitoring. Birk et al. (2012) argue that there are gaps in traditional monitoring methods from requiring a lot of monetary- and time resources, which hinders monitoring to be executed as regularly as needed. The limited frequency of monitoring creates a limitation of the spatio-temporal resolution and coverage as well as a lack of indicating all ecosystem elements. Also, there is a problem in technological development where the processing of data evolves faster than data management strategies develop, creating an ineffective and uncoordinated management system (Birk et al., 2012; Kelly et al., 2020).

In order to achieve an integrated system, it is important to clearly define hypotheses and drivers behind suggested changes. Benedetti-Cecchi et al. (2018) underline that marine ecosystems across jurisdictional boundaries are beneficial to create coordination and cooperation between regional and national boundaries. A key variable to understanding current short-term fluctuations are according to them methodological standardization, long-term integration and large-scale integration of monitoring programs (Benedetti-Cecchi et al. 2018). SIME (2017) also encourages standardized monitoring methods and believes this increases consistency, comparability and accessibility of data. Increasing collaboration between authorities and researchers could improve the scientific basis for appropriate actions and therefore facilitate the process where researchers submit proposals to agencies. However, this relies on more streamlined methods and stricter control of data submission with direct feedback from the data collectors. It also requires a common station register and a contractual responsibility (Bendetti-Cecchi et al. 2018; SIME, 2017).

There are further parts of traditional monitoring methods that could be improved, especially in terms of deriving more trustworthy results. Benedetti-Cecchi et al. (2018) believe that the overall problem is that most of the current monitoring stations are controlled at a local level and often sporadic in terms of spatial and temporal resolution. The report argues that it is important with conformity to adapt to the scalability and comparability of biological observations and to encounter current monitoring challenges. Society needs to develop their scientific capabilities by promoting technical innovation and engaging different knowledge by working cross-disciplinary to prioritize right and improve the biological observations (Benedetti-Cecchi et al. 2018).

UN (2017) describes another dilemma within monitoring, that marine resource management has legislative and causality dilemmas that complicate the establishment of marine environmental policies and create public engagement. There is a legislative dilemma since the government is the sole entity with property rights of the ocean and in charge of its maintenance. There are a large number of stakeholders utilizing resources from oceans for example for cultivation, however, it is hard to monitor its environmental effects and determine its environmental impact. Marine resources are integrated into a complex system and the causal relationship between environmental damage and the main cause is problematic to identify. This creates a prisoner's dilemma, where none of the stakeholders feel responsible for their effects and where it is hard to hold them or anyone responsible for the threats which minimize the individual's force to act (Benedetti-Cecchi et al. 2018; UN, 2017). Robinson et al. (2018) emphasize that public engagement and CS could reduce the dilemma that arises from vague property rights in marine resources by creating societal motivation where individuals feel obligated to take responsibility. By getting involved in scientific research they understand their environmental footprint and what they can potentially do to dampen the consequences. Open science creates an open dialogue between researchers and CS that spurs co-creation (Robinson et al. 2018).

3.2 Possibilities in Marine Monitoring

Open science is transforming society and has created a paradigm shift where digitalization changes communication patterns and extends on knowledge banks, facilitating societal challenges and innovation (Kelly et al. 2020). Guidi, et al. (2020) extend this research by explaining how open science makes it possible to analyze large volumes and a high variety of data. They emphasize that open data access provides opportunities to understand marine environments from a more complex perspective since it creates a marine science community and openly shared research. According to them, researchers can use existing data banks to understand the outcome of previous actions and guide them through how to create the most effective resource management. Open data access consequently increases reviewing of scientific reports, which makes monitoring projects and collected data more scrutinized. Incorporating open science into seems to be a promising avenue to increase engagement and environmental development all around the world (Kelly et al. 2020; Guidi et al. 2020).

Another possibility with open science and citizen science is that it could be beneficial for science, technology and innovations (STI) by bringing new perspectives and new methods to the current monitoring. UNESCO (2020) believes that open science and CS are both essential parts of research development by making scientific findings accessible to all levels of society and increasing reproducibility, transparency, sharing and collaboration of data. They mean that open science can address interconnected and complex issues in society in economic or environmental matters by accelerating STI. Open science allows co-creation, co-evaluation and increases the quality of research where the scientific process is under scrutiny and critique which would accelerate human knowledge and narrow STI between and within countries. It also expands the research community by making the public, researchers and policy makers work together (UNESCO, 2020). Earp and Liconti (2019) agree and underline CS's potential to create new scientific research and innovation as it integrates society in the scientific process and develops new solutions to environmental challenges. Public access to research data increases engagement and the tendency of developing new ideas to science (Earp & Liconti, 2019; UNESCO, 2020).

Furthermore, the inclusion of citizens into scientific research could be efficient for monitoring and increase societies' engagement in policy making. Citizens science would accordingly to Levine, Richmond and Lopez-Carr (2015) be efficient since individual opinions would be taken into consideration in policy making. These opinions are important to ensure that different perspectives, and not only researchers and policymakers, are approached in decision-making for marine conservation. The notion of space and place is fundamental when shaping policies, which makes resource users with experience of the area a trustworthy source to collect and interpret this marine data. Many of the current researchers lack local knowledge or have a restricted spatial and temporal access to the monitored area. Socio-cultural and socio-spatial dimensions are important in understanding the complex integration between humans and marine resources (Levine et al. 2015). Robinson et. al (2018) agrees that citizens should help out in establishing policies and be further integrated into research since they possess valuable knowledge in the area. They further underline that CS is effective to examine regional development and find appropriate solutions for specific areas (Levine et al. 2015; Robinson et. al, 2018).

Cormier and Kannen (2019) emphasize the importance for governments to evaluate its specific maritime space and to not reproduce the MSP from governments worldwide. Marine planning and its policies should differ between countries due to the different political, cultural, and social constructs. They emphasize long-term planning as a fundamental part for sustainable water management and that governments must carefully monitor their marine areas to understand the effects of measurements and its overall health. CS could be useful for regional development by allowing municipalities and authorities to overcome time and data deficits and also create longitudinal engagement for public participation and not just a top-down deficit model (Cormier & Kannen, 2019).

3.3 Citizen Science and Machine Learning

Citizen science has expanded during recent years due to increased digitalization and insights of its positive effect on STI. Earp and Liconti (2019) further explain CS and that the recent increase is due to the digital transformation, where entities working with marine conservation have been able to create monitoring algorithms with the help of the public. The algorithms are based on crowdsourcing and rely on technology and the effectiveness of reporting digitally. Earp and Liconti (2019) emphasize that crowdsourcing allows for a contribution to the analysis of large datasets and where the data is not only analyzed by a small team or retrieved through machine learning. CS is highly accurate due to digitalization that has created new possibilities and facilitated sharing and analysis of large datasets. This increased interest in digitalization can be identified in Fig. 2 created by Follet & Stretov (2015), that show the growing interest for conducting research through CS methods (Earp and Lictoni, 2019; Follet & Stretov (2015); Robinson et al., 2018).

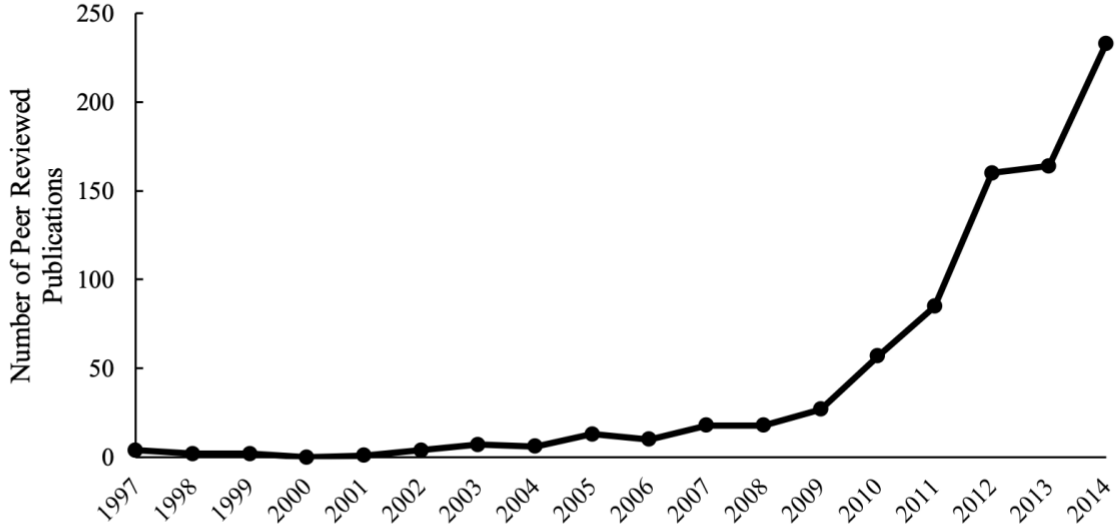

Figure 3: The growth of published peer-reviewed articles on citizen science from 1997 to 2014 (Follet & Stretov, 2015)

Lotfian, Ingensand and Brovelli (2021) describes the connection between CS and machine learning and how there are both benefits, risks and future challenges with combining them. Many arguments are underlining the potential of using machine learning for data processes and arguing that incorporating machine learning brings new adjustments to CS tasks by streamlining data collection, automated processing and validation. The paper further investigates different CS cases where machine learning seems successful, but where there is a risk of relying on artificial intelligence and the superiority of computers. CS and machine learning have been exciting for a while, but it is not until recently that they have been more incorporated and started acting as a new learning paradigm for citizen scientists. Previous CS has primarily been centered around footage collection; however, new technology has changed where this type of data can be extended with AI. This could increase interdisciplinary collaboration and streamline detection through images (Lotfian, Ingensand & Brovelli, 2021).

3.4 The Negative Aspect of Citizen Participation

Problems that arise when incorporating CS is guaranteeing that the data collection and its processing is reliable, especially as there are reasons to believe that citizens are not providing as trustworthy sources of information as researchers. Earp and Licontini (2019) emphasize that CS can create unequal participation with only a selected sample participating which excludes a large part of the public and hinders public engagement. The challenge is to make sure that research is not only conducted by a certain group of society and that different people and perspectives are integrated. Another possible problem with public engagement is that it can create a non-mutually beneficial relationship with deficient synergies between researchers and the public. Rotman, Preece, Hammock, Procita, Hansen, Parr, Lewis & Jacobs (2012) describes the motivational problem were scientists and volunteers obtain different motives for participation, where scientists want to advance science and their own professional career whereas volunteers' motivations are more temporal and derived out of curiosity and commitment to conservation (Earp & Liconti, 2019; Rotman et al. 2012).

There are also opposing perspectives regarding cost-effectiveness of CS and if efforts from training and supervision is worth the outcome. Lotfian, Ingensand and Brovelli (2021) argue that training participants has shown to improve data quality, however, it is not always simple, and it is both time consuming and requires financial support. Ai could be beneficial to incorporate in the training process since it can exchange a real tutor and consequently decrease associated staff costs. Alfonso et. al (2022) disagree and argue that the costs for CS are possibly higher than just using researchers in the projects. There are costs associated with creating the CS communities as well as implementing the technical tools, which are possibly higher than executing a single campaign with experts who possess more knowledge in the subject. Goldstein et al. (2014) argue that the costs are higher, however, the results are more cost-efficient compared to traditional field technique. When surveying squirrels, the traditional method detected the presence of gray squirrels in 4 out of 14 sites whereas the CS sighting report gave a clear delineation of the zone invaded by the species (Alfonso et al. 2022; Goldstein et al. 2014; Lotfian, Ingensand & Brovelli 2021).

Lotfian, Ingensand and Brovelli (2021) also analyze whether automation is beneficial or detrimental for CS projects and underline that machine learning can create incorrect scientific results and that it is more effective to only include humans. There are certain projects investigating biodiversity for citizen science where machine learning cannot detect new and rare species. They are used only for processing what they have been programmed to do, and hence these types of species fall under the radar and are not detected. Also, machine learning can make participants in projects less motivated since the number of contributors to the project increases with machine learning, making each individual less special (Lotfian, Ingensand & Brovelli 2021).

Serwadda, Ndebele, Grabowski, Bajunirwe, and Wanyenze (2018) can identify potential issues with open data and that resource inequities between countries may result in different open data possibilities, compromising on national ownership and increasing inequality. Low- and middle-income countries (LMIC) have less technological resources compared to high-income countries which prevents their access to open science and could enhance "colonial science". The technological inequality will drive different access to data among communities, making data and science more centered in high-income countries. There is also a risk where researchers from LMIC use and interpret data from northern countries and apply it to their own country's research just to save resources and not conduct the research themselves. These LMIC investigators will not publish data but instead wait on institutions from high-income countries to initiate this research. However, the data is maybe not fully applicable and can worsen the research quality in LMIC. They believe that data sharing is necessary, but open data can misuse and violate people's privacy and create greater inequalities, especially since there is an absence of risk management and an international policy framework. In order to not worsen inequality between countries, there is a need for developing an international policy framework where LMIC can participate and have equal access to the data to create a sustainable data sharing community (Serwadda, Ndebele, Grabowski, Bajunirwe, and Wanyenze, 2018)

Based on this literature, the thesis will further look at the case of Sweden and the effectiveness of our monitoring. What of these challenges and possibilities are important for Swedish marine conservation? Which elements are missing in Swedish marine monitoring, and could citizen science be a solution to make it more effective?

4. Theoretical Framework

This part presents the theoretical framework which is essential for understanding the thesis' analytical discussion. Firstly, Fitz-Gibbon (1981) discusses Performance Indicators (PIs) as a template for assessing monitoring, and important factors to measure performance with validity. Furthermore, two different monitoring assessments are described, one developed by several key stakeholders on the directive by HELCOM and the other one developed by Alfonso, Gharesifard and Wehn (2021).

4.1 Measuring Program Implementation

Fitz-Gibbon (1978) presents a theoretical framework for how to measure an implemented program and to ensure that it is monitored effectively and making progress. This framework is based on performance indicators (PIs) which are metrics designed to evaluate the specific context. PIs measure a particular element of an activity, a section of the system that produces an output, and this element should be measured regularly. There are different sets of PIs that constitute a monitoring system depending on the goals and purposes of the investigated target. To measure the performance of the outcome, the system creates specific criteria for each indicator to achieve and for every unit responsible for monitoring to observe. She explains that we have to develop tentative models, and measure varying variables in each project, to understand the inputs, the process and the outputs or outcomes of a system. Input describes the collection of information section, the process is the analysis of the data section and output is the part that explains the results. PIs and the variables measuring them can vary, however, their common characteristic is that they create a framework for feedback and valuation of outcomes (Fitz-Gibbon, 1978).

Fitz-Gibbon (1996) further argues that there are some preconditions before using the PIs to be aware of to assure that the monitoring is as effective as possible and track the performance correctly. It is important that a unit of responsibility is monitoring the structure of the system to control that the information retains high quality. She describes that someone must be the principal of the monitoring and be responsible for tracking results and a holistic responsibility. This ensures that measuring is not duplicated and that monitors commit to their tasks and execute their tasks correctly. Another important factor for obtaining reliable, precise and high-quality monitoring is to compare the system with a counterpart. The unit or responsibility should be aware of how similar systems are performing to understand if their results are reasonable (Fitz-Gibbon, 1996)

4.2 Constituted Monitoring Systems

Mack et al. (2020) has written a synthesis of marine monitoring that can be applied to detect their potential to assess marine areas. They developed these indicators to distinguish gaps in traditional monitoring systems and saw the potential to decrease their monetary- and time costs. According to the authors, the gaps in traditional monitoring are identified as:

(i) Insufficient monitoring of existing indicators in space and time, which especially applies to oxygen conditions, phytoplankton, zooplankton, benthic habitats and species, and the monitoring of mobile species.

(ii) The lack of indicators that adequately reflect the descriptors of the MSF, including food webs, sea-floor integrity, contaminants, marine litter, and underwater noise/energy.

(iii) Ecosystem elements and drivers of change, which are not monitored so far, including climate change and ecosystem services.

(iv) Insufficient regulations on data handling or storage, in particular regarding some descriptors such as biodiversity (i.e., benthic habitats and species), non-indigenous species, bycatch, hazardous substances, and marine litter.

(v) The lack in coordination of the monitoring between countries, which especially applies for the descriptors mentioned in the previous gap (Mack et al. 2020)

The authors present methods that could potentially fill these monitoring gaps and consequently exchange or supplement the traditional methods. These are called novel methods and strive towards a technological readiness level of seven or higher. Readiness level is a method for programs during the acquisition phase to estimate its maturity of technology. The methods should use stand-alone techniques and exclude traditional material sensors or human analysts in the process. By filling these gaps, they exceed traditional monitoring methods and are more cost-efficient (Mack et al. 2020).

The metrics used for this synthesis can be divided into costs and applicability and are the following:

Costs

- **Investment cost:** This includes one time investments of material and training of workers, the technology necessary for monitoring, and the personnel training expenses. In citizen science projects, this also includes the costs of starting a webpage (Mack et al. 2020).
- **Monitoring costs:** Costs for running the monitoring, called running costs (Cowen & Tabarrok, 2021). This includes the time consumption (hours the researchers and citizens worked to collect data), and staff costs (Mack et al. 2020)

Applicability

- **Reliability:** Assessed based on the failure safety to run the project and the precision of collecting the data (Mack et al. 2020)
- **Environmental Impact:** This metric was rated as either *beneficial, low impact* or *moderate. Beneficial* means that the project had positive impacts on the environment. A *low* impact is caused by actions that have an impact but not necessarily a negative one, for example anchoring objects to the seafloor. Monitoring methods that actually cause damage to the physical habits are rated as *moderate* (Mack et al. 2020).
- **Added Value:** Describes the novelty that a method adds to the traditional monitoring. This is categorized by its *spatial/tempora*l data resolution (Mack et al. 2020).
- **Limitations:** Describes the shortcomings of a method, a metric that determines how trustworthy a monitoring method is (Mack et al. 2020).
- **Required Expertise:** This metric describes the level of knowledge that is required to conduct the sampling, surveying or to analyze the data. *Low* categorizes people without any specific professional knowledge, *moderate* categorizes people who are trained for the project and *high* categorizes project that need special skills to be investigated (Mack et al. 2020)

Alfonso, Gharesifard and Wehn (2021) created another system for evaluating monitoring and understanding its complementary effects and evolution of costs compared to traditional monitoring. Costs are defined as the relationship between required investments and the actual data collected. The complementary effect defines how much citizens based monitoring coming from models or in-situ networks are filled in space and time. The authors propose a methodology to account for the value of CS and develop their metrics based on observing several CS cases. The metrics used for this synthesis can be divided into costs and complementary are listed below (Alfonso et al. 2021).

Costs

- **Costs of event-based interactions with stakeholders:** Includes the costs that were necessary to establish a contact with the citizens, the different meetings that were necessary to interact. This is for example marketing campaigns or education of citizens (Alfonso et al., 2022).
- **Values of the costs in relation to number of observations:** This metric is calculated with the following formula:

$$Cost\ per\ detection\ = \frac{Aggregate\ costs\ in\ SEK}{Number\ of\ locations}$$

  Aggregate costs equal monitoring and investment costs and number of locations equals the spots where data for the scientific research was collected (Alfonso et al., 2022).

Complementary

- **Spatial complementarity**: Explain how the project is geographically organized and how large areas of the site are monitored. This metric describes the coverage of the investigation and where the site is observed from many different locations. To calculate this indicator, the authors divided the investigated area by the number of spots that data was collected from to understand the coverage of the investigation and how many hectares each spot is collecting data for. This metric is calculated with the following formula (Alfonso et al., 2022).

$$SC\ = \frac{Investigated\ area\ in\ hectare}{Number\ of\ locations}$$

- **Temporal complementarity:** This metric explains to what extent citizens provide observations at times for which in-situ networks are unable to provide data. This is based on the time frame of execution and during what hour the input, process or output is performed. If a project obtained *high* temporal efficiency, the data was collected frequently and during different times of the day (Alfonso et al., 2022).

While performance indicators are useful for assessing program implementation, they are not without challenges. Glass, McGaw and Lee Smith (1981) argues that PIs also can be deficient for making people distort facts and focusing on wrong indicators. By only focusing on specific PIs, the system might exclude other essential indicators by staring blindly at the metrics they are attempting to measure. The intended aim of the metrics might actually not derive the desirable outcome, the unit of responsibility should instead monitor and measure several indicators based on the situation at hand to understand the larger picture. Moreover, they criticize that people might try to affect the indicators and adopt specific behaviors which are contrary to the desired outcome and instead worsens the quality. An example is the application of statistical methods in football games. A player can have a high percentage of passes caught, however, these statistics is useless if there is no scored goal. Instead of creating high quality, they argue that PIs can make the system distracted (Glass, McGaw & Lee Smith, 1981).

Applying PIs and assessing monitoring can be difficult in circumstances where systems are non-measurable. In natural science, the outcomes of certain phenomena can be unpredictable and complex to measure. More specifically, Glass, McGaw and Lee Smith (1981) use the weather as an example and describe that it is extremely complicated to accurately predict the weather days ahead as the atmospheric process is advanced and affected by multiple variables. It is hard to measure and predict weather variables, e.g., cloud formation or heating, making it difficult to create PIs for weather conditions. Another example of non-measurable conditions is ethical assessments. This is because they are built on philosophical and subjective preferences, making it difficult to create PIs that relate to several persons of varying moral aspects. This described sensitivity where unreliable conditions create uncertainty, in combination with the problem of measuring phenomenon accurately, complicates the production of PIs. This is called a nonlinear system and it is described by Davies (1987) as a system where changes in output are not linear with changes in input. When change is unproportionally, variables might change counterintuitively. Most systems are, according to him, nonlinear in nature, to different degrees. Non-statistical monitoring under conditions where outcomes are hard to predict, are useless according to the authors (Glass, McGaw & Lee Smith, 1981)

5. Methodology, Data, and Limitations

This part describes the methodology behind the study and explains the chosen approach in terms of research design, choice of performance indicators, the cases selected, and ends with pointing out limitations with the study.

5.1 Scientific Research Approach

In order to answer the research question, an explanatory research design and a qualitative methodology is used through a comparative case study. To answer the research question and understand if citizen science should be a priority and considered in Swedish policy-making, the thesis uses textual data, in form of government policy documents and other relevant reports and material, creating a foundation to study the problem of marine conservation holistically and with the aim to capture relevant marine resource management. The case study then compares the investigated citizen science projects by using PIs that are created from text analysis.

5.2 Interview Method

The interviewees were chosen through purposive sampling (Creswell et al. 2018). They are eligible as they possess extensive information and data in the marine conservation and marine monitoring area from working and researching in the field. Johanna Bergkvist, henceforth described as Interviewee 1, was interviewed for 60 minutes through Zoom and answered questions about the Stora Amundön project. She has been working for a company called Marine Monitoring for seven years and is responsible for project planning, field sampling, species identification, evaluation and reporting. Matthias Obst, henceforth described as Interviewee 2, was interviewed for 60 minutes through Zoom to answer questions about the Koster Seafloor Observatory. He works as a researcher at the department of marine science and is currently active in several roles in European marine infrastructure projects.

5.3 Research Design

Initially, various data and information were collected and analyzed to understand the research field of monitoring. In the second phase, two specific monitoring cases were chosen based on findings from the initial phase. In particular, they were chosen as they represented recent developments in the monitoring field and also as analysis indicated the research question would be relevant and interesting if applied to these. The last phase consisted of deep-analysis of each of the cases in the form of text analysis, comparison using metrics, and insights from interviews. The procedure of each case is divided into three sections: input, process and output.

Case 1 is a marine monitoring project called “Kartläggning av marina habitat i reservat Stora Amundön” and it will be compared to Case 2, a CS marine project called “Koster Seafloor Observatory” or KSO. These two cases are projects with similar aims and focus on surveying seafloors. However, their processes for data analysis and categorizing of habitats differ. In the Koster Seafloor Observatory, henceforth called as KSO, project and participants contribute by analyzing marine photographs and categorizing different species and habitats to build an algorithm for the project. In the Stora Amundön project, three researchers are in charge of the analysis and mapping the distribution of habit-forming species.

5.4 Choice of Performance Indicators

To identify which PIs would be essential for this case study, Fitz-Gibbon’s (1978) theoretical framework for PIs is used as a template to understand how one can measure monitoring effectively. Besides, Alfonso et al (2022) and Mack et al. (2020) reports are used to select relevant metrics and to find applicable measurements for three perspectives: costs, applicability and complementarity. These metrics allow for analysis and comparison of the effectiveness of the different cases’ monitoring methods by evaluating time and costs. The aim is to understand and estimate the complementary effects of CS to traditional monitoring methods.

Costs

- *Monitoring costs,* the project with the lowest aggregate costs in monitoring (Mack et al. 2020)
- *Investment costs,* the project with the lowest aggregate costs in monitoring (Mack et al. 2020)
- *Cost per detection,* the project with the lowest cost per detection *(*Alfonso et al. 2022)

Applicability

- *Reliability metric.* assesses failure safety to run the project and the precision of collecting the data (Mack et al. 2020)

- *Environmental impact,* assess if the monitoring methods create any environmental threat (Mack et al. 2020)
- *Required expertise,* assess the level of knowledge necessary to conduct the monitoring (Mack et al. 2020)

Complementary

- *Spatial complementarity (*Alfonso et al. 2022)
- *Temporal efficiency (*Alfonso et al. 2022)

NOTE: The project that derived the *highest/biggest* results for this indicator is rated with **+** and the projects that achieved the PIs with *lower/smaller* values were rated with **-.** Note that it is not necessarily beneficial to obtain the + since monitoring is categorized as more effective with low costs and not with high costs (Mack et al. 2020).

Table 1. An overview of relevant PIs to compare to monitoring cases

PIs	Stora Amundön	KSO
Investment cost	+/-	+/-
Monitoring cost	+/-	+/-
Cost per detection	+/-	+/-
Reliability	+/-	+/-
Environmental Impact	+/-	+/-
Required expertise	+/-	+/-
Spatial detection efficiency	+/-	+/-
Temporal efficiency	+/-	+/-

5.5 Case Selection

This research investigates two marine monitoring projects to evaluate the applicability and complementary effects when including public engagement. The Cost-Benefit analyzes the opportunity cost and analyzes whether CS is an effective mechanism to evaluate environmental policies and the health of the ocean. The chosen monitoring projects are surveying areas in Västra

Götaland, see fig. 6, where the red indicator illustrates where the KSO project was executed and the green indication shows the Stora Amundön project.

Figure 4: Map of Västra Götaland (Göteborg Miljöförvaltningen, 2017)

The first case, “The Stora Amundön” is executed by Marine Monitoring AB in Västra Götaland who were assigned to monitor the area for Göteborgs Stad which in turn was assigned to investigate the area on behalf of SwaAM. The data was collected with footage from a drop-camera that recorded the seafloor to investigate the health of the seafloor and to map the existing marine life and its habitat. The aim was to extend the knowledge about species distribution patterns and important biotypes and to understand the natural values in the nature reserve (SwaAM, 2022). The nature reserve creates a lot of value for the biological diversity and there is a maintenance plan to ensure that the marine environment is sustainably conserved. The municipality's decision of making this area a nature reserve has created regulations, protecting it from new exploitation and negative impact in the form of buildings, roads, bridges etc. Göteborgs Stad argues that it is important to preserve, nurture and develop the area's natural and cultural values and to ensure that the area continues to be accessible to the visiting public (Göteborg Miljöförvaltningen, 2017).

Figure 5: Map of the Stora Amundön Nature Reserve (Göteborg Miljöförvaltningen, 2017)

The second case, KSO, was monitored in Kosterhavets national park which was announced in 2009 to be Sweden's first national marine park. The area consists of 388 km2 and is located in Västra Götaland and it is well-known for its variety of rare marine environments and species that create high biodiversity, for example it is the only spot in Swedish waters with coral reefs

(Kosterhavets Nationalpark, n.d). The environmental code has established some regulations for the monitoring of marine environments, however, Västra Götalands Län (2022) describes that Kosterhavet has special maintenance plans, for example, regulations regarding what businesses are allowed to protect against exploitation.

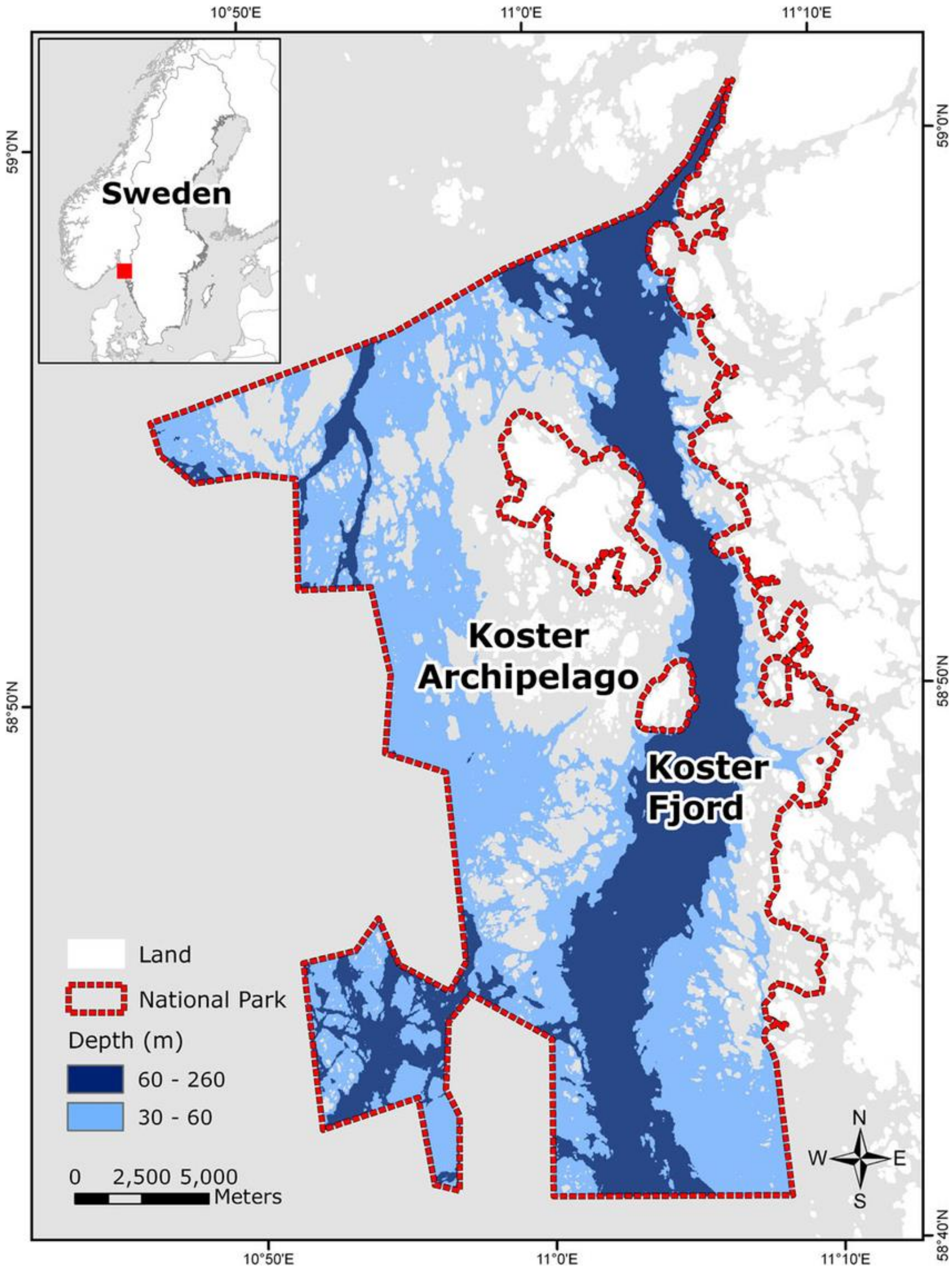

Figure 6: Map of the Koster National Park (Kosterhavets nationalpark ,2022)

Anton, Hermishuys, Bergström, Lindegarth, and Obst (2021) present their open-source modular approach called KSO, where extensive subsea footage was analyzed with a Remotely Operated

Vehicle (ROV) and processed with the help of a trained algorithm created by citizens. The researchers developed a tool for a wider community and large volumes of image data could be analyzed by this community. The aim with the project was to understand how climate change and human impact have influenced the area and if the national parks protective status has protected the seafloor habitats. Scientists in the project upload the ROV footage to a CS website and citizens then analyze the pictures by classifying them based on pre-created categories. The citizens work through two different workflows, one that is aimed at classifying the pictures and another that is aimed at drawing rectangles around the observed individuals in the pictures. The last part of the analysis consists of a trained object-detection model that tracks and identifies species based on the citizen's annotations. These classifications eventually created machine learning algorithms that were used to extract species observations from other footage. It is accessible through an Application Programming Interface (API) and the authors argue that their algorithm is ready for implementation in national monitoring programs where useful data products are created from the image-based sensors (Anton et al. 2021).

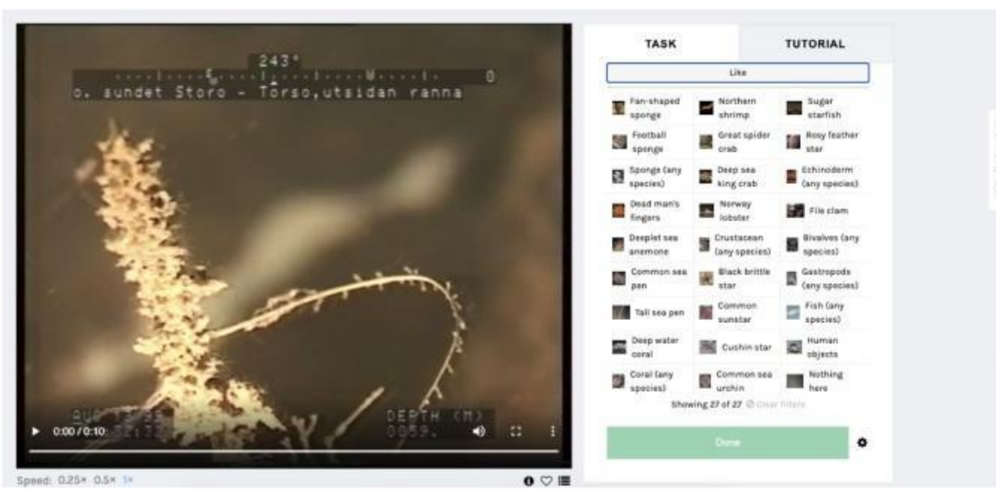

Figure 7: Footage from the Koster Seafloor’s Citizen Science Website (Ocean Data Factory, 2021)

5.6 Limitations

It should be noted that this thesis is subject to several limitations. Firstly there is a limitation with external validity as it is not certain that the results of these specific cases and the analysis performed in this research are applicable in other contexts. Secondly, one should have in mind that the compared monitoring cases differ in several aspects and it is hard to be certain which of the differences are driving the outcomes. Thirdly, there is a risk of subjectivity as the author of the thesis and the interviewees are all experienced in the field of ocean monitoring. Lastly, there is a critique (explained in section 4.2) against using PIs as a monitoring method given the risk that certain systems are too complex to measure (Glass, McGaw and (1981).

First and foremost, the research paper conducts a cost-benefit analysis on two different monitoring projects based on pre-designed indicators. The aim of the text is to dig deeper into these cases and to investigate each case thoroughly to understand CS complementary ability in comparison to regular monitoring. However, these cases from Västra Götaland could be exceptions and not applicable to all different monitoring scenarios. This is called lack of external validity where the findings are only applicable for the specific cases and not applicable in all cases (Creswell et al. 2018). It should be noted that this thesis does not aim to be applied to all contexts of monitoring worldwide, it specifically analyzes CS potential for Sweden and for marine conservation. To answer the research question about CS effectiveness the results do not solely rely on the case study, yet incorporate the case findings with governmental and scientific reports.

Secondly, finding two identical cases with similar methodology but where one uses CS and the other one without CS, was particularly problematic. Therefore, another limitation is that the two projects differ slightly in being executed under different conditions and using different materials to collect the data. The difference with public engagement is not a limitation since that factor is a necessity for answering the research question of this paper. However, the fact that the KSO project has a larger budget and expenses in relation to the Stora Amundön project is a problem since this could mean that the materials are the actual explanation for the effectiveness of the project, not the CS. Both projects use underwater cameras as the main source of data collection, however, the drop-cam is descended into the water and takes a long shot while being dragged from a boat while the ROVs record for a longer period of time and are not dependent on being dragged by a boat. The differences between the cases are counteracted by applying the PIs to the report and creating a metric and measurement to assess. The cases are therefore not just compared to one another, they are compared to the designed PIs, costs, applicability and complementary.

Another limitation is subjectivity since parts of the results are derived from interviews of people involved in the investigated project. The interviewed individuals are involved in the project's output, and by all means, want to present their work in a positive manner. Even if they do it unconsciously, they could exclude essential information or emphasize unimportant information. They can also be affected by the Hawthorne effect, making them change their answer due to knowing that they are being studied (Cresewell et al. 2018). This restraint and credibility problem was counteracted by not using the self-report material as a primary source, it was solely used to verify and check data that was obtained from reviewed scientific reports. The research then used extended data material with reviewed reports to strengthen the findings and verify the claims made by the interviewees.

As previously stated in the theoretical framework, Glass, McGaw and Smith (1981) criticized PIs as a method and argued that it can be difficult to monitor systems due to their complexity and from being unpredictable. This complicates the choice of variables to measure and what criteria to set up for the PIs, which makes PIs a unreliable method to measure outcome with (Glass, McGaw & Smith, 1981), This is counteracted by Taylor-Fitz (1978) who argue that some systems are nonlinear and more complex than others. However, most systems are measurable, one just has to design a well thought out system and base the PIs and its criteria on previous research in the field.

6. Findings and Analysis

This chapter presents the main findings regarding the effectiveness of CS based on an analysis of reports and conducted interviews. More specifically, the data and information presented from the government reports is aiming to describe the effectiveness of CS in terms of costs and efficiency, measured by previously described PI measures (see section 5.4). Besides presenting the cases in relation to the performance indicators to understand their achievements, the section presents some possible arguments for how CS can be complementary in comparison to methods excluding the citizen factor in either input, process or output during the monitoring.

6.1 Costs of the Projects Identified in Reports and Interviews

Regarding investment costs, the cases expenses differed. Stora Amundön had lower investment costs due to not investing in any new material for their operation. They were granted 90 000 SEK from Göteborgs Stad who was chosen as a client for SwaAM to execute the project, and these expenses were placed as monitoring costs, for example staff costs for three workers and gasoline. KSO was granted 4 000 000 SEK from Sweden Innovation Agency, SwaAM, Swedish Research Council and NEIC. Their investment costs were larger since they created an algorithm, started a new website for the project and set a campaign for a strategy to succeed with gathering volunteers and founders for the project. They did not spend as much monetary resources on the monitoring since they used databases from ROV cameras. The cost per detection was calculated to 530 SEK for Stora Amundön and 433,33 SEK for KSO (Anton et al. 2021; Göteborg Miljöförvaltningen, 2020).

Regarding monitoring costs, Interviewee 1 describes that the time consumption for planning the Stora Amundön project was one week, collecting the data required 12 hours and analyzing the data required one week, Interviewee 2 describes that the KSO project was time-consuming since the planning required managing several under-explored segments, creating the algorithm and forming the structure of the project for how the volunteers' analysis should be easily incorporated. He further states that this planning process required approximately 6 months. Another monitoring cost for KSO was salaries to the 13 researchers who participated in the project whereas Stora Amundön obtained three paid workers.

6.3 Application Efficiency Identified in Reports

It is essential to consider the reliability aspect for both the Stora Amundön and KSO project. Reliability was measured based on the failure safety of the projects and the precision required for collecting the data. Based on the PIs, Stora Amundön showed lower risk of failing (Mack et al. 2020). The project used a drop-cam for collecting the data which is described as a precise method for collecting sub-sea images (Göteborg Miljöförvaltningen, 2020).

The KSO initiated a novel monitoring project to investigate how their monitoring could complement traditional methods (Anton et al. 2021). The project leaders spent approximately six months on planning the project since the monitoring method is based on a developed algorithm, which is a fairly unexplored way of analyzing data and currently not categorized as an traditional monitoring method (Birk et al. 2012). The project was exposed to a risk of using a less explored monitoring method (Alfonso et al. 2021). It was also exposed to risk of involving volunteers, who obtained less experience in the marine monitoring area and who possibly possessed less motivation (Rotman et al. 2012). KSO was reliable from the perspective that it was reviewed throughout the process by several external actors: Wildlife.ai, See Analytics AB, University of Gothenburg, Nordic E-Infrastructure Collaboration, Swedish Biodiversity and Data infrastructure and Ocean Data Factory (Anton et al. 2021).

Regarding environmental impact, both projects are categorized as beneficial in their impact. This performance was assessed based on to what level the method interrupted the ecosystem and based on how well the project worked towards the EQs. One can argue that the projects have a low environmental impact since their actions did not have any large effect on the environment. The impacts are low since the required material, for example the drop-cam and ROV camera, is designed to not have any negative environmental footprint. The beneficial rating is derived based on the aims of the projects. Both projects have stated that their intention is to work towards marine conservation which is an essential part of SDG 14 (Alfonso et al. 2021; Göteborg Miljöförvaltningen, 2020).

6.4 Application Efficiency Identified in Interviews

Interviewee 1 described the planning process as a simple task since she had monitored similar projects earlier, it took them approximately one week to plan. Marine Monitoring was assigned to monitor from the directive of Göteborgs Stad who were assigned the project from SwaAM. SwaAM’s purpose is to work towards SDG 14 and implement Sweden's MSP, which means that what Marine Monitoring observed was according to their plans and necessary to observe in accordance with plans of authorities. This indicates that what the project was monitoring was precise in the perspective that it did not collect any unnecessary or redundant data, which SIME (2017) describes as a problem with many current traditional monitoring methods. However, one negative aspect is the lack of review throughout the project by any external actor. The team reviewed each other's analysis before deriving any conclusions, however, one can argue that the project would be more reliable if the researcher's analysis was reviewed by an external actor since this otherwise can create researcher bias. Creswell et al (2018) argue that research bias lowers validity since researchers can influence the systematic outcome to derive certain outcomes (Creswell et al. 2018; Mack et al. 2020).

Interviewee 2 counteracted and argued that the classification process was fairly simple and did not require any expertise knowledge. The volunteers had continuous possibilities for contact with the researchers in the project through web-channel and chatbot, which counteracts this problem. The chatbot can support and give advice to volunteers, answer volunteers’ questions and help out in case of needed assistance for the identification. Interviewee 2 had the motivational problem in mind when communicating to the citizens and argued that the researchers strained to make the participants feel commitment by explaining the importance of their contribution.

Regarding the required expertise factor, the Stora Amundön was rated by the PIs to require more expertise compared to the KSO since the seafloor data collected for the KSO could be analyzed by citizens without professional knowledge in the marine field. Interviewee 1 said that their monitoring required high expertise and she believed that it would not be effective to use volunteers in the project since volunteers lack knowledge in the area as analyzing and identifying the bottom-dwelling is too advanced. She further stated that Marine Monitoring occasionally hired project leaders during certain projects since they obtained special knowledge and essential new contributions. However, she believed that it would not be effective to use volunteers because they do not obtain enough knowledge in the area, where analyzing and identifying the bottom-dwelling is too advanced. KSO required experience in the planning section of the project which implied the development of the website and the algorithm to be used by the volunteers. However, the input and identification of the species did not require any expertise.

6.5 Complementary Efficiency Identified in Reports

The KSO is rated higher in spatial and temporal efficiency metrics compared to Stora Amundön. The Stora Amundön project investigated an area of around 1103 hectares and monitored through releasing a drop-cam in around 170 spots. This means that every stop investigated around 6,48 hectares. Regarding the KSO the project surveyed around 39 000 hectares through 9230 locations. This means that every stop investigated around 4,22 hectares and argued to be more spatially effective. However, the KSO did not use any citizens for data collection, so its spatial efficiency was not due to citizens participation. The reason for their large database was due to the fact that they analyzed open data that has been systematically collected since the late 1990s. The reason for KSO being rated higher in the temporal efficiency indicator is that the data is collected during a wider time frame. The Stora Amundön collected its marine data for three days and used this data for creating a report about the habitat mapping in Stora Amundön. The KSO used data that had been collected from the 1990s and where they systematically collected footage that could be sufficient to use to develop the algorithm. As Matthias Obst states “This approach differs from normal national, regional or local monitoring programs since data is broad in spatial and temporal scales by being routinely collected by several research institutes” (Anton et al. 2021; Göteborg Miljöförvaltningen, 2020).

6.6 Future Monitoring Ideas based on Interview Results

Interviewee 1 argues that future monitoring should aim for technological alternatives and she believes in immense progress for the future. She believes that the methods with the greatest potential are remote models, for instance, drones or satellites. These methods can cover large areas and are efficient for the automated identification of species. She describes how these technological advancements could create more precise algorithms for the identification of species. She argues that DNA sampling is another method for the future where researchers can test plankton samples and receive answers about the overall well-being of the marine area. She believes in a combination of human capital and computer knowledge to achieve the most beneficial results for monitoring. Furthermore, Interviewee 1 believes that current monitoring and technology are not efficient and trustworthy enough to rely on and there are examples of recent monitoring that used satellites and derived incorrect results. Interviewee 1 discussed the legal dilemma where it is complicated to access other projects' monitoring data and to gain permission for some monitoring tasks. She believes that the SwaAM organization is too bureaucratic and therefore hinders innovation and complicates surveying. The problem with data acquisition is that it is often confidentiality covered or expensive to purchase. This is ineffective since the tendency to share data worsens and a lot of monitoring is executed several times since it is elaborate for the researcher to obtain data banks from previous monitoring.

Interviewee 2 believes that CS has great potential in future governmental marine projects, especially those investigating biodiversity. Many authorities are already using it, for example for tracking birds in bird watching. He means that it is not as commonly used for marine conservation since it requires a lot of effort to collect the data and monitor under water. His forecast is that CS will be commonly used in about five years with new technological developments, yet more used in specific cases and especially local projects. Regarding the lack of motivation aspect, Interviewee 2 described it as uncomplicated to motivate volunteers and that it requires low effort to create engagement. One complication is the juridical aspect, since it can be against The General Data Protection Regulation (GDPR) to make individuals collect and share data. Another time-consuming aspect is that the researchers should create a purpose and narrative with their participation to make them gain from the monitoring as well, but still the research has to be scientific and contribute with trustworthy data. The summarized view is that CS has potential, however there are some aspects to have in mind and adjust to.

6.7 Results for Each Case

Comparing the cases in terms of chosen PIs, this study has been able to show that traditional methods and CS methods demonstrate differences in their input, output, and process stages in terms of surveying and monitoring. In general, KSO had higher investment costs yet lower monitoring costs and Stora Amundön had higher monitoring costs and lower investments costs.

In terms of applicability, traditional methods appear to be easier to apply. Regarding complementarity, CS methods seem to result in higher spatio-temporal effects. What generalizations can be made from it?

NOTE: The project that derived the *highest* results for this indicator is rated with **+** and the projects that achieved the PI with *lower* values were rated with **-.** However, it is not always beneficial to obtain the + since monitoring is categorized as more effective with low costs (Mack et al. 2020).

Table 2. Overview of Stora Amundön and KSO PIs

PIs	**Stora Amundön**	**KSO**
Investment cost	-	+
Monitoring cost	+	-
Cost per detection	-	+
Reliability	+	-
Environmental Impact	+/-	+/-
Required expertise	+	-
Spatial detection efficiency	-	+
Temporal efficiency	-	+

7. Analytical Discussion

To answer the research question of *how effective CS is as a policy tool to monitor marine conservation in Sweden*, the results from the cases will be compared to PIs and guidance from governmental and research reports. This section will discuss what gaps CS could fill in marine monitoring processes and how it complements traditional monitoring methods. It will also discuss the future of monitoring and what elements that could be necessary to streamline marine resource management and what aspects could be interesting for future research.

7.1 Streamline Marine Resource Management

By investigating governmental objectives and assessments of Swedish MSP and monitoring, one can understand that there are several possible angles to act upon that could support Swedish marine conservation in coping with the EQs. The question is further to what extent CS compliments these gaps and if it would be beneficial to integrate this new type of method for gathering and allowing for analysis of data. One recurrent suggestion, both recommended by SIME and the European marine board report, is that current monitoring should be further integrated and that all systems should be standardized to facilitate cooperation. If all monitoring systems work under the same premises, it is easier to compare and examine results. One can argue for two different scenarios and outcomes when integrating and investing in CS (Benedetti-Cecchi, 2018; SIME, 2017). Based on the results, citizen science could be less effective for Swedish monitoring and actually complicate the standardization of systems.

This thought is further suggested by Anne Bowser (2017) stating that inclusion of CS into all monitoring systems would possibly offset the standardization progress and create a hindrance for authorities due to the lack of commonly established routines. The suggestions from the external examiners assessing Swedish marine monitoring is that we should enhance a standardized system that facilitates cross-disciplinary working and sharing of information and expertise, and integrating CS could possibly obstruct its implementation by focusing on integrating CS. One deficiency with current CS methods is that data banks are hard to reuse and that scientists disagree regarding what format the standardization and information should take (Anne Bowser, 2017).

External examiners of Swedish monitoring argue that there is a lack of communication between monitoring entities and that working cross-disciplinary is more effective. SIME (2017) describes that joint analysis and inquiry-based assessment are two other important factors in order to understand information beyond its initial data collection context and hinder global challenges. Stora Amundön might be affected by research bias since the researchers monitor on routine and there are few external reviewers that can question their results. Design bias, selection bias and data-collection bias are just a few of the biases that could occur when not including external entities (Creswell et al. 2018). Interviewee 1 described that the data collection required three days and the planning for the expedition required approximately one week. This was possibly not the most beneficial research method, but it was preferred by the researchers since it was according to their routine. It could create a situation that Glass, McGaw and Smith (1981) describes, where Stora Amundön measures senseless indicators without a purpose since they previously have used these performance indicators and therefore distorts data. Interviewee 2 describes KSO as an open source to analyze subsea data, and another angle is that standardization would gain from adding CS since it can increase communication between authorities and support the sharing of knowledge and data. In this aspect citizen science would be effective and complementary for creating spatial and temporal data (Anne Boweser, 2017; Creswell et al. 2018; Glass, McGaw & Smith, 1981).

Another challenge for marine monitoring is from a legislative perspective where both interviewees and reports can find problems regarding marine property rights and confidential information. UN (2017) describes a legislative and causality dilemma with marine conservation, where it is hard to determine the property rights of water and where it is difficult to distinguish the causality of the problems. Robinson et al. (2018) argue that CS have a societal benefit from creating individual motivation where citizens experience a sense of fulfillment from participating and having an impact on marine policies. This can raise public awareness and make citizens aware and interested in their environmental footprint. Both Interviewee 1 and 2 describe that they have encountered legislative dilemmas in their research. Interviewee 1 experienced problems when receiving permission for accessing specific data and executing monitoring. The process for achieving this is unnecessarily complicated and she believes that communication between authorities and each county is not amenable. The report of UNESCO (2020) proposes that CS is beneficial by making it accessible to all levels of society and increasing the collaboration of data. However, the citizen science project encounters problems regarding GDPR and the inclusion of citizens creates new legislative problems (Robinson et al. 2018; UN, 2017). This makes citizen science less effective and results in lower scores in the PIs applicability, since it complicates the application of the method.

In contrast to traditional monitoring, Interviewee 2 underlined that his CS project is effective for having an educational purpose and extending individuals' environmental knowledge. This is also supported by the report from UNESCOs (2020) that argues that open dialogue between researchers and citizens could spur education and co-creation which would enhance STI. According to UNESCO, education and open dialogues are effective in marine monitoring for making scientific findings accessible to all levels of society and increasing the reproducibility, transparency, sharing and collaboration of data. However, the statement that it makes scientific findings accessible to all levels of society is opposed by Serwadda et al. (2018) that believe that LMIC would not receive the same educational level as high-income countries with opening up science and that CS would not create an educational purpose, more a backlash for the LMIC countries (Serwadda et al. 2018; UNESCO, 2020)

7.2 Citizens Science Complementary Effects

Unexpectedly, traditional monitoring and CS seem to be appropriate for different projects. Based on Sweden's current management of marine resources, one can argue that CS would not be a necessary complement to all monitoring projects in Sweden and instead complicate the input, process and output. As for Stora Amundön, data indicates that including citizens would only complicate the process and potentially derive inaccurate data and results. The explanation is that research expertise is necessary for the data analysis and including citizens in the investigation could derive wrong results. However, it could be complementary to specific cases, for example the squirrel project that was investigated by Goldstein et al. (2014) where adding CS gave clearer data results and was cost-efficient for the research. Alfonso, Gharesifard, and Wehn (2022) argue that CS effectiveness for projects is determined based on the amount of knowledge and experience that is required from the participating citizens and based on the opportunity costs for the researchers for informing and guarding volunteers. This research indicates that CS will not be difficult to apply to projects where tasks are simple and the instructions are easy to follow. Alfonso et al (2022) believe that CS could be cost-effective and an effective complement to traditional monitoring. However, it is not always the most effective monitoring method and complicates the process which outweighs its complementary benefits (Alfonso et al. 2022; Goldstein et al. 2014).

This study implies that projects striving for the collection of larger datasets can benefit from CS. One example is in KSO, where the project created an algorithm that can be used for extensive data banks and applied to future databases. This algorithm was created from a three-hour-long database but could be applied to footage archives from 1990 and for future data processes (Anton et al. 2021). This indicates a potential with CS, creating innovation and facilitating analysis and sharing of data by not only complementing the KSO but also allowing for further use of the algorithm in future monitoring projects (Earp and Liconti, 2019). However, the study implies that the Stora Amundön project would not derive better results from incorporating CS, due to the fact that its analysis is very complex.

My study has investigated a CS case where the public is active in the analyzing and surveying part of the project. For future research, it could be interesting to examine a monitoring project where volunteers instead are incorporated into the data-collection process. For example Goldstein et al. (2014) research presents a study where incorporating CS into data collection created a more comprehensive snapshot of the locations to lower costs and overall be more effective than traditional surveying (Goldstein et al. 2014). It could be interesting to find a CS project in Sweden with a similar structure, one example of such a monitoring case is Vattenfokus in Sörmland (Vattenfokus, n.d).

CS methods seem to have great potential and the scientific research in this field is developing at a fast pace. However, the method is still relatively unexplored and there is potential for improvement. CS might have complementary effects from having high spatio-temporal effects and create social value. However, including CS as a component can be time consuming and require additional efforts and considerations. If you take Stora Amundön and KSO as an example, both projects monitor seafloors, however, the KSO project can explain the biodiversity whereas the Stora Amundön project detects less species and smaller areas. The Stora Amundön project is mapping an area without analyzing the ecosystem since it does not really investigate environmental changes. Both the investigated projects are focusing on marine monitoring in the same county, yet, their input, output and process differs. Combining CS into Stora Amundön might only be time consuming and derive less trustworthy results. Furthermore, incorporating CS into this project might be beneficial years ahead, when strategies and juridical problems are solved. There is an abundance of research in marine monitoring, yet, CS is still a relatively new field and has potential.

8. Conclusion

Marine resources and marine areas are facing severe threats and there is an urgent need to decrease humans' environmental impact to counteract these challenges. Marine monitoring is an essential part in understanding the well-being of marine life and establishing effective policies aiming toward SDG 14. One upcoming monitoring method is CS which seems to have complementary effects by collecting spatio-temporal data and creating new value and innovation. The thesis has evaluated CS from a cost, applicability and complementary perspective by comparing two case studies of Swedish marine monitoring and conducting text analysis on governmental reports. The results from the thesis have partly been able to distinguish in which contexts CS can be more effective compared to traditional methods, yet, there is still space for future research and for a more profound analysis of CS.

One can argue that citizen science can be effective as a policy tool to monitor marine conservation in Sweden, yet, not in all cases. The method requires a more consistent framework and it is not the most effective monitoring method nor adequate for all marine conservation projects. It seems to have the greatest potential in local projects where there is a large selection of volunteers and where these citizens might possess more local knowledge compared to scientists. Also, citizen science could be a cost-effective alternative to traditional monitoring for analyzing and collecting large data sets. However, it is important that the tasks for the citizens are simple and easy to comprehend and not create unnecessary time consumption for researchers. In addition, citizen science is a new method and findings indicate that the method will continue and develop to become more effective in the future. Interestingly, citizen science appears to generate complementary positive effects that are not connected to the costs nor efficiency of the projects as such, but rather lead to benefits for citizens. For example, allowing for knowledge sharing of environmental projects and acting as a source of education in the area.

Further studies are required to establish broader citizen science communities in Sweden and to incorporate knowledge about its application in Swedish monitoring. Given that CS is discussed in several governmental and academic reports, in combination with experts in the field describing benefits with the method, it seems to have huge potential for future monitoring. However, it is not yet commonly used and more research regarding CS efficiency appears to be necessary to further understand its strengths and weaknesses. This research highlights additional questions to be resolved in the area; for example what investments that are necessary to make CS more effective. A potential suggestion is to extend the usage of Application Programming Interfaces (APIs) in CS, possibly facilitating sharing and the use of metadata to advance citizen science and citizen participation in monitoring.

Citizen science has the potential to decrease research biases and create innovation that could be beneficial for Swedish marine policy-making. It will probably be integrated and gain more attention in Swedish MSP over time. However, there is a need for further research in the field and applying it at a fast pace could possibly complicate the process of streamlining and standardizing Swedish monitoring. Citizen science can be seen as an uncut diamond, it has large potential but has to be further polished before being implemented into Sweden's marine conservation strategy. An interesting question to consider for future CS marine monitoring projects is: do positive complementary effects outweigh potential complications?

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