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Indicators for evaluating impacts from marine macroplastics using an Ecosystem Service approach

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The objective of the thesis is to develop and evaluate indicators related to ecosystem services that may be affected by marine macroplastic debris. The following activities will take place as part of the thesis:

1. Continue the literature review initiated in the project thesis on ecosystem services and indicators for measuring impacts from marine macroplastic.

2. Develop a structure and categorization of ecosystem services with regards to marine macroplastic issues to operationalize the approach.

3. Develop and/or select requirements to indicators that will be selected and developed.

4. Develop and/or select indicators for evaluating impacts from marine macroplastic.

5. Discuss and evaluate indicators and application.

6. Conclude and recommend further work relative to the approach.

Preface

This thesis is part of the course TIØ4925 - Safety, Health and Environment, Master's Thesis. The thesis is the ending work of the Health, Safety and Environment (HSE) master's program, at the Norwegian Natural Science University (NTNU). The work in this thesis is a contribution to the Interreg NPA (EU) funded project Circular Ocean.

First, I want to thank my supervisor, Dina Margrethe Aspen. Thank you for all your counselling through mails, phone calls, skype meetings and personal meetings. It has been much appreciated and crucial for my understanding of the task and the outcome of the thesis. Thank you.

I also want to thank my classmates whom I spent a lot of time with writing this thesis, and over the course of the last two years. Through the ups and downs of being a student, I have always enjoyed the social atmosphere of our class. Our gatherings for lunch, parties or other social events have been fun and motivating, and made my last years of studying worth the effort. Thank you all.

Abstract

The purpose of this thesis was to evaluate how indicators that describes the impacts of marine macroplastic may be related to marine ecosystem services. Part of the task objective was developing a set of indicators that related to both subjects. To answer the assignment, the following research questions were chosen:

1. Which pressure, state and impact indicators have been developed in relation to marine macroplastic?
2. How can ecosystem services be used to structure impact assessment from marine macroplastic?
3. Which indicators may be used to measure impacts on marine ecosystem services from marine macroplastic?

Systems Engineering, which looks to ensure the realisation of successful systems, was the overarching methodology of the thesis. This approach applies life cycle models to ensure verification and validation of the different stages in the life cycle of systems. This thesis has applied a vee-model for the development of an indicator set. An environmental indicator framework, called the DPSIR-framework, was used to categorise the indicators and describe pressure (input), state (amount) and impact (social, economic and ecological) due to macroplastic, and to give the thesis a more systematic structure.

A literature review for active macroplastic indicators revealed that these were few in number. Only one indicator related to impact and state was identified and a couple of pressure indicators related to lost or abandoned fishing gear. Several proposed future indicators were also identified and reviewed for selection for the indicator set.

Ecosystem services may be used to structure the impacts of marine macroplastic. This can be done by individually classifying both subjects and connecting the impacts of macroplastic to the different services. The connection may highlight the relation between impacts of macroplastic and marine ecosystem services, and can assist in the selection and development of related indicators.

The targeted indicators in this thesis can provide information on how the the social, economic and ecological impacts of marine macroplastic affect marine ecosystem services. Potentially, they can also be used to value the services, enhancing their influence on policy. These types of indicators are ideally suited for direct services, which have direct benefits and a strong link to human well-being (e.g. fish). Future research should focus on challenges with determining the direct services of impacted species and measuring complex services. 10 indicators were identified for the indicator set, while two were developed.

Sammendrag

Formålet med denne avhandlingen var å evaluere hvordan indikatorer som beskriver effektene av marin plast kan relateres til marine økosystemtjenester. En del av oppgavens mål var å utvikle et sett med indikatorer som kunne relateres til begge emnene. Følgende forskningsspørsmål ble valgt for å besvare oppgaven:

1. Hvilken press-, tilstand- og påvirknings indikatorer har blitt brukt til å beskrive effektene av marin makroplast?
2. Hvordan kan økosystemtjenester bli brukt til å strukturere effektene av marin makroplast?
3. Hvilke indikatorer kan bli brukt til å måle effektene av marin makroplast på økosystemtjenester?

”Systems Engineering”, som søker å realisere suksessfulle systemer, er den overordnete metodologien for avhandlingen. Denne tilnærmingen bruker livssyklus modeller for å verifisere og validere ulike steg i livssyklusen til systemer. Denne avhandlingene har brukt en ”vee-model” for utviklingen av et indikator sett. DPSIR-rammeverket har blitt brukt til å kategorisere indikatorene og beskrive press (tilførsel), tilstand (mengde) og påvirkning (sosiale, økonomiske og økologiske effekter) som følge av makroplast, og for å gi oppgaven en tydeligere struktur.

Et litteratursøk etter aktive makroplast indikatorer viste at disse var få i antall. Kun en aktiv tilstand og påvirknings indikator ble identifisert og et par press indikatorer relatert til tapt fiskeutstyr. Flere foreslåtte indikatorer ble identifisert og ble vurdert for indikatorsettet i denne oppgaven.

Økosystemtjenester kan bli brukt til å strukturere effektene av marin makroplast. Dette kan bli gjort ved å individuelt klassifisere begge emnene og deretter knytte effektene av makroplast til de forskjellige tjenestene. Denne forbindelsen kan fremheve relasjonen mellom effektene av makroplast og marine økosystemtjenester, og kan assistere i valg og utvikling av relaterte indikatorer.

De forespurte indikatorene i denne avhandlingen kan gi informasjon om hvordan sosiale, økonomiske og økologiske effekter av makroplast påvirker de marine økosystemtjenestene. Potensielt kan de også brukes til å valuere tjenestene, noe som kan øke deres politiske påvirkningskraft. Denne typen indikatorer er mest passende for direkte tjenester, som har direkte fordeler og en sterk link til menneskelig velvære (eks. fisk). Fremtidig forskning bør fokusere på utfordringer med å knytte direkte tjenester til marine dyrearter som er påvirket av makroplast, samt å måle komplekse økosystemtjenester. 10 indikatorer ble identifisert i denne avhandlingen og to ble utviklet.

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Abbreviations

ALDFG	Abandoned, lost or otherwise discarded fishing gear
DPSIR-framework	Driver-pressure-state-impact-response-framework
ES	Ecosystem services
EEA	European Environment Agency
ESI	Endangered species indicator
EU	European union
GES	Good environmental status
GFI	Ghost fishing indicator
GHG	Greenhouse gases
MEA	Millennium Ecosystem services
NOAA	National Oceanic and Atmospheric Administration
OECD	Organisation for Economic Cooperation And Development
PSR-framework	Pressure-state-response-framework
RP	Revealed preference
RSC	Regional Seas Programme
SE	Systems Engineering
SDG	Sustainable development goals
UNEP	United Nations Environment Programme

1 Introduction

1.1 Background

The development of plastic has become a vital part of society's economic and social development. Since its large-scale production origin in the 1950s, it has offered several great benefits to humanity in numerous sectors, including health and food preservation, transportation and by enhancing the digital age. In 2016, approximately 335 million tons of plastic was produced. In the past, the production rate has grown exponentially and it is expected to do so in the future as well (Kershaw 2016). It is estimated that around 50% of the produced plastic is used for single use disposal, such as packaging, contributing to the enormous production rate (Hopewell, Dvorak et al. 2009). Plastics great characteristics have led to it being host for several applications, but is at the same time leading to a significant social, economic and ecological cost (Kershaw 2016). Between 4.6-12.7 million tons of plastic debris ends up in the ocean every year, and it is further estimated that 150 million tons have accumulated in the world's oceans, causing problems for marine biota, fishing, tourism and marine ecosystems (Commission 2018).

1.2 Purpose and objectives

To understand the marine plastic issue and come up with policy responses, there is a need to quantify and describe the effects of plastic on the marine environment. The purpose of this thesis is to evaluate how indicators that describes the impacts of marine macroplastic may be related to marine ecosystem services (ES). Before doing this, it is important to know which indicators are already available for marine macroplastic and how to connect the impacts of macroplastic to marine ES. The following research questions have been chosen for the assignment:

1. Which pressure, state and impact indicators have been developed in relation to marine macroplastic?
2. How can ecosystem services be used to structure impact assessment from marine macroplastic?
3. Which indicators may be used to measure impacts on marine ecosystem services from marine macroplastic?

Part of the task objective is to develop a set of relevant indicators that meets several predetermined requirements. This set will contain selected indicators as well as developed and operationalised indicators.

1.3 Method

The thesis is conducted as a multi-disciplinary study, combining literature review with quantitative and qualitative techniques for identifying and developing indicators. Answering the research questions required exploring existing work in the field (literature review). The literature review methodology is presented in chapter 2, while the methodology and method for selecting and developing indicators is presented in chapter 6. This study did not involve collecting data or in any way manage data where personal information or sensitive data is recorded.

1.4 Scope and limitations

The marine plastic issue can be divided into macroplastic and microplastic. Microplastic is defined as particles with a diameter less than 5 mm (Kershaw 2016). This thesis aimed to select and develop indicators related to marine macroplastic (>5 mm). This specification was implemented to limit the scope of the task, due to time restrictions. It is important to mention that ingestion of marine plastic by marine biota will include both macroparticles and microparticles, but this overlap is inevitable and regarded as ok for this task.

This thesis also aimed to develop and identify macroplastic indicators and not ES indicators. ES indicators are defined as information that efficiently communicate the characteristics and trends of ES, making it possible for policymakers to understand the condition, trends and rate of change in services (Brown, Reyers et al. 2014). The purpose of this thesis is addressing the impacts of macroplastic on marine ES, and not to measure the service in it self.

This thesis also looked to develop indicators related to the pressure macroplastic put on the marine environment due to input, the state of the marine environment due to macroplastic pollution and the impacts of macroplastic on the marine environment. Due to the scope of the task, driving forces and response to the issue, were not addressed in this thesis. Potential input of plastic is also not addressed. A further description of this terminology is presented in chapter 4.1.1, in relation to the DPSIR-framework.

1.5 Structure of the thesis

This thesis is divided into three parts. Part I presents theory relevant for the development of the indicator set and the connected methodology for providing this information. Part II consists of methodology and results. Part III involve discussion and conclusion of the work in this thesis.

Part I

Chapter 3, 4 and 5 in this thesis aim to introduce relevant topics related to marine plastic, indicators and ES. Chapter 3 present the marine plastic issue and its social, economic and ecological impacts, as well as related policy to the issue. Chapter 4 introduces indicators, environmental indicators and relevant indicator terminology and requirements. Chapter 5 provides an overall presentation of ES, together with marine ES. Before these chapters, a short presentation of how this literature was obtained, is presented.

Part II

The second part of this thesis presents the results and the related methodology. Chapter 6 presents the research methodology and related method for the development of the indicator set. This chapter set the foundation for chapter 8, where the actual indicator set development take place. The structure of chapter 8 is based on the presented vee-model (a Systems Engineering model) presented in chapter 6. Chapter 7 searched to explore active and developed marine macroplastic indicators.

Part III

The last part of this thesis involves discussion and conclusion of the work performed in this thesis. Chapter 9 presents a discussion of the work, based on the research questions. This chapter also contain a discussion of the methodology and methods applied in the thesis, as well as future research and recommendations. Chapter 10 ends the report by presenting concluding answers of the research questions.

2 Literature review methodology

Chapter 3, 4 and 5 in this report, is based on a traditional literature review. A traditional literature review search to describe current literature without a given methodology, and can be seen as a summary of previous work with an interpretation. This literature review can also be classified as a conceptual review, which seeks to give a better understanding of different areas in conceptual knowledge (Jesson, Matheson et al. 2011).

Internet search engines have been used to gather peer-review literature and grey literature. Peer-review literature is academic peer-reviewed and published journals, while grey literature is non-academic and non-peer-reviewed (Jesson, Matheson et al. 2011). Scientific search engines like Scopus and Google Scholar have been used to gather literature from reports, books, articles and internet pages. Often, the material was obtained from the reference-list of found literature. Literature have also been found in google, often grey literature. The validity of this literature has either been checked by searching for it on Google Scholar, or the author has been recognised as a reliable source, like for example United Nations (UN) or the European Union (EU). The literature review was performed with a critical mind-set, and literature was included or excluded based on its relevance and credibility.

3 Marine plastic

Plastic is a widely used material, highly regarded for its characteristics like light weight and high durability (Ryan, Moore et al. 2009). It is derived from the polymerisation of monomers extracted from oil and gas, and around 4-6 percent of the world's oil production goes to the production of plastic, while 3-4 percent is used to provide energy for the process (Hopewell, Dvorak et al. 2009). Plastic can also be made from coal and renewable and biodegradable resources like grains and potatoes, but the main source is oil and gas (PlasticsEurope 2016). Plastics durability is also what makes it an environmental threat as most plastic items can last from hundreds to thousands of years in the natural environment (Bergwitz-Larsen, Bjørkhaug et al. 2016). Because of this, plastic can even be found in remote areas like uninhabited islands, Arctic ice and deep oceans (Kershaw 2016).

There are several different pathways for plastic into the marine environment. Plastic debris can be transported to the ocean through rivers, floodwaters, sewage, coastal areas and also be transported with the wind. Sea-based sources like the fishing industry, shipping, offshore mining and extraction and other offshore activities is also a great contributor to the marine plastic pollution. After entering the ocean, it is estimated that 70 percent of the plastic sinks to the ocean floor, 15 percent floats on the surface and 15 percent is washed ashore (Bergwitz-Larsen, Bjørkhaug et al. 2016).

It is difficult to acclaim the input of marine plastic to different sources as plastic debris is transported with currents. Floating debris can be transported with currents over great distances and accumulate in whirlpools, so-called gyres. There are five major ocean gyres in the world, where a substantial amount of plastic accumulates. Because of the large amount of plastic debris in these gyres, streams with large concentrations have been called "garbage patches". The largest of these streams is the well known pacific garbage patch (Kershaw 2016).

3.1 Harm caused by marine litter

Marine litter is defined by "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and costal environment, and studies reveal that marine litter consists of 60-80 percent plastic, depending on where it is found (Allsopp, Walters et al. 2006). Marine plastic is often addressed through marine litter (e.g. impact, monitoring and policy). Harm caused by marine litter, and therefore also macroplastic, can be divided into social harm, economic harm and ecological harm (Galgani, Hanke et al. 2013). These impacts are presented below and a summarisation is also presented later in chapter 8.3.

3.1.1 Social and economic impacts

There are several social and economic impacts related to marine litter. Social impacts can include disturbance in the recreational, aesthetic and educational values of marine areas (e.g. beaches and coastal areas), and the risk of loss in public health (e.g. due to ingestion of microplastic). Floating litter may also serve as a threat to human lives due to the risk of colliding with floating objects when navigating through the marine environment. Marine litter can cause economic impacts for a range of maritime industries as well, including aquaculture, fisheries, shipping, tourism, power stations and industrial use. To give some examples, marine vessels can take damage through collision or motor entanglement, leading to repair and income cost. Disturbance from marine litter can also lead to implications for tourism due to loss of revenue in coastal areas. Another example is the impact on power stations. Many power stations rely on seawater for cooling water. Marine litter can cause blockage of cooling waterintake screens, leading to removal and maintenance costs. The economic cost of marine litter is expected and estimated to cost millions of euros each year (Mouat and Lozano).

3.1.2 Ecological impacts

Ecological impacts of marine litter relates to its impacts on the marine environment (Galgani, Hanke et al. 2013). Today, there is a major concern related to marine litter's impact on the marine biota. Marine litter can harm different marine species through entanglement, ingestion and smothering, and fatality has been well documented for birds, reptiles, fish, and marine mammals (Kershaw 2016). According to United Nations Environment Programme (UNEP), marine litter harms over 600 marine species, with 15 percent of these being endangered (Wilkie 2017). Even though the evidence of impacts on many species is evident at an individual level, it is still difficult to quantify the possible population-level effects. For now, it is difficult to know if these impacts are sufficient to cause a decline in populations of a certain specie through for example death or injury, or by reducing their habitat and reproductive success (Kershaw 2016).

Entanglement is an issue for many species as plastic items in the marine environment can potentially become entangled around marine biota. Playful and curious marine species like seals and whales are especially prone to plastic entanglement (Bergwitz-Larsen, Bjørkhaug et al. 2016). Entanglement can cause suffocation, immobility and lacerations, and ultimately lead to death. A large part of the entanglement issue is related to abandoned, lost or otherwise discarded fishing gear (ALDFG), presented further down. Marine biota may also try to use marine litter as shelter or as nesting material. As an example, birds can collect plastic items and use it to build their nest, leading to their young getting entangled (Miljø 2001). Research reveals that there is large number of marine species with entanglement records. Entanglement is evident for marine invertebrates, fish, birds, seals, turtles and cetaceans.

Plastic ingestion has also been documented for a wide variety of marine species. For some species it is difficult to separate the marine litter from food and they therefore end up eating the debris. If the plastic or litter have an unnatural shape that makes it not pass through the digestive system, it will accumulate in the body. The effects of this depends on where in the body the litter gets stuck. If it gets stuck high up in the oesophagus, the airways can get blocked and the animal dies of suffocation. This happens often to sea turtles, who mistake plastic bags for jellyfish. When plastic get stuck further down the oesophagus it may hinder the uptake of nutrition leading to starvation. If the plastic enters the stomach, it can hinder digestion and lead to starvation. The plastic debris can also cause internal wounds and bleeding (Bergwitz-Larsen, Bjørkhaug et al. 2016). Another concern regarding ingestion of plastic is the uptake of chemical additives from the plastic. Evidence of ingestion is usually collected from the dissection of beached carcasses (Kershaw 2016). As with entanglement, research reveals several marine species with documented records of ingestion. Ingestion is especially evident for fish, birds and cetaceans. More about species impacted by plastic entanglement and ingestion can be read in UNEPs report “marine plastic debris and microplastics” (Kershaw 2016).

Marine litter can also affect benthic habitats, such as coral reefs. Especially derelict fishing gear can be destructive as nets and lines can attach to corals and break them off due to currents. When the debris is freed it will again attach to the corals and the process will start over again (Allsopp, Walters et al. 2006). The debris can also smother the corals and lead to anoxia (depletion of oxygen) and hypoxia (deprivation of oxygen in organisms) (Gregory 2009). Coral reefs offer several marine ES, more thoroughly described in chapter 5.1.

Another concerning ecological impact, related to floating litter, is the transportation of species to new habitats. Research reveals that certain marine species, such as the crustacean barnacle and molluscs, can connect to floating debris and use it as a mobile home. From here they can spread to areas where the specie is not naturally found, causing problems for local species due to competition (Bergwitz-Larsen, Bjørkhaug et al. 2016).

Abandoned, lost or otherwise discarded fishing gear (ALDFG)

A large proportion of the marine litter entanglement issues is related to abandoned, lost or otherwise discarded fishing gear (ALDFG), which consist mainly of plastic materials (Kershaw 2016). Fishing gear include all types of fishing equipment, including different nets, longlines, trawls and shellfish traps and pots. Reasons for lost fish gear could be environmental (e.g. currents), gear conflict (unwanted entanglement), gear condition (e.g. breaks loose) or inappropriate disposal at sea (Brodbeck 2017).

There are several environmental and economic consequences related to ALDFG. Two major financial costs include replacing lost fishing gear and reduced earnings due to lost fishing time. There is also reported instances of boat motors being entangled in fishing gear, leading to repair cost (Brodbeck 2017). Another serious issue related to ALDFG is “ghost fishing”. Ghost fishing is when lost or abandoned fish gear continues to catch fish and other marine biota after the gear is no longer under the control of a fisherman (NOAA 2015). This process can reduce commercially valuable fish stock and the stock of other marine biota. Different equipment causes different problems. Sein nets (2mm thick) is not expected to catch many fish due to the visibility of the net. Longlining is also not associated with a high catch rate as the bait is lost and the hooks rust. There is a larger concern related to the catch rate of gillnets, trammel nets ad traps, as they can continue to catch fish and shellfish long after being lost (Brodbeck 2017). In a study involving a gill net and a trammel net being deliberately abandoned, Kaiser et al. (1996) investigated the types of organisms caught in ghost nets over time. The study revealed that the nets caught mostly fish in the first couple of weeks, while after this it caught mostly crustaceans. The nets continued to catch crustaceans up to 9 months after being deployed (Kaiser, Bullimore et al. 1996) . Studies also reveal that the catching efficacy of fishing gear will significant decrease over time after being lost, as the gear begins to break down (Brodbeck 2017).

Observing “ghost fishing” offer several implications, as the gear is under water in a natural and uncontrolled environment. Different survey methods with different type of nets, locations and species caught, makes generalisation difficult. Factors like fish being eaten or deteriorate because of lice, will not be detected in a catch rate observation study. As ghost fishing can occur long after the fish gear gets lost, it also makes surveys time consuming. These challenges make it difficult to generalise result and report average numbers for “ghost fishing”, but if most variables were similar (i.e. same gear, period, location), this generalisation could be possible. According to Laura Brodbeck, because of the lack of such studies, this generalisation is not currently achievable (Brodbeck 2017). It is also difficult to gather data on ALDFG in general for several reasons. Most gear is not collected and the main reason for gear loss is through gear conflict, storms or currents (NOAA 2015). Gear loss due to illegal fishing and deliberately disposal is also contributing to insufficient data and poor reporting (NOAA 2015).

3.2 Marine litter policy

Several different measures have been adopted to try to hinder litter from ending up in the ocean or try cleaning up the existing litter. Global, international and national initiatives have led to conventions, agreements, programs and activities in response to the marine litter issue. Measures for minimising the waste includes reuse and recycling, education, producer responsibility and eco-design. There have also been local and global clean-up programs which encourages people to join in clean-up operations (Allsopp, Walters et al. 2006). Marine plastic is being monitored as part of the marine litter monitoring and being addressed through marine litter policies as well.

The United Nations Environment Programme (UNEP) is considered as one of the biggest environmental players, with their governing body; the United Nations Environment Assembly (UNEA) being the highest-level decision making body on environmental issues. UNEA has the membership off all 193 UN Member States (Finska 2018). The legal framework for activities at sea are set out by United Nations Convention on the Law of the Sea and General Assembly Resolutions (Galgani, D. Fleet et al. 2010). UNEP have developed several sustainable development goals (SDGs) related to marine litter, to be reached by year 2030. Several of these goals address reduction of marine litter by year 2020 and 2030. UNEP also stand behind conventions, activities and programmes addressing marine litter and have published several reports on the issue (Kershaw 2016). An important initiative is the Regional Seas Conventions

(RSCs), a legal framework that aim to protect the oceans and seas at a regional level. Over the last 40 years, 18 RSCs have emerged, involving more than 143 countries. These are both UNEP administrated and non-UNEP administrated. All conventions take on a similar approach, but have been tailored by its own governments and institutions to fit their environmental challenges (UNEP n.d.). The four European RSCs are (Comission 2016):

- The Convention for the Protection of the Marine Environment in the North-East Atlantic - the Oslo Paris Convention (OSPAR)
- The Convention for the Protection of the Marine Environment in the Baltic Sea Area - the Helsinki Convention (HELCOM)
- The Convention for the Protection of Marine Environment and the Coastal Region of the Mediterranean - the Barcelona Convention
- The Convention for the Protection of the Black Sea - the Bucharest Convention.

Another important environmental player is the European Union and their governing body, the European Commission (EC). The EU's Marine Strategy Framework Directive (MSFD) is a legislative measure for the protection of the marine environment across Europe, adopted on 17. June 2008. The aim of the MSFD is to achieve Good Environmental Status (GES) in EU's waters by 2020. In order to achieve this, each member state is required to develop a marine strategy for their own waters. To help Member States interpret GES in practice, MSFD sets out eleven qualitative descriptors, which describes the marine environment after GES is achieved. Descriptor 10 addresses marine litter and states that "properties and quantities of marine litter should not cause harm to the coastal and marine environment" (Comission 2017).

Other serious marine litter players include National Oceanic and Atmospheric Administration (NOAA), European Environment Agency (EEA), Environmental Protection Agency (EPA) and Non-Governmental Organisations (NGOs), among others.

3.2.1 Marine litter monitoring

A large part of the marine litter governance is through monitoring. One of the requirements of the MSFD is that all Member States shall establish and implement coordinated monitoring programmes for ongoing assessments of the environmental status for their marine waters. The proposed protocol for monitoring marine litter involves beach surveys, floating litter surveys, benthic litter surveys and surveys on litter ingested by marine biota. These methods are also similar to the methods of organisations outside of EU, like the NOAA. They generate mostly information about the amount and composition of the marine litter, but to some extent they also generate information about the distribution of the litter and the impacts on marine biota (Ryan, Moore et al. 2009). As mentioned, monitoring the marine litter pollution source and spatial distribution is complicated. This is due to the various sources of pollutions (land- and sea-based) and distribution through currents, in addition to several possible depositions. It is difficult to acclaim the pollution to a certain polluter, but by categorising the marine litter (e.g. fishing items and sewage-related debris), monitoring trends in the amount and composition can lead to mitigation measures related to the input (Galgani, Hanke et al. 2013).

For beach litter, information on the amount and composition of litter is related to a certain length or area of the beach or coastline. For floating and benthic surveys, amount and composition is related to area, width or line transect. Beach surveys are viewed as the simplest and most cost effective way of monitoring marine litter and is therefore the greatest source of information on its abundance (Ryan, Moore et al. 2009). Litter ingestion by marine biota is also being monitored. For the Northern Fulmar, ingestion of plastic has been monitored since the 1980's. The Northern Fulmar is a seabird that is located mostly in the Northern Pacific, High Artic, and Northern Atlantic (Avery-Gomm, O'Hara et al. 2012). They live most of their life at sea, where they feed of fish, crustaceans and other sources of food at the sea surface, over a vast migratory range. Because of this, the Northern Fulmar is prone to ingest plastic and surveys reveal that up to 95 percent of these birds have plastic in their stomach (NINA n.d.). The main reason for monitoring plastic in Fulmars's stomach is to obtain an ecological relevant measure for the abundance of floating plastic debris and to estimate ecological harm (van Franeker, Meijboom et al. 2004). Monitoring of turtle ingestion has recently been developed, based on the protocol for monitoring ingestion by the Northern Fulmar. Methods for monitoring ingestion by fish is currently being developed, but focuses on microplastic (Directive 2013).

4 Indicators

The word indicator originates from the Latin verb "indicare", which has several meanings including to disclose or point out, to announce or make publicly known, or to estimate or put a price on. The goal of indicators is to communicate information. A commonly understood meaning of indicators is that they provide information to a matter of larger significance or makes perceptible a trend or phenomenon that is not immediately detectable. Easier explained, an indicator is something that points to the occurrence of something else. Examples of indicators are how a drop in barometric pressure may indicate a coming storm or how threatened species can be an indicator for biodiversity loss (Hammond and Institute 1995).

According to the World Resource Institute (WRI), indicators have two important characteristics (Hammond and Institute 1995):

- They quantify information so that its significance is more apparent.
- They simplify information about more complex phenomena to improve communication.

Indicators mostly consist of a specific measured variable or a combination of several variables (EFSA n.d.). Determining how to measure the indicator by choosing variables is called operationalising (Dahlum 2016). Indicators are often presented in statistical or graphical form, but they are distinct from statistics or primary data. Primary data can be seen as original data collected for a specific research goal, which indicators are compiled from. Figure 1 presents the information pyramid, which illustrates how indicators are based on primary data and analysed data (Hammond and Institute 1995).

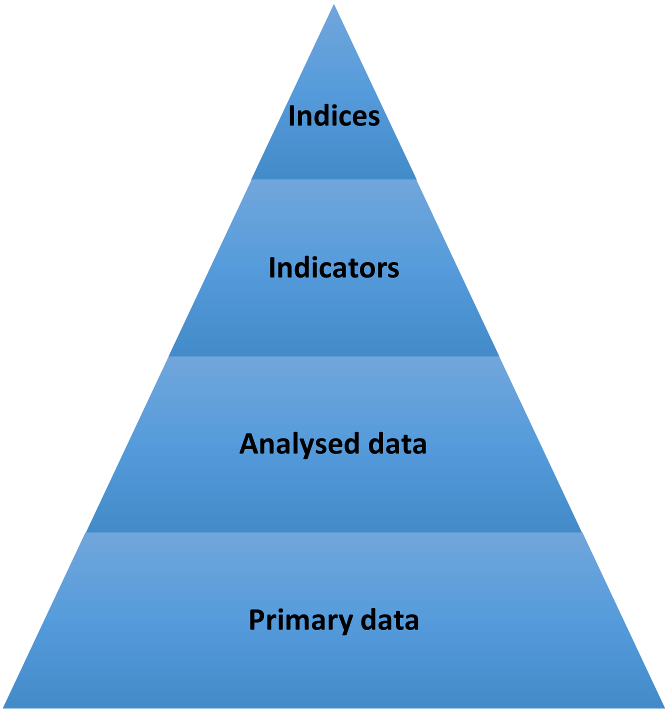

Figure 1: The information pyramid. Inspired by Hammod and institute (1995)

Indicators can be used for many purposes and at many levels. Different level of use and communication includes community, sectoral, national or international levels. Indicators are widely used around the world today in different fields like economics, environment, politics, industry and research, to mention some. Their main objective is to give support to decision making in these different fields. Indicators are often developed in relation to policy making, to give information about progress toward social goals (e.g. sustainable development) (Hammond and Institute 1995). According to UNEP, indicators makes data relevant for society and policy. They list the following values of indicators in policymaking (van Woerden, Wieler et al.):

- providing feedback on system behaviour and policy performance;
- improving chances of successful adaptation;
- ensuring movement toward common goals;
- improving implementation;
- increasing accountability.

Indicators are often combined into an index. Indexes, also called indices (top of figure 1), make it easier to interpret complex information where there is a wide range of topics. They are often used to assess and compare performance against benchmarks or among performers. Combining indicators in one index can make it easier to communicate information then it would be comparing several discrete trends. Some well-known indices include the Gross Domestic Products (GDP) index, Human Development Index (HDI) and the Environmental Performance Index (EPI). As an example, the HDI combines longevity, knowledge and standard of living to give an indication of human development in a country (van Woerden, Wieler et al.).

There is a lot of different therminology related to indicators. Table 1 presents different types of indicators. The meaning of this is to give an overview of different indicator terminology presented in this report. It is also a good reference point for the reader to go back in the report for a reminder of definitions.

Table 1: Categorisation of indicators.

Categorisation	**Description**
Leading indicator	Leading indicators are input oriented and are used for prediction. They can be hard to measure, but easy to influence. An example, indicating weight loss, could be calories taken in and calories burned (Manuele 2009).
Lagging indicator	Lagging indicators are output orientated. These indicators are easy to measure, but difficult to improve or influence. An example, related to weight loss, is the measure of weight (Manuele 2009).
Performance indicators	These indicators say something about the environmental performance linked to a reference level or a policy target (Gubbay 2004). An example of a performance indicator is the emission of greenhouse gasses (GHG). Several countries have set a level target for GHG emissions (Hammond and Institute 1995).
Descriptive indicator	Indicators that describes the impact on the environment or human health. Examples include emissions or concentrations of other pollutions (Gubbay 2004).
Quantitative indicator	Objective indicators which are possible to count. E.g. % of population who votes (Commision n.d.).
Qualitative indicator	Subjective indicators. Measure for example quality, opinions, perceptions or system development (Commision n.d.).
Core indicators	UNEP defines core indicators as: "indicators that provide clear and straightforward information to decision makers on trends and progress for specific issues"(van Woerden, Wieler et al.).

4.1.1 **Environmental indicators**

Environmental indicators provide information about the environment and human activities that affect it, in order to guide policy and management decisions (Gubbay 2004). Examples include measure of greenhouse gases to indicate global warming or timber harvest rate to indicate the productivity of natural resources (van Woerden, Wieler et al.). The need for environmental indicators comes from an increasing concern over environmental issues in the last decades. In 1979, Rapport and Friend for Statistics Canada developed a framework called The Pressure-State-Response (PSR)-framework. This framework was later adopted by OECD, which in 1993 published a report providing guidance and consistency on the development and use of environmental indicators. The PSR-framework highlights links between human activities that put pressure on the environment, the state of the environment due to pressure and the response from society through policies.

4.1.2 **The DPSIR-framework**

The Driver-Pressure-State-Impact-Response (DPSIR)-framework is derived from the PSR-framework, and includes drivers and impact. Drivers are the driving forces of the pressure and impact is the damage done to the environment (Gabrielsen and Bosch 2003). The DPSIR-framework is used by most of the European Union (EU) Member States and by the European Environment Agency (EEA) for analysing environmental issues. Figure 2 presents the DPSIR-framework with examples related to each element of the model (Gubbay 2004). The figure shows driving forces, like industrial processes and transport, putting pressure on the environment through pollution, altering the state of the environment. This can include altering air, water or soil quality, leading to impact on human health, biodiversity loss or economic damage. Knowledge about the impacts can lead to policy responses like for example clean production, public transport and regulations. These are only examples, but the DPSIR-framework can be used in relation to several environmental issues, including the marine plastic issue (Gubbay 2004).

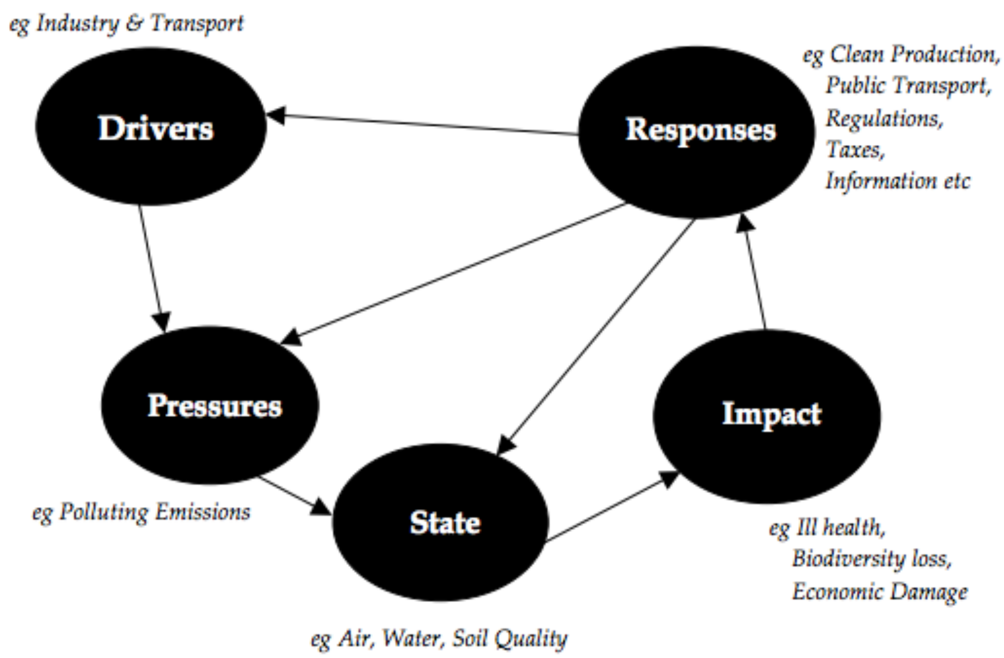

Figure 2: The DPSIR-framework (Gubbay 2004).

4.1.3 Indicator requirements

Poorly defined, inaccurately measured, noisy, biased or delayed indicators can lead to bad decision making. It is therefore important to have a set of indicator requirements to ensure that the indicators hold a certain performance level (Meadows 1998). A lot has been written about different requirements for developing indicators, to give them the desirable values and qualities. Most of the different environmental stakeholders and players operate with many of the same requirements. In table 2, UNEPs requirements for developing environmental indicators are presented (van Woerden, Wieler et al.). These requirements have many similarities to the requirements given by other environmental stakeholders like the OECD, EEA and Department for Environment, Transport & the Regions (DETR), among others (Gubbay 2004) (OECD 2003).

Table 2: UNEPs requirements for developing indicators (van Woerden, Wieler et al.).

UNEP's indicator requirements
Be developed within an accepted conceptual framework.
Be clearly defined, easy to understand and interpret, and able to show trends over time.
Be scientifically credible and based on high-quality data.
Be policy relevant.
Be relevant to users, politically acceptable and a basis for action.
Be responsive to changes in the environment and related human activities.

Provide a basis for international comparison by providing a threshold or reference value.
Be subject to aggregation (from household to community, from community to nation).
Be objective (be independent of the data collector).
Have reasonable data requirements (either data that are available or data that can be collected periodically at low cost).
Be limited in number.

Often, the indicators require numerical data. These are mostly primary data, and are the output of monitoring systems and surveys. Because most project don not have the time and resources to gather these data themselves, having a substantial amount of data available for the indicators are important. Therefore, it is essential to have knowledge about the data availability before developing indicators (Pintér, Zahedi et al. 2000).

Another important consideration is to select the right number of indicators related to an issue. Here, many indicators can make it difficult to interpret the information, while few can lead to a limited understanding of the issue. Developing indicators based on priority issues is a useful way of making sure to select the right amount of indicators (van Woerden, Wieler et al.).

5 Ecosystem services

Ecosystem services (ES) is defined by The Millennium Ecosystem Assessment (MEA) as "the benefits humans derive from ecosystems". MEA is an assessment called for by UN's secretary Kofi Annan in year 2000, with the objective of assessing the consequences of ecosystem change for human well-being. The natural environment provides human beings with several services like production of clean water, raw materials, climate regulation and crop pollination, to mention some. The MEA classifies ES into four different categories (Reid 2005).

- Supporting services: services seen as necessary for the production of all other ES. Examples include primary production and soil formation.
- Provisioning services: services obtained from the ecosystems. These services could be food, wood or fuel to mention some examples.
- Regulating services: benefits obtained from the ecosystems acting as regulators. Examples include climate regulation and water purification.
- Cultural services: nonmaterial benefits humans experience from ecosystems. These services could be aesthetic-, spiritual- or recreational experiences.

The MEA claims that human well-being is related to the health of ecosystems, and that by improving the health of the ecosystem you can improve human well-being. Figure 3 illustrates this relation by presenting how the four categories of services lead to different aspects of human well-being. It further illustrates that improving these aspects can lead to freedom of choice and action (Reid 2005).

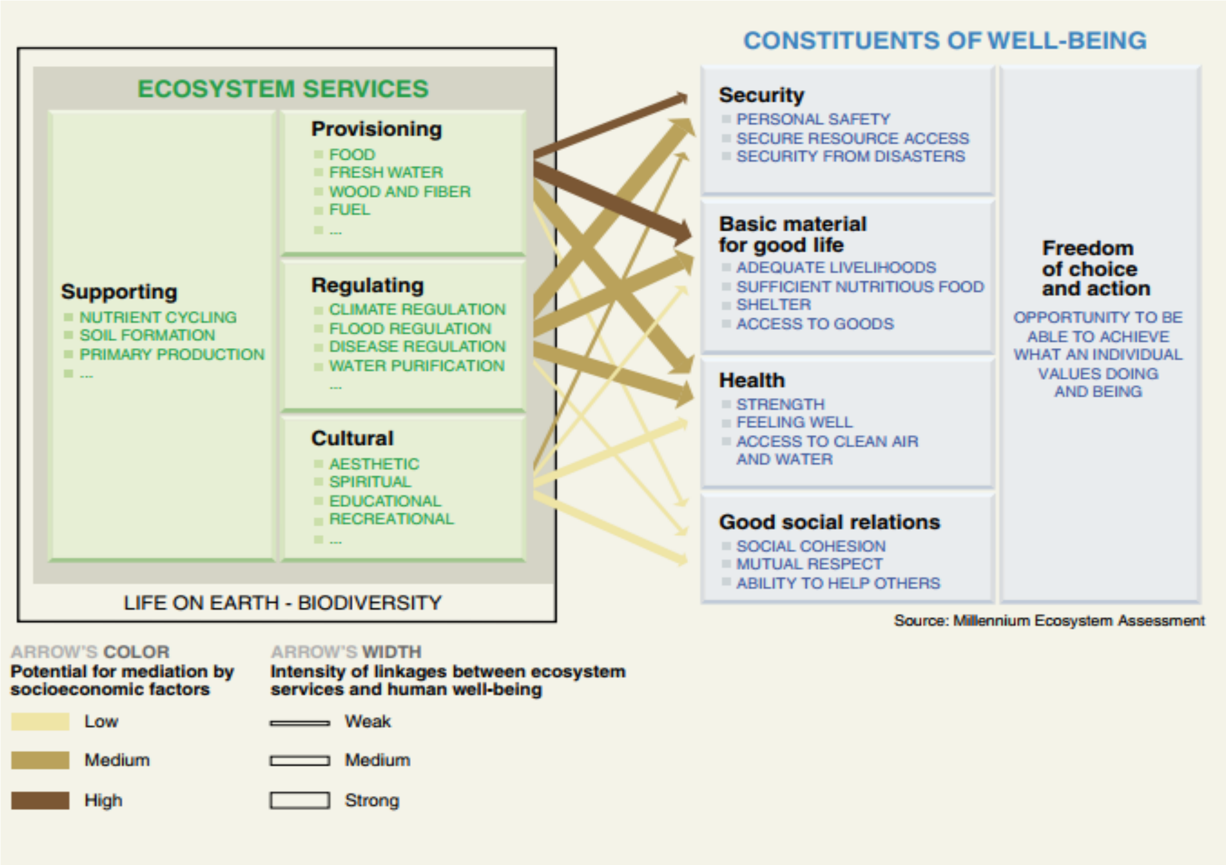

Figure 3: The relationship between ES and the constituents of well-being (Reid 2005).

Even though our ES have led to human well-being by providing basic needs and economic prosperity, overexploitation in the last century have led to more than half of the world's ecosystem being lost. During this period, biodiversity has decreased tremendously. ES are supported by ecological networks of species, where all the species vary in importance. Biodiversity therefore plays an important role, and a healthy and biodiverse ecosystem underlies the provision of ES. Even so, Bouma and Beukering (2015) says that the relationship between biodiversity and ES is complex and non-linear. Biodiversity forms the basis for ES, but biodiverse ecosystems do not necessarily provide more ES than ecosystems that are less diverse. Some species are more important than others. Bouma and Beukering (2015) advice to focus on the species that provide final services or obviously contribute to final services. The final services are services that leads to real social benefit and contribute to human welfare. This include provisioning, regulating and cultural services (Bouma and Beukering 2015). More on biodiversity's role on the ES can be read in the book "Ecosystem services" by Jetske Bouma and Pieter Van Beukering.

Mapping and determining importance of ES are used in scientific papers and journals to highlight the importance of the ecosystems. This is done through a biophysical quantification and social assessment of the ES. These assessments are often performed when a change or a proposed change is being implemented in an area, and can help in pointing out overlooked services and to give a deeper understanding of ecosystems. Ecosystem Service Assessments (ESA) are also conducted and involves a more fixed guideline involving defining study area, mapping services and stakeholders and determine management options (Everard and Waters 2013). To give two examples, it has been used in the proposed introduction of a dam and to assess the impacts of invasive alien plants on ES (van Wilgen, Reyers et al. 2008, Everard and Kataria 2010).

It is also possible to conduct an economic valuation of the ES. A number of economic valuation methods have been developed to estimate the values of services. In these valuations, there is made an important distinction between market-based and non market-based methods. Market-based valuation is when values are derived from actual market prices, including both production values and consumption values. In market-based methods there is also a distinction between direct and indirect market valuation methods. For ES traded on the market, their economic value can be derived from actual market transactions. Examples of this are timber, fuel and fish. This method is easy to apply as it only needs general available information like prices, quantities and costs, and due to simple modelling and few assumptions. For many services, direct market-based methods do not exist. In these cases, services are valued through indirect market valuation, referred to as revealed preference (RP). RP methods are based on the behaviour of the producers and the consumers, and identify the way that non markets influence the actual market. Non-market valuation, also called stated preference (SP) methods are used when no market prices and RP-methods are available, and when the changes in ES are hypothetical. These methods use surveys to state their preference for hypothetical change in the provision of ES ‘s (Bouma and Beukering 2015). This thesis does not involve any valuing of services through the identified or developed indicators, but the possibility of valuation is discussed.

5.1 Marine ecosystem services

This subchapter seeks to give an understanding of available ES in the marine environment. The full classification of these services is presented in chapter 8.3.

Oceans and seas provide a number of services and goods, providing basic needs and supporting the livelihoods for the well-being of humans. Services and goods each year from oceans are conservatively estimated valued at US$2.5 trillion. These services include food for millions, climate regulation, jobs and aesthetic experiences (WWF n.d.).

There are some differences in the classification of marine services. Several papers classify the services into supporting-, cultural- and regulating and maintenance services (Liquete, Piroddi et al. 2013). Others still classify the services into supporting services, like the Food and Agriculture Organization (FAO) within UNEP (FAO n.d.). This thesis will operate with the first mentioned classification. Marine services within these groups of services is presented below.

5.1.1 **Provisional services**

One of the greatest benefits and service provided by the oceans is the supply of seafood. Fisheries provide a critical part of the human diet on a global scale, with seafood making up to 17 percent of the animal protein, which the world consumes. The demand for seafood is expected to double in the next two decades as well. Around 87 percent of the global fish supply comes from the wild caught marine fish. Because of the demand for fish, fisheries around the world generate critical resources, economic gain and a source of employment (Wealth n.d.). Another great service provided by oceans are the storage and provision of water for human consumption and other uses. Oceans also provide raw materials (e.g. salt, sand, wood and algae) and space for delivering renewable energy (e.g. offshore windfarms) (ROA n.d.).

5.1.2 **Cultural services.**

Traveling and tourism are also large services provided by the marine environment. These services are worth over nine percent of the world's gross domestic product (GDP) and support over 100 million jobs. Coastal tourism is the biggest part of this industry. Coastal ecosystems generate, among other things, clean calm water, beaches and stunning vistas. There is a distinction between nature-dependent tourism and nature-based tourism. Nature-dependent include all tourism depending on key benefits provided by ecosystems. Some examples include clear and calm water from beaches (e.g. breaking waves) and water quality (e.g. by oyster reefs or mangroves). Nature-based tourism relates to services like wildlife watching, boating, fishing and scuba diving (Wealth-A n.d.).

5.1.3 **Regulating and maintenance services**

Regulating and maintenance services provides services such as climate regulation, coastal protection, ocean nourishment, life cycle maintenance, biological regulation and water purification. Coral reefs provide several of these services through for example protecting coasts from erosion and flooding by reducing wave energy. They also provide a habitat for many marine species. Even though they only occupy a small percentage of the world's oceans, coral reefs contain a high percent of its biodiversity. Around a third of the world's fish species are found on coral reefs, providing habitat and supporting marine biodiversity (UNEP-A n.d.). Marine ES also provide nutrient recycling, supporting marine ecosystems (Wealth-B n.d.). Plants and algae can provide climate regulation services through carbon sequestration from greenhouse gases and enhance air quality (FAO n.d.). Biological regulation is another service that involves how species adapt to changes in their environment, through for example pathogens or invasive species (Bich, Mossio et al. 2016).

6 Research methodology and methods

International Institute for Sustainable Development (IISD), UNEP and other environmental players, recommends using a fixed process for developing environmental indicators (Pintér, Zahedi et al. 2000). This thesis follows the methodology of Systems Engineering (SE) for selecting and developing indicators. SE is chosen to provide a framework and a systematic approach for this process, so that the indicators fits their intended purpose and meet their requirements. The method described in this chapter is similar to recommended approaches from aforementioned environmental players (Pintér, Zahedi et al. 2000). This chapter initiates part II of this thesis, meant to present methodology and results.

6.1 Systems Engineering

Systems Engineering (SE) is a multidisciplinary approach that looks to ensure the realisation of successful systems. A system can be defined as a set of interaction between elements. These elements could be technical, natural or social elements, or a collection of all three. Successful systems are defined as systems that satisfy the demand from customers, users and other stakeholders (SEBoK n.d.). The system in this thesis is the set of indicators.

In SE customers provide needs to a system engineer. A system engineer is a person who practices the SE discipline. He or she makes sure the elements of a system fit together. An important concept in SE, is the life cycle model. After the needs of the customer is fully understood, the system engineer runs the system through a life cycle process. This process consists of a number of stages regulated by a set of decisions to make sure the system is ready to move on to the next stage. There are several types of life cycle models, each individual model more applicable for the specific system. All life cycle models falls under one of the three categories below (SEBoK n.d.):

1. Primarily pre-specified and sequential processes.
2. Primarily evolutionary and concurrent processes.
3. Primarily interpersonal and emergent processes.

This thesis will follow a vee-model, falling under category one, pre-specified and sequential processes. The vee-model, formed like a V, involves a sequential progression of planning, specification and products, which are put under configuration management (SEBoK n.d.). The model breaks the system into smaller sub-systems and components down the development latter (left side of the v). It begins with a system concept definition and goes further down to developing requirements and later on design. The right side of the vee-model illustrates the realisation of the system aligning with the sub-systems on the left side. The model focuses on continuously verification and validation throughout the process, involving stakeholders participation (Sutherland, Kamiyama et al. 2015). The vee-model is used in several different fields (e.g. astronomy and software development), leading to different variations in use of the model (Sutherland, Kamiyama et al. 2015). According to National Aeronautics and Space Administration (NASA), who apply the SE approach for small and large projects, verification and validation has the following definitions (NASA 2007):

- **"Verification** of a product shows proof of compliance with requirements – that the product can meet each "shall" statement as proven through performance of a test, analysis, inspection or demonstration (or a combination)."
- **"Validation** of a product shows that the product accomplishes the intended purpose in the intended environment – that it meets the expectations of the customer and other stakeholders as shown through performance of a test, analysis, inspection, or a demonstration."

The vee-model for this thesis is presented below in figure 4. This model is tailored for this project and serves as a basis for the development of the indicator set. The main objective is to develop and identify indicators systematically against requirements to make sure they meet their intended purpose and have the right characteristics. As long as this is done, small deviations in the vee-model is seen as acceptable. The main modification is adding an exploration stage, shown on the top left side on the figure. The exploratory stage in this thesis is meant to explore active marine macroplastic indicators available for selection. The system exploration is presented in chapter 7, while the indicator set development (system development), representing the rest of the vee-model, is presented in chapter 8.

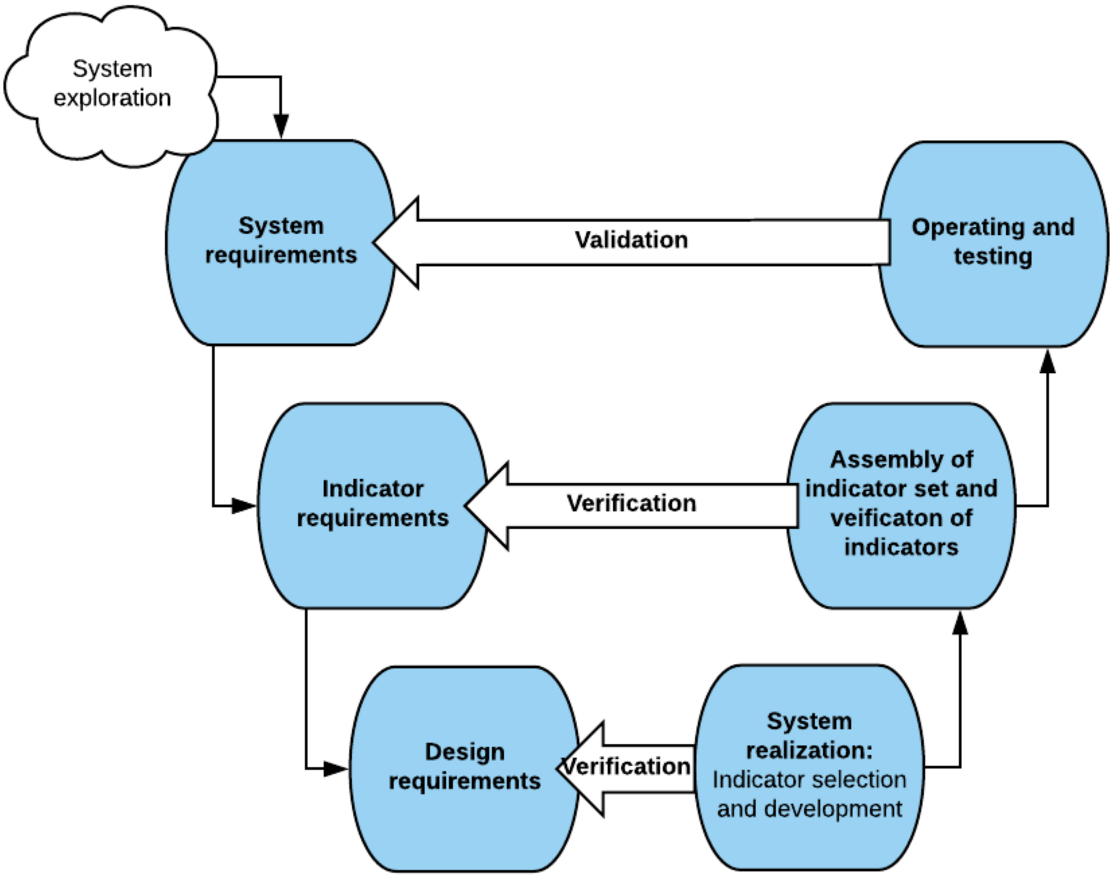

Figure 4: The vee-model for this project.

The first stage of the indicator set development involves identifying the system requirements. These are the requirements of the stakeholders and can be seen as the purpose of the indicators. The next stage is developing the indicator requirements. These requirements are based on the indicator requirements presented in chapter 4, with some modifications. The last stage on the left side of the vee-model involves determining the design requirements. This stage summarises and classifies both marine ES and imapcts of macroplastic. The impacts of marine macroplastic is then connected to the different services, so to make the selection and development of indicators easier and more apparent. The realisation of the indicator set take place on the right side of the vee-model. The first step involves identifying and developing indicators. This step verifies the indicators against the design requirements to make sure they indicate marine macroplastic impacts and may be related to marine ES. This process also involves use of indicator requirements, but a thoroughly verification of the indicators against the indicator requirements is first presented and discussed in the next stage (chapter 8.5). The last stage of the vee-model is meant for operating and testing. This thesis does not involve this stage due to the scope of the task, but opens up for further work, especially for indicators meeting the data requirements. Even though the original vee-model focuses on stakeholder participation, this is not possible for this project due to the lack of participants.

The verification process will be through analysis, as this thesis does not involve operating and testing. As there will be no testing of the indicators, it will not be possible to validate the indicators and demonstrate how they accomplishes their intended purpose in the intended environment. Therefore, this thesis only involves verification.

7 System exploration

7.1 Existing marine macroplastic indicators

This subchapter aims to present current developed indicators for marine macroplastic. The purpose of this is to investigate indicators available for selection to the indicator set. It is also to make sure not to develop indicators that already exist. Indicators from stakeholders, organisations, conventions, programs and indexes have been reviewed to make sure to identify as many relevant indicators as possible. It is not possible to know if all relevant indicators have been reviewed. This is due to the amount of environmental players involved in the issue, and the fact that smaller players may have developed indicators for use on a local level, making them hard to identify. Relevant environmental players explored for indicators include UNEP, EU, RSCs, NOAA, EEA, among others. This chapter also create the foundation to answer research question one, further discussed in the discussion chapter. Only pressure, state and impact indicators have been review, due to the scope of the task. As the DPSIR-framework illustrates (figure 2), pressure is related to the input of the pollution. As mentioned, potential input is not included. State indicators will indicate the amount of plastic in the marine environment, while impact indicators indicate the social, economic and ecological impacts of macroplastic.

Initially, the main objective of this chapter was to identify active indicators. As few active indicators were identified, proposed future indicators were added to the review, to provide the selection process with more options.

7.1.1 State indicators

As marine plastic is mostly monitored through the aforementioned methods (see marine litter monitoring), the most used indicators are related to trends in the amount and composition of marine litter. As these methods measure composition, the related indicators can potentially be converted to address marine plastic. In MSFDs descriptor 10, four marine litter indicators are listed for development and use. These four indicators are trends in the abundance and composition related to the amount of beach litter, floating litter, benthic litter and litter ingested by marine biota. Other indicators are listed under development, like litter ingestion by other marine biota, entanglement indicators and microplastic indicators (Commission 2010). OSPAR have agreed to use three of these indicators as common indicators among the Member States. These indicators are trends in the amount of beach litter, seabed litter and plastic particles in the stomach of the Northern Fulmar (MSFD 2010). Quantities of plastic particles in the stomach of the Northern Fulmar is the longest-standing biological indicator for marine plastic, and have been monitored in the North Sea since the 1980's (Avery-Gomm, O'Hara et al. 2012). These seabirds are chosen as an indicator species by MSFD and OSPAR. As mentioned, this indicator measures mostly the abundance of floating plastic. OSPAR have formulated a quantitative target (threshold) where less than 10 percent of a sample of 50-100 beach stranded fulmars should have more than 0.1 gram of plastic in their stomach over a period of at least five years (Commission 2009). When it comes to beach litter, OSPARs indicator provides information on the total number of litter items per 100 meter beach or coastline. It also provides information on the composition of litter by counting different types of items, including different types of plastic. This indicator is used to calculate average numbers in percentage and medians, and presents results in tables and graphs to make information more detectable. Figure 5 presents an example of this, where marine litter composition by material is presented for different OSPAR maritime areas in 2014-2015 (OSPAR n.d.).

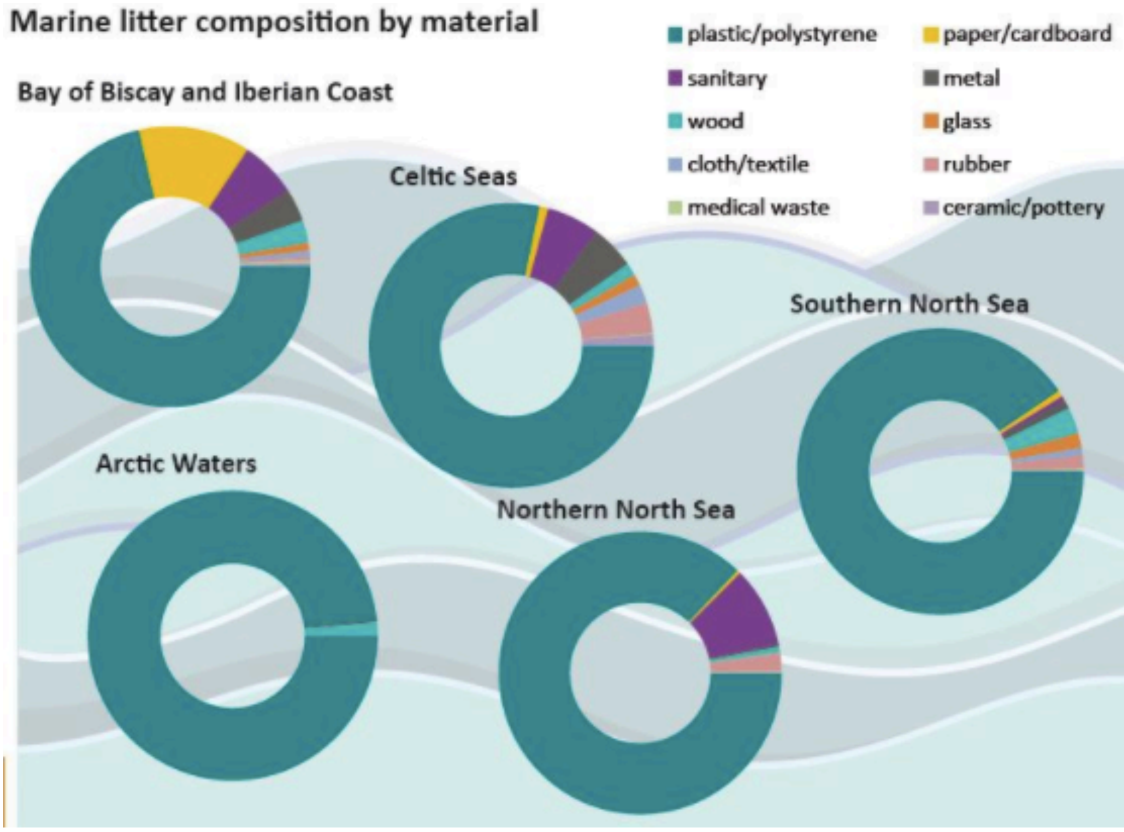

Figure 5: Marine litter composition for different OSPAR maritime areas (OSPAR n.d.).

OSPARs indicator on benthic litter provides information on number of items per km^2, both in total and by category and subcategory. Surveys have been performed using SCUBA diving, trawl surveys, sonar and the use of manned and unmanned submersibles (OSPAR-A n.d.).

The Barcelona convention have listed some of these indicators as part of their common indicator list as well, targeting trends in the amount of floating litter, beach litter and benthic litter. HECOM is also considering the same indicators for their core indicators (MSFD 2010). For floating litter, there are different monitoring methods used for monitoring macro- and microliter. For macrolitter, visual surveys are performed, counting number of items against a given area (km^2), while for microlitter and smaller fragments of litter, trawls are used to collect and count the litter (UNEP 2015).

In Norway, two of these indicators have been adopted; amount (grams) of plastic in the stomach of the Northern Fulmar and trends in the amount of beach litter. Beach litter is measured for beaches on Svalbard and Rekvika outside Tromsø, registering litter items for both 100 meter and 1000 meter beach areas (Miljødirektoratet 2015).

7.1.2 **Pressure indicators**

As mentioned earlier, it is difficult to acclaim the input of marine litter to its source. This is due to the different pathways, depositions and currents. This also makes it difficult to developed indicators related to input of plastic (pressure), other than potential input. This is possible for ALDFG though, because the source is known (fishing activity). In the report "Impact of Ghost Fishing via Derelict Fishing Gear", NOAA presents ALDFG indicators from around the world, all connected to pressure. These indicators are presented in appendix A, table 8 and 9. Table 8 presents a summary of gillnets (lost, abandoned or discarded) indicators, while table 9 present a summary of trap gear (lost, abandoned or discarded) indicators, collected from around the world. These indicators involve different fishing and different fish gear. Most of the indicators involve lost fish gear (number or length), either per boat or over time (or both). Examples are gear lost/per boat/ per year, gear lost/per day and length of net/per year. All indicators are related to quantification of gear loss (NOAA 2015). No other active pressure indicators were identified.

7.1.3 **Proposed indicators**

When it comes to impact indicators, active indicators are hard to identify, but as mentioned these are under development. Several proposed future indicators were found, related to pressure, state and impact, and is addressed here.

In the report "Marine plastic debris and microplastics", UNEP presents several proposed indicators. These are indicators that have been proposed in relation to the implementation of the Global Partnership on Marine Litter (GPML). This initiative was launched by UNEP at the Rio+20 meeting in 2012, seeking to protect human health and global environment by the reduction of marine litter. The proposed indicators target environmental performance, pressure, state and impact. In appendix B, proposed indicators for environmental state, social and economic impacts and ALDFG are presented, in table 10, 11 and 12. The proposed indicators on environmental performance are not presented as they address driving forces on the DPSIR framework and this thesis only focuses on pressure, state and impact indicators (Kershaw 2016).

Another potential future indicator found was HELCOMs test indicator, related to ghost fishing. HELCOM have developed a test indicator for their core indicators, counting drowned mammals and waterbirds in fishing gear. The purpose of the indicator is to provide a descriptive evaluation of whether the number of incidentally entanglement of marine mammals and waterbirds are below mortality levels that enable reaching good status, but no thresholds levels have been determined yet (HELCOM n.d.). The indicator measures harbour porpoises and three bird species which includes greater scaup, long-tailed duck and common guillemot. Other than this, there are no variables and measurement units specified for the indicator. The indicator is yet to be agreed as common indicators for HELCOMs Member States and results will be considered as intermediate (HELCOM n.d.)

8 Indicator set development

This chapter represents the development of the indicator set. It systematically follows the vee-model presented in chapter 6, starting with system requirements.

There is no overarching goal or purpose of the indicator set, like with indexes. It is merely a collection of available, proposed and developed indicators that meets requirements on the left side of the vee-model. The size of the indicator set is not specified and is not considered to be of importance. Use and implementation of the indicator set, and potential policy responses is also addressed, as this moves outside the scope of the task.

8.1 System requirements

This subsection is a summarisation of system requirements previously presented in the introduction chapter. The system requirements target the stakeholders and customers need, which can be related to the purpose of the indicators (SEBoK n.d.).

As mentioned, the main objective of the indicators is to meet their intended purpose. One of the main purposes of the indicators is to quantify and describe the impacts of marine macroplastic related to pressure, state and impact on the DPSIR framework. This can provide society with information on the effects of macroplastic and potentially lead to policy responses. As the DPSIR-framework illustrates (figure 2), describing an element of an environmental issue may lead to finding out another element. For the marine plastic issue, describing plastic's pressure on the marine environment (e.g. amount of input) can lead to finding out the state of the environment (e.g. amount of marine plastic), leading to describing the impacts (e.g. ecological impact), and ultimately leading to policy responses (e.g. clean-ups or legislative measures). An objective for this thesis is therefore developing a set of indicators that describes the different elements of marine macroplastic implications related to pressure, state and impact. Another important purpose of the indicators is that it has the ability to relate the impacts of macroplastic to marine ES. The second system requirement is that the indicators can be be connected to any of the classified marine services presented in the design requirements.

8.2 Indicator requirements

The indicator requirements chosen in this subchapter is based on the requirements of several environmental stakeholders, especially UNEP's requirements presented in chapter 4.1.3. Modifications, specifications and changes that are made to these requirements are made so that the indicators are able to meet their intended purpose directed towards the system requirements. These requirements are directed towards the individual indicator and not the whole set.

The requirements used for selection and development of indicators in this thesis, is presented in table 3 below. The indicators meet the requirements by affirming the key questions.

Table 3: Indicator requirements for the development of the indicator set.

Requirements	Key questions
Measurability	Is macroplastic impact data available for the indicator or can it be collected at a reasonably cost?
Transparency	Is the indicator easy to understand for users and non-users?
Policy relevance	Is the indicator policy relevant and can it lead to policy response?
Sensitive to changes	Is the indicator sensitive to changes in the ES over time?
Spatial relevance	Is it possible to aggregate or disaggregate the indicator for use on different spatial scales, and still remain its ability to indicate the change of interest?
Threshold values	Is there a threshold target developed for the indicator?

As it is difficult to speculate on whether or not the data is scientifically credible and of high quality, this is not put as a requirement in table 3. Monitoring and surveys of marine plastic is mostly performed by credible governmental and recognised environmental players, and this is an assumption when discussing data availability and potential.

It is desirable that the indicators meet these requirements, but not a must that they meet all off them. Some of the indicators meet certain requirements to a less degree. This is presented and discussed in chapter 8.5.

8.3 Design requirements

The design requirements for the indicators involve presenting the "product specifications" (SEBoK n.d.). This subchapter is divided into three parts. Part one focuses on summarising and presenting how the indicators must indicate the impacts of marine macroplastic. Part two focuses on classifying the marine ES and part three connects the impacts of macroplastic to the marine ESs. This process is meant to make the selection and development process more apparent and systematic.

This part answers research question number two, which search to find out how ES can be used to structure the impact assessment from marine macroplastic. The process is discussed further in the discussion chapter.

8.3.1 Classification of marine macroplastic impacts

Related to marine macroplastic, the indicators need to indicate one of the following:

- Pressure – related to input of macroplastic to the marine environment.
- State of the environment due to macroplastic – concentrations of macroplastic in the marine environment.
- Impact – harm caused by marine macroplastic. Includes social, economic and ecological impacts.

Pressure indicators are input oriented and will be described as leading indicators. State and impact indicators are output oriented and will be classified as lagging indicators. All indicators selected and developed are quantitative indicators.

Figure 6 and 7 presents a summarisation and classification of the harm caused by marine macroplastic. This classification is based on the literature presented in chapter 3.1 (harm caused by marine litter), which builds on several literature sources. Figure 6 presents the social and economic impacts, while figure 7 presents the ecological impacts. One of the design specification and requirements is that the indicators address one of these impacts.

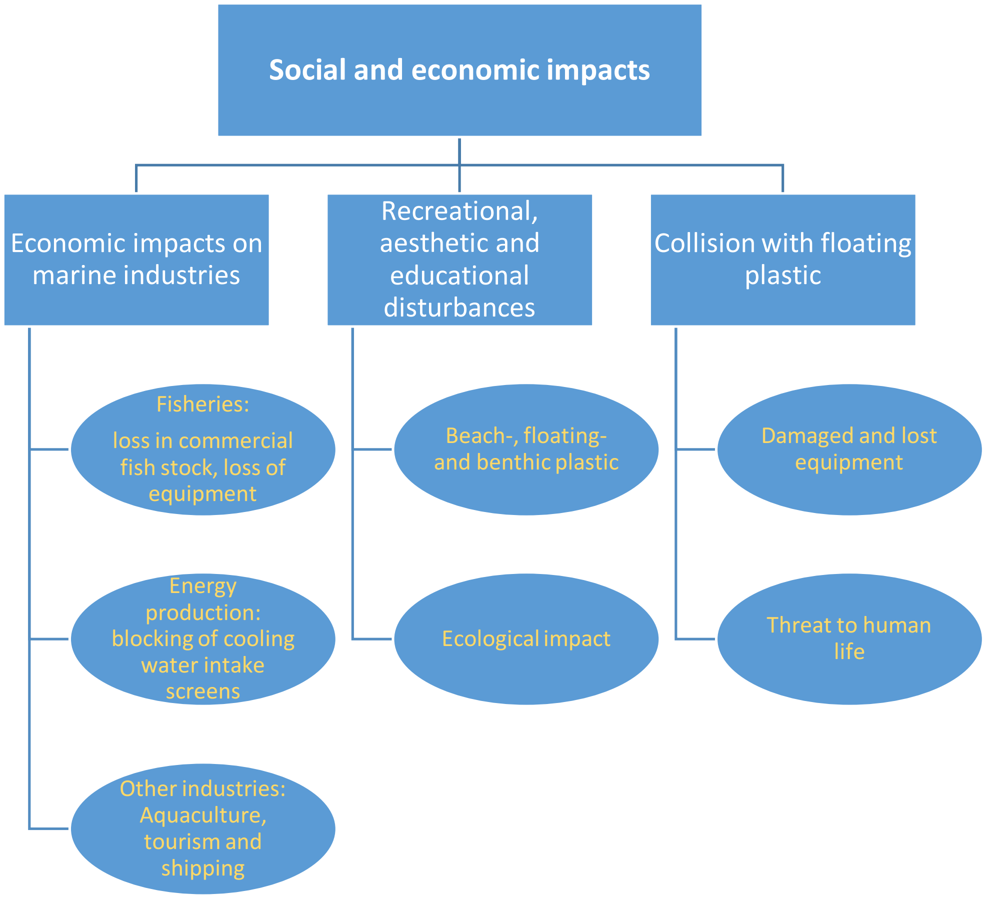

Figure 6: Social and economic impacts of marine macroplastic.

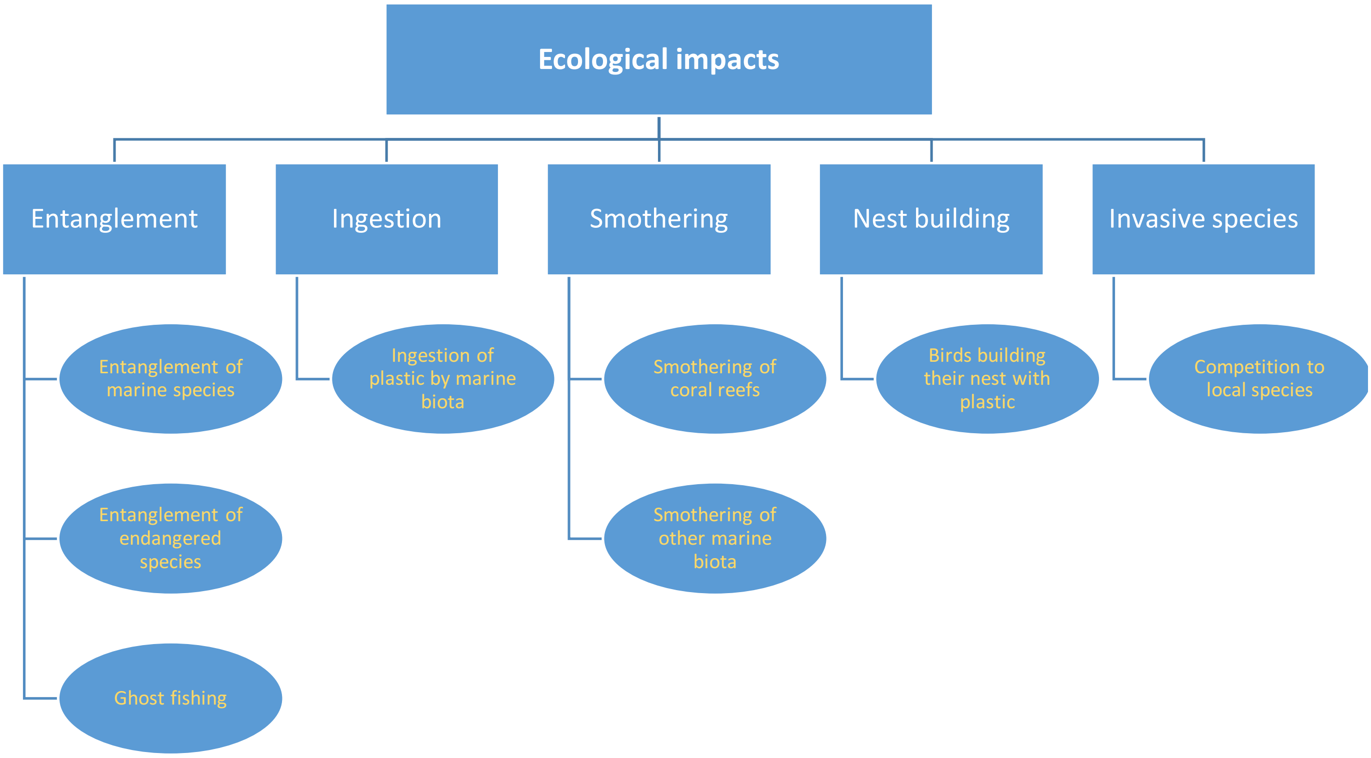

Figure 7: Ecological impacts of marine macroplastic.

8.3.2 Classification of marine ecosystem services

As well as indicating the impacts of marine macroplastic, the selected and developed indicators also need to relate to marine ES. This is the second design requirement for the indicators.

To identify and develop indicators related to ES, it is important to categorise the different services provided by the world's oceans and coastal areas. This classification makes it easier to identify services and to connect the impacts of marine macroplastic to them. Figure 8 presents the classification of marine ES for this thesis. The classification is based on previous work, which has been summarised by Liquete et al. (2013) and was presented in chapter 5.1. Several of the services classified below will not be addressed any further as it is not intuitive or perhaps possible to connect the impacts of macroplastic to them.

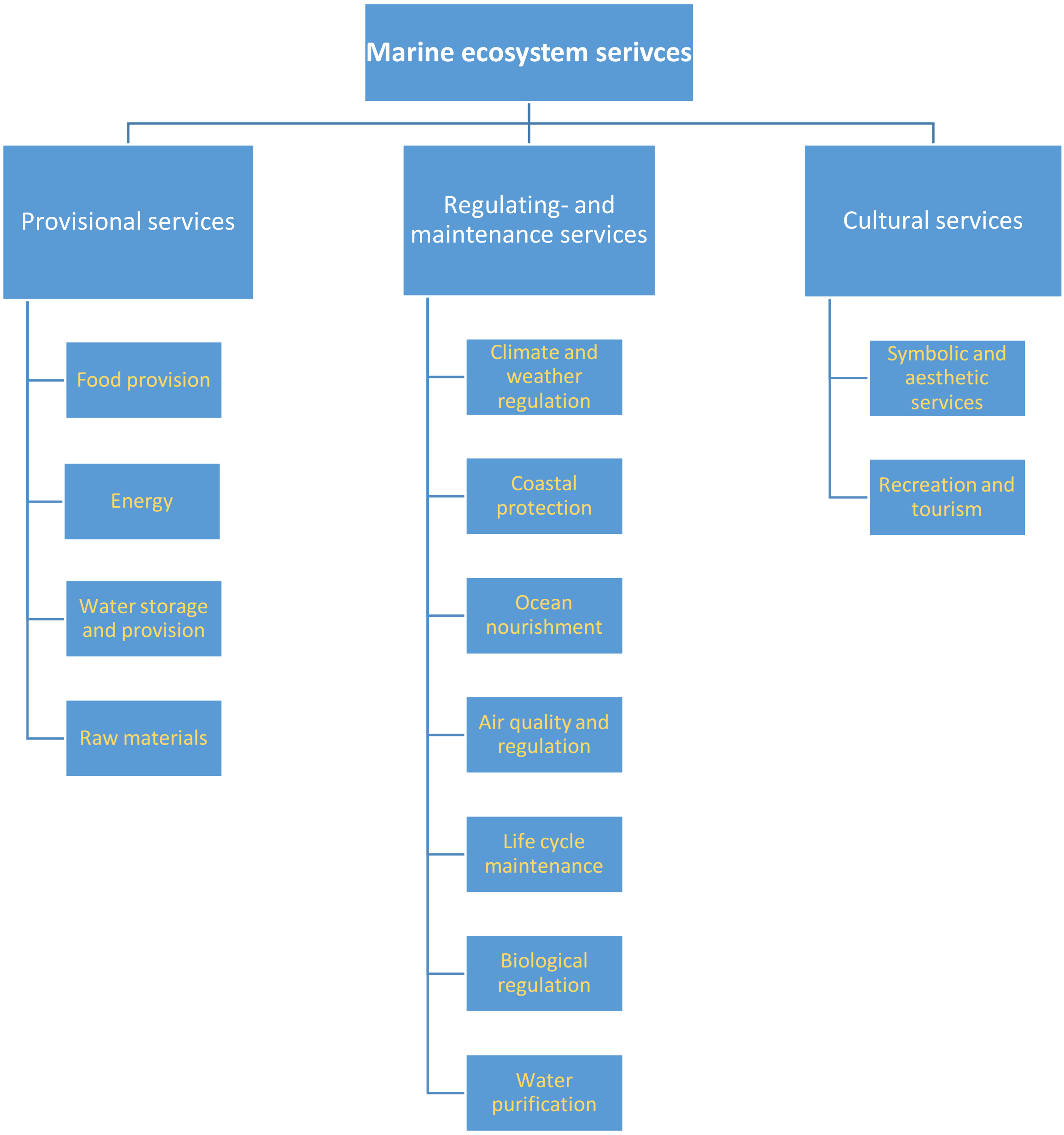

Figure 8: Classification of marine ES (Liquete, Piroddi et al. (2013).

8.3.3 Connecting the impacts of marine macroplastic to marine ecosystem services

The last part of the design requirements involves connecting the impacts of macroplastic to the different marine ES. The connection done in table 4 is no blueprint of what services is actually affected, but a suggestion for what seems intuitive and logical to the author of this thesis. It is therefore important to emphasise that the table is merely an idea on how to connect the different impacts and that macroplastic may affect other services as well.

The complexity of ES make it a challenging task to place some of the ecological impacts. As mentioned, ES are supported by ecological networks of species, where all species vary in importance. Ingestion and entanglement of marine biota caused by plastic, can lead to a disturbance in the assembly of the species (e.g. abundance, richness and evenness). To determine the ecological importance to some of these marine species or groups of species, and plastics effect on the assembly, moves outside the scope of the task. Ingestion and entanglement issues is therefore addressed under cultural services (except for fish).

Table 4: Impacts of macroplastic connected to marine ecosystem services.

Ecosystem Services	Classification of marine ecosystem services	Marine macroplastic impacts
Provision services	Food provision	-Ghost fishing
	Energy	-Blocking of cooling water intake screens
Regulating and maintenance services	Life cycle maintenance	-Smothering of coral reefs
	Coastal protection	-Smothering of coral reefs
	Biological regulation	-Invasive species
Cultural services	Symbolic and aesthetic values	-Amount of plastic on beaches, floating plastic and benthic plastic
		-Entanglement
		-Ingestion
		-Impact on endangered species
		-Use of plastic as nesting material
	Recreation and tourism	-Amount of plastic on beaches, floating plastic and benthic plastic

8.4 System realisation

8.4.1 Selecting indicators

The selection of indicators will be based on the following:

- Developed and proposed marine macroplastic indicators presented in chapter 7.1.
- Indicator requirements presented in chapter 8.2
- Design requirements presented in chapter 8.3.

As mentioned, a thorough verification against the indicator requirements is first presented and discussed in the next subchapter.

Developed indicators were first evaluated for selection. These included indicators related to beach litter, benthic litter, floating litter, Northern Fulmar and the ALDFG indicators in appendix A. After this, the proposed GPML indicators presented in appendix B, were reviewed together with HELCOM's test indicator.

In table 5, the selected indicators are presented. The table presents the indicators together with information on the impacts of macroplastic, variables, ES category and DPSIR relevance. Under the table, reasoning and explanation for choices is elaborated.

As the table shows, indicator 7-10 have no denominating measurement unit. Some of the indicators are also not very specific. This is because they are under development. These variables can be determined and specified in relation to their usage, and the indicators have been added to the list because they meet the design requirements and several of the indicator requirements. Even though indicators have been omitted from the list does not mean they are excluded for future use. It is important to repeat that the indicators selected and developed in this thesis is a collection of indicators with high potential for policy relevance that meet the desirable requirements.

As mentioned previous, surveys on beach-, floating- and benthic litter measure composition, making it possible to convert their related indicators to address marine plastic and not marine litter. This is done in table 5 for beach-, floating- and benthic plastic, so that these indicators are directed towards marine macroplastic. This conversion is discussed later. For beach plastic, the measurement unit of 100 meters have been chosen as done by OSPAR and Norwegian standards. It is also possible to use 1000 meters as a metric, but this specification is not seen as of great importance for the objective of this thesis.

Table 5: Selected indicators

Indicator	Macroplastic impact	Variables	Ecosystem service category	DPSIR
1	Beach plastic	# of macroplastic items (>5 mm) / 100 m coastal area	-Cultural: aesthetic, recreation and tourism	State
2	Floating plastic	# of macroplastic items (>5 mm) / m^2	-Cultural: aesthetic, recreation and tourism	State
3	Benthic plastic	# of macroplastic items (>5 mm) / m^2	-Cultural: aesthetic, recreation and tourism	State
4	Ingestion by the Northern Fulmar	Amount (g) or composition of plastic / per bird	-Cultural: aesthetic and symbolic	State
5	Lost fish nets	# of nets lost or abandoned / per year	-Provisional: food provision (indirect)	Pressure
6	Lost traps	# of traps lost or abandoned / per year	-Provisional food provision (indirect)	Pressure

7	Entanglement of cetaceans	# of cetaceans injured by ALDFG	-Cultural: Symbolic	Impact
8	Entanglement of birds	# of birds killed by ALDFG	-Cultural: Symbolic	Impact
9	Ingestion by cetaceans	Mass of plastic items in guts of cetaceans	-Cultural: Symbolic	Impact
10	Blocking cooling water intakes in coastal power stations.	Loss of energy generation capacity (and income) and risk of accidental damage due to blocking cooling water intakes in coastal power stations.	-Provision: energy	Impact

= number

State indicators

The most commonly used indicators in the marine litter policy, is the indicators related to beach, floating and benthic litter, and the Northern Fulmar indicator. All these indicators are interesting because they describe litter, or in this case marine plastic, in different parts of the marine environment.

The beach plastic indicator is easy to connect to cultural services. Plastic on beaches presents problems for the aesthetic experience and can lead to people not visiting them, further leading to problems for tourism. Floating plastic also cause aesthetic disturbances as plastic in the water surface is noticeable. It can also cause problems for tourism, especially near the coasts. Benthic plastic can present aesthetic disturbances for more shallow waters and for tourism in areas with coral reefs and popular diving areas.

The fourth state indicator, indicating floating plastic through plastic ingested by the Northern Fulmar, is another interesting state indicator. This is a well developed indicator with a great number of data behind it and a threshold value. It is also the only active state indicator presented in this thesis that only address plastic and not litter. The more knowledge gathered about this bird, the greater the possibilities to connect the impacts of ingestion to other services. In this thesis though, this indicator is only connected to cultural services. Knowing the magnitude of impact on these birds can have a cultural symbolic impact on society.

Pressure indicators

There are two pressure indicators selected in table 5. These are the two ALDFG indicators, number 5 and 6, related to fish nets and traps respectively. These indicators cannot be used directly to measure the impact on any service, but indicating the number of lost fish nets and traps can be used to predict the risk of ghost fishing, relating it to food provision. These pressure indicators can be seen as leading indicators, and as described in the background theory, leading indicators are used for prediction. It would have been possible to choose less specific ALDFG indicators like the first one in table 11 in appendix B, counting all abandoned fish gear, but as previous mentioned, generalising ghost fishing is only possible if most variables are the same (i.e. same gear, time period, location). Therefore, it seems fitting to choose two ALDFG indicator where at least the fishing gear (fish net or trap) is specified. Type of fishing gear can also be further specified through choosing the type of fish net (e.g. gillnets) or type of trap if wanted. For the fish net indicator, other variables were available like length of fish net, counting incidents per boat or counting days instead of year. Number of nets were chosen over length of the net as this may be more transparent for people not using the indicator but only interpreting the results. The indicator is chosen to count number of lost fish nets per year so to make the issue more evident. Higher numbers may have a greater impact on policy, especially if these indicators would be used to calculate the value of ghost fishing. A longer time period can provide this. The same arguments apply for the chosen variables of the lost traps indicator.

Pressure indicators measuring quantity of litter derived by cruise industry and commercial shipping were also reviewed. As mentioned it is difficult to connect plastic to input sources, and therefore measuring the input from these industries could be complicated. This is more apparent with ALDFG, where the input stems from fishing activity. Potential input is not addressed in this thesis, but it may be that this is the targeted use for these indicators.

As the connected surveys to the four state indicators also measures composition of the marine litter, these indicators could address pressure from different plastic items. This could be used to measure risk of ecological and social impacts for different items. As for now, such indicators are not added to the list. The reason is that it is difficult to connect a potential impact to different services. To do that, there would need to be an understanding of which items caused different problems. For the two ALDFG indicators, this is possible because of their connection to ghost fishing. This may be possible for other items or groups of items, but then the impacts need to be understood. This moves outside of the scope of the task, and will therefore not be addressed any further.

Impact indicators

As mentioned, it is difficult to connect most marine species to any ES other than cultural services. Marine species that are included in food provision (e.g. fish and shellfish) and regulating and maintenance services (e.g. coral reefs), are the exception. There is only one of the proposed GPML indicators addressing fish, counting the number of fish caught in ALDFG, presented in table 11 (appendix B). As this indicator is not very specific, making it hard to generalise its results, it is not added to the list of selected indicators. A more specific version of this indicator is developed in the next subchapter.

Three of the selected indicators in table 5 address ecological impacts of macroplastic. Two of these are directed towards entanglement. The first one, number 7, is counting the number of cetaceans injured by ALDFG. Cetaceans are found in most part of the world and as mentioned, several species of cetaceans are impacted by plastic entanglement. This makes the indicator possible to aggregate to different spatial scales. The same goes for the other entanglement indicator, counting number of birds killed by ALDFG. Entanglement of both these groups of species is evident in the marine environment and when addressing cultural services, it may be a good idea to target those species with a large number of impacts related to it. These type of indicators may not meet some of the same issues related to measuring ghost fishing, like for example fish being eaten by lice. HELCOMs test indicators have been excluded from the list as they address individual species. To determine the ecological importance of these species and connect them to any of the marine ES, may require a greater expertise of the services of these species.

The third ecological impact indicator is number 9, counting the mass of plastic ingested by cetaceans. As mentioned, there are several species of cetaceans with documented records of marine debris ingestion. There have been reported cases of whales ingesting severe amount of marine plastic. As an example, in Sotra outside Bergen in Norway, a stranded whale with 30 plastic bags inside of it was found. This incident created media attention to the marine plastic issue and helped change peoples attitude towards the plastic pollution issue (Ertesvåg 2017). A quantification of plastic ingestion by cetaceans could help to highlight the severity of this issue.

One social and economic impact indicator has also been added to the list. This is the indicator measuring blocking of cooling water intakes in coastal power stations. This indicator is easy to connect to ES (energy) and may be used to calculate value for this service as well. It is though less specific and open for modification and determination of measurement units.

8.4.2 Indicator development and operationalising

As mentioned, part of the task description is developing indicators. The approach for the development process is much of the same as for the selection of indicators, but at the same time look at what type of impacts were not addressed by the selected indicators. This approach seems reasonable as the selected indicators covers several of the macroplastic impacts to some extent. Amount of plastic in the marine environment is well covered by the state indicators, presented in the last chapter. Pressure indicators are difficult to connect to anything other than ALDFG as it is difficult to connect marine plastic to its sources. The two pressure indicators seem to cover this issue. It is therefore most interesting to develop impact indicators related to any of the issues not already addressed. As mentioned earlier as well, too many indicators on an issue can make it difficult to interpret information. Table 6 presents which impacts and services were addressed by the selected indicators (shaded in green) and which ones were not.

Table 6: Overview of macroplastic impacts covered and not covered by the selected indicators. Green as a highlight colour indicates that the subject is represented by the selected indicators.

Ecosystem Services	Classification of marine ecosystem services	Marine macroplastic impacts
Provision services	Food provision	-Ghost fishing
	Energy	-Blocking of cooling water intake screens
Regulating and maintenance services	Life cycle maintenance	-Smothering of coral reefs
	Coastal protection	-Smothering of coral reefs
	Biological regulation	-Invasive species
Cultural services	Symbolic and aesthetic values	-Amount of plastic on beaches, floating plastic and benthic plastic
		-Entanglement
		-Ingestion
		-Impact on endangered species
		-Use of plastic as nesting material
	Recreation and tourism	-Amount of plastic on beaches, floating plastic and benthic plastic (including on coral reefs)

As mentioned, a ghost fishing indicator counting number of fish killed, is targeted for development. The main reason for this is food provisions strong linkage to human-well being and the possibility for market based valuation, leading to a high potential for policy impact.

The fact that this type of indicator is listed as a proposed indicator by UNEP, is also an indication that it might be possible to implement. The second indicator to be developed is an endangered species indicator. This indicator also has a potential strong impact on policy. The development of the indicators involve operationalisation by selecting fitting variables. Threshold values is not developed, as this would require a deeper understanding and expertise of the issues. The two impact indicators will serve as lagging and descriptive indicators.

Challenges met with developing indicators for the impacts not addressed are discussed in the discussion chapter.

Ghost fishing indicator (GFI)

A ghost fishing indicator (GFI) related to number of fish killed in fish nets, is an indicator with the potential of great policy impact. As illustrated in figure 3, provisional services are closely linked to human well-being, and as pointed out in chapter 5.1, the demand for seafood is large worldwide. An indicator measuring the number of fish killed in fish nets could be used to highlight the severity of this issue. This indicator could also be used to measure the change in commercial fish stock, providing possibilities for calculating the loss in economic value through market-based valuation. The ghost fishing indicator (GFI) is operationalised below:

- GFI = Mass (kg) of market fish killed annually by lost or abandoned gillnets in a given region

As mentioned earlier, by specifying variables (i.e. same gear, time period, location), a generalisation for ghost fishing could be possible. This indicator focuses on gillnets as this type of fishnet is associated with a high catch rate. Another specification is that the fish killed in these nets are distributed on the market. This specification is to avoid counting fish that is not eaten or distributed. The indicator also specifies that the measurement should be performed in a given region. This region could be part of a country region, a fishing zone or a sea region. If this is specified for the indicator, results could be compared across similar regions. The indicator also focuses on looking at annual changes in the provisional service. By looking at impact over a longer time period, the indicator has a higher chance of policy impact by presenting higher numbers. This will especially be evident if the indicator is used to calculate changes in the commercial fish stock. The higher the number for economic losses, the greater impact it will have on marine policy. Mass (in kilograms) is chosen as a measurement unit as this would make valuation possible and more effortless.

Endangered species indicator (ESI)

The second indicator to be developed is related to the entanglement of endangered marine species. As mentioned, UNEP reports that marine litter harms over 600 species, with 15 percent of these being endangered. This would equal to around 90 species being impacted. Species going extinct could have an impact on both cultural (symbolic) and regulating services, as well as the biodiversity loss. This indicator measures the impact on symbolic cultural services, as it is difficult to determine biodiversity services. Even though the indicator will be directed towards cultural services, endangered species could still have an impact on biodiversity, making the indicator more policy relevant. The endangered species indicator (ESI) is operationalised below:

- ESI = Endangered marine species impacted by macroplastic entanglement

For this indicator no measurement units have been added. The reason for this is that it would be interesting to look at how the number of endangered species impacted increase or decrease over time. It may not be that the number of incidents is enough for a yearly or periodically measurement. Area has not been specified for this indicator for the same reason. There is also no specification on whether or not the endangered specie is killed or just injured. This is because it may be difficult to determine the cause of death for some incidents. Entanglement may lead to both injuries and death. By not specifying this, the indicator could include all incidents and quantify the total number of impacts. This would provide information on the magnitude of macroplastic's impact on endangered species. The collection of data for the indicator is further discussed in the next subchapter.

8.5 Indicator requirement verification

This subchapter presents the verification of the indicators against the indicator requirements. The full set of indicators is presented below in table 7, consisting of the selected indicators presented in table 5 and the developed indicators presented in chapter 8.4.2. The table contains a score (good, ok or bad) for each indicator related to the different indicator requirements described in table 3. Good, represented by the colour green, means that the indicator meets the requirement and answers the related key question in a satisfying way. Ok, represented by the colour yellow, means that the indicator meets the requirements to some degree. Bad, represented by the colour red, means that the indicator does not meet the requirement in a satisfying way. The indicators and their verification against the indicator requirements is further discussed under the table. Only the Northern Fulmar indicator have a threshold value connected to it. Threshold values is not addressed in this chapter, but is mentioned in the discussion chapter.

Table 7: Verification of indicators.

Indicator	Macroplastic impact	Measurability	Transparency	Policy relevance	Sensitive to changes	Spatial relevance	Impact
1	Beach plastic	Ok	Good	Good	Good	Good	State
2	Floating plastic	Ok	Good	Good	Good	Good	State
3	Benthic plastic	Ok	Good	Good	Good	Good	State
4	Ingestion by the Northern Fulmar	Good	Good	Good	Bad	Bad	State
5	Fish nets	Ok	Good	Good	Good	Good	Pressure
6	Fish traps	Ok	Good	Good	Good	Good	Pressure
7	Cetaceans entanglement	Ok	Ok	Good	Ok	Ok	Impact
8	Bird entanglement	Ok	Ok	Good	Ok	Ok	Impact
9	Cetaceans ingestion	Good	Good	Good	Ok	Ok	Impact
10	Marine energy impact	Good	Good	Good	Ok	Ok	Impact
11	Ghost fishing indicator (GFI)	Bad	Good	Good	Ok	Good	Impact
12	Endangered species indicator (ESI)	Ok	Good	Good	Ok	Ok	Impact

8.5.1 **State indicators (1-4)**

The first three state indicators (beach-, floating- and benthic plastic) meets all the requirements in a satisfying way, except for the measurability requirement. The problem with converting these indicators to measure marine macroplastic (>5mm) is that their related monitoring surveys only count the number of items and does not necessarily differentiate between macro- and microplastic. If the indicators were to be accurate, these surveys would have to be based on data differentiating between larger and smaller plastic object. As litter objects is not measured or weighed as well, the differentiation on micro- and macroplastic would not be accurate. This can be seen as a weakness, and they have all been given a score of ok on measurability. Except for having some issues in meeting the measurability requirement, they meet the other requirements. All three indicators are transparent and policy relevant. It is not very imaginable that these services would change, especially when considering their connection to aesthetic experiences. If less people would visit the beach or coastal areas (change in nature-based tourism), the indicators would still say something about the impact on these marine areas. That is why they have a good score on the sensitive to changes requirement. They can also be aggregated as beaches are found all over the world and all oceans consist of a water surface and a benthic area.

When it comes to the Northern Fulmar indicator, this have scored good on measurability, transparency and policy relevance, and bad on sensitive to changes and spatial relevance. Spatial relevance is scored bad because this bird only lives in the Northern North-Sea, and therefore the indicator cannot be aggregated to other areas. The indicator also scores bad on sensitive to changes. If the population of the specie where to change due to reasons that did not involve macroplastic (e.g. access of food or migration), the results of the indicator would not take this into account and its results would be challenging to use. Other than that, this indicator meets all requirements satisfyingly. It has been monitored over a long time and have a lot of data behind it. It is also policy relevant, especially as it says something about the ecological impact of plastic as well, even if this is not the aim of the indicator in this case. The indicator is also transparent and easy to understand.

8.5.2 **Pressure indicators (5-6)**

The two pressure indicators, related to input of fish nets and traps, meets all the requirements in a satisfying way, except for the measurability requirement, where they score ok. The measure of lost or abandoned fish gear would most likely not be through surveys, but through reporting of incidents. As it would be inevitable to miss several incidents of lost and abandoned gear, they both only score ok on this requirement. Both indicators are policy relevant, especially as they can be used to predict ghost fishing or be connected to the issue. The indicators may be aggregated to other spatial scales, as fishing activities is performed in most areas in the world (both with fish nets and traps). When it comes to the sensitive to changes requirement, both these indicators are leading indicators and will predict changes in marine food provision, independent of changes in the service. Both indicators score good on transparency, as they are straightforward and easy to understand.

8.5.3 **Impact indicators (7-12)**

Impact indicator number seven and eight both address entanglement. These indicators have scored identical on all requirements. They have both scored ok on the measurability requirement, for the same reasons as the pressure indicators. It would seemingly be several incident not measured. Both indicators also score ok on transparency. This is because it may not be intuitive for all people what ALDFG involves, as the type of gear is not specified. Both indicators score good on policy relevance. As mentioned, by addressing the impact from fishing activity, it may be possible to direct policy measures directly to the fishing industry. Entanglement of cetaceans and birds is also very noticeable and can have a symbolic effect on humans, enhancing their policy relevance. Both indicators have scored ok on sensitive to changes. This is because if the population of the involved species changes, the result of the indicator may change to better or worse, without a correlation to the amount of marine plastic. On the other hand, high variations in the groups of species targeted does not seem very plausible, as these are very large groups of species. When it comes to spatial relevance, both indicators score good, as cetaceans and birds are found in seas all over the world.

Indicator number 9, related to ingestion of plastic by cetaceans, scores good on the requirements, except for the sensitive to changes requirement. It has a score of ok on this requirement for the same reasons as with the entanglement indicators. When it comes to measurability, the data collection for this indicator would probably be similar to that of the Northern Fulmar, sampling dead carcases. On the policy relevance requirement, it also have a good score. As mentioned with the stranded whale with 30 plastic bags inside of it, these type of incidents have the potential to affect consciousness in societies and impact policy. This indicator also has a good score on the spatial relevance requirement for the same reasons as with the entanglement indicators.

The one indicator related to social and economic impacts (number 10), measuring marine energy impact, has been given a high score for measurability, transparency and policy relevance. It scores high on measurability because impacts are easy to detect, and as long as there is a good reporting system, incidents will get documented. It is also given a good score on policy relevance. This indicator has great potential for valuing the impacts through market based valuation, enhancing its relevance. The indicator is also transparent and easy to understand. When it comes to the sensitive to change requirement, this indicator has an ok score. Sensitivity to changes depends on the variables chosen for the indicator. If the indicator were to measure the loss of energy generation or income per accidental damage, it would absolutely be sensitive to changes. Then it would not matter how much the service changed. If it did not do this, but measured loss in general or per area instead, then it would score bad on this requirement, as the marine energy marked may be susceptible to change, especially considering the future of marine oil and gas. As the indicator lack a variable to determine this, it has just met the requirement with a score of ok for now. When it comes to spatial relevance, the indicator has an ok score as well. This is because coastal power stations are more present in some ocean areas and less present in others. The two developed impact indicators are discussed under.

Developed indicators (11 and 12)

When it comes to the two developed indicators, they both have a good score on transparency and policy relevance. Their policy relevance is evident and was discussed in the last subchapter. The GFI has scored bad on measurability. As mentioned, there are several problems with observing ghost fishing. If this indicator is to be implemented, it requires developed survey methods and reporting. This would be time consuming and require resources, making measurability the indicator's main weakness. The ESI has scored ok on measurability. This is for the same reasons as the other ecological impact indicators, not all incidents would be reported. When it comes to the sensitivity to changes, the ESI have an ok score. If more marine species became endangered for reasons not involving plastic, this indicator would not detect this, and a higher number of incidents may occur. For the GFI, this requirement is also scored ok. This is because the worldwide fishing population in general is high, and if the population is growing or sinking, it may not have the same impact on the amount of fish caught in fish nets. The last requirement, spatial relevance, has the GFI scoring good for the same reasons as the pressure ALDFG indicators. The ESI have an ok score on this one. This is because the number of endangered species varies around the world. At the same time, the indicator can be applied for large areas with documented incidents or present results on a global scale.

9 Discussion

The discussion chapter initiates part III of this report, which includes a conclusion and is the ending part of this thesis. This chapter is based on the research questions and also contains recommendations for future research, as well as a discussion of the thesis framework.

9.1 Marine macroplastic indicators

The first research question searched to identify active pressure, state and impact indicators related to marine macroplastic. The purpose of this was to investigate available indicators for selection, and to avoid developing indicators already available. Research question one is repeated below:

1. Which pressure, state and impact indicators have been developed in relation to marine macroplastic?

This research question was answered in chapter 7.1. It took an approach to explore environmental stakeholders, players, organisations, conventions, programs and indexes, to search for active marine macroplastic indicators. The results revealed few active indicators. One of the few indicators actually addressing marine plastic is the Northern Fulmar indicator, indicating mostly floating marine plastic and to some extent also ecological impact. Indicators related to marine litter monitoring can potentially be converted to address marine plastic instead of marine litter, as pointed out earlier in the report. These indicators are related to beach-, floating- and benthic litter, and together with the Northern Fulmar indicator, they were the only active state indicators identified in this thesis.

Several active pressure indicators, related to ALDFG, were identified. These were found in a NOAA report and is presented in appendix A, table 8 and 9. As one of the limitations of this thesis was that potential plastic input to the marine environment would not be addressed, it did not come as a surprise to not identify other pressure indicators. As pointed out previous in the report, it is difficult to acclaim marine litter to any source of input due to different pathways, depositions and currents transporting the litter far from its source. For ALDFG the source is known as this gear has its origin in fishing activity, making these pressure indicators possible to implement. No active impact indicators were identified, but several proposed impact indicators and a test indicator from HELCOM were found.

As it was difficult to identify active indicators, it was interesting to find several proposed indicators. These indicators are presented in UNEPs report "Marine plastic debris and microplastics", and were proposed in relation to the implementation of the Global Partnership on Marine Litter (GPML). The indicators were reviewed for the indicator selection in this thesis as the active indicators were few in numbers. This provided the selection process with more options. Because these indicators have been proposed in relation to an UNEP initiative, they should be possible to implement and use in the future. The review of proposed indicators was based on this assumption.

This thesis only addressed macroplastic and not microplastic, and at the same time did not involve driving forces for plastic pollution and potential input, limiting the search for indicators. Without these limitations it may have been possible to identify more indicators and it would be possible to review a couple more of the proposed indicators presented in appendix B. As plastic is monitored as part of marine litter, it makes pure plastic indicators less probable to identify as well.

9.2 Connecting the impacts of marine macroplastic to marine ecosystem services

The second research question is repeated below:

2. How can ecosystem services be used to structure impact assessment from marine macroplastic?

Ecosystem system services may be used to structure the impacts of macroplastic. The connection highlights the relation between impacts of macroplastic and marine ES, and can assist in the selection and development of related indicators. This subchapter first summarises and discuss the process of connecting the impacts of marine macroplastic to ES, and further presents challenges met in this process.

The first step of connecting these two subjects, is individually classifying them, done in the design requirements in chapter 8.3. For this thesis, the social, economic and ecological impacts of macroplastic (presented first in chapter 3.1) was first classified. This classification was presented in figure 6 and 7 (chapter 8.3.1). A systematic listing gave an overview of all the impacts caused by macroplastic. Second, the classification of marine ecosystem services took place in chapter 8.3.2, presented in figure 8. This classification was performed on the basis of previously published work. These classifications made the process of connecting impacts of marine macroplastic to marine ES more apparent. Connecting the impacts was intuitive and went without implications, except for some of the ecological impacts, further discussed below.

One of the main challenges in the process of connecting the impacts of macroplastic to marine ES is connecting the ecological impacts to any direct service (except for food provision), as addressed several times in this report. In ES, it is advised to focus on species that provide final services or obviously contribute to final services. For marine species, it is challenging to attribute services to specific species, other than fish and shellfish which contributes to human well-being through the benefit of seafood. The three entanglement indicators (cetaceans, birds and endangered species) and the ingestion indicator (cetaceans) are connected to cultural services for this reason. As the classification of marine ES offers no classification for biodiversity and assembly of species, there were no options for classifying these impacts to anything other than cultural services. It is worth repeating here that biodiversity forms the basis for ES, but biodiverse ES do not necessarily provide more services than ecosystems that are less diverse (chapter 5). This makes even the endangered species indicator (ESI) difficult to connect to directs services. In the future, the role of impacted marine species in the ecosystem may be determined and more specific, and it may be possible to say something about their final services outside cultural services. Knowledge on how entanglement and ingestion impacts affect the marine species's assembly would also need to be present. This knowledge could strengthen the bond between these marine species and human well-being, and enhance the possibilities for policy measures related to the issues. Even though cultural services have a weaker bond to human-well being than provisional services and regulating services, these type of indicators would still have an effect. As mentioned, seeing marine animals suffer can have a conscious effect on humans, even though their direct service to society is less clear. The importance of biodiversity would also still be relevant, even if it could not be pointed out directly as a service. The ecological impact indicators's connection with symbolic cultural services is therefore found valid.

9.3 Indicator potential

The goal of the last research question was to identify the potential of pressure, state and impact macroplastic indicators that may be related to marine ES. Research question three is repeated below:

3. Which indicators may be used to measure impacts on marine ecosystem services from marine macroplastic?

The research and indicator verification process in this thesis shows that pressure, state and impact indicators have the potential to measure different impacts of macroplastic on marine ES. Different impacts and services offer different strengths and challenges. This subchapter will further discuss this research question by highlighting the strengths of such indicators and by looking at challenges met with selecting and developing indicators. Challenges is presented under future research and recommendations.

9.3.1 Indicator strengths

One of the strong characteristics of these indicators is that they address two subjects at the same time. Quantifying the impacts of marine macroplastic and at the same time measuring its effect on marine ES, give the indicators great potential for policy impact. This is illustrated in the verification process of the indicators (chapter 8.5) as all selected and developed indicators scores high on policy relevance. Even though cultural services may not have as strong of a link to human well-being as provisional services, combining it with the impacts of marine macroplastic enhances its policy relevance. Marine policy is addressed in chapter 3.2, and policy measures could include reuse and recycling, education, producer responsibility and eco-design, clean ups and legislative actions. By informing and educating society on the impacts of marine macroplastic and its effect on the marine ES, these indicators could potentially lead to such responses.

Another great characteristic of these indicators is the possibility for valuing the economic cost of marine macroplastic impact. For indicators in this thesis, this is especially evident for the social and economic impact indicator (marine energy) and the GFI indicator, as these services can be valuated through market based valuation. Providing a measure for the economic cost of these impacts can help pointing out the severity of the impacts and enhance their effect on marine policy. Valuation would also be possible for the ALDFG pressure indicators by predicting the probability for ghost fishing and the impact on commercial fish stock. For the state indicators this valuation would be more complicated, as it could be challenging to say something definite about how marine macroplastic affects the tourism industry. For the ingestion and entanglement indicators (not related to ALDFG and seafood), this valuation is not possible through market based valuation, and as long as they are connected to cultural services they seem difficult to valuate at all.

One of the strengths of ALDFG indicators, is their ability to trace plastic pollution to its source (fishing activity). By connecting the plastic pollution to its source and measure its impacts on ES, it may be possible to implement policy measures directly to the fishing industry. This could be for example incentives for delivering fishing gear not in use, so to decrease illegal dumping.

9.3.2 Future research and recommendation

Together with challenges met with connecting ecological impacts to marine ES, the challenges identified below are issues that should be addressed if implementing these type of indicators. Challenges are related to indicator requirements and based on the verification process in chapter 8.5

To validate these indicators, it would be interesting to test some of them (those who meet the measurability requirements) in a case study. This would also finish the last step of the vee-model in this project, validating the indicators against their purpose.

Measurability

As seen in table 7, several of the indicators only have a score of ok on the measurability requirement. For the state indicators there is the aforementioned problem with converting the indicators to address macroplastic instead of marine litter. This thesis does not seek to speculate on how marine plastic should be measured or how it will be in the future, but if these types of indicators are to be implemented, there need to be monitoring methods that makes a distinction between micro- and macroplastic. The three ALDFG indicators and the three entanglement indicators also does not meet this requirement to a satisfying extent. As pointed out earlier in the report, it seems inevitable that all incident would not be documented. On the upside, there is a rising consciousness and concern about the plastic pollution in the world society, and the issue is getting more and more attention in world policy. This will hopefully lead to more research on the issue, and provide more resources for monitoring and surveys in the future, providing indicators with more data.

Determining what variables to measure for ES and macroplastic impacts that is difficult to measure, can be a challenging process. This became evident in the process of developing indicators (chapter 8.4.2), for the impacts not addressed in this thesis. There were good reasons for choosing the indicator impacts chosen for development, like scoring strong on policy relevance, but there would also have been challenges with developing indicators for the marine macroplastic impacts not chosen. An example of this is to measure the impact on coral reefs. As benthic surveys mostly count litter items, it is difficult to say something about the area of corals being smothered or impacted, or the amount of pressure put on them. Hollow objects, like fish nets, also does not lead to the the same problems related to hypoxia for the corals. Invasive species would also be difficult to measure, and difficult to discuss and verify in this thesis due to the lack of knowledge and research on the issue. Plastic as nesting material, is also an impact where it is challenging to determine what to measure and which variables to choose for the indicator. As it is recommended to have knowledge on measurability and data availability, these impacts were not chosen for development. This does not mean that it would be impossible or extremely difficult to make such indicators happen, it only offers a reasoning for why the chosen themes were not selected for development. It may also be that such indicators should be developed by professionals with expertise on the issues, or include their assisting in the process. It would be interesting to look at how to measure these impacts and services in the future and develop indicators that convey information on these issues.

Regarding measurability, it is worth noting that most of the indicators in the developed indicator set assumingly would not have enough data behind it to present results, to date. This means that data would need to be collected, but except for maybe the ghost fishing indicator, this should be feasible.

Sensitivity to changes

Something else to be attentive on is that some of the indicators are not very sensitive to changes. If the marine ES change, the indicators might not be able to detect this change. Examples include change in assembly of species and increase or decrease in service (e.g. marine energy and tourism).

Spatial relevance

Indicators addressing specific marine species or group of species (e.g. Northern Fulmar or turtles), also meet challenges related to spatial relevance, as they cannot be aggregated to areas where the specie is not found. For marine species bound to specific areas and sea regions, indicator data may not be aggregated.

Threshold value

Only one of the indicators reviewed in this report has a threshold value (Northern Fulmar indicator). As there were only four active indicators reviewed this is understandable. Several of the indicators reviewed for selection in this report were proposed indicators. Threshold values can be important to measure policy performance and for the implementation of these indicators, threshold values should be up for evaluation.

9.4 Evaluation of thesis framework

9.4.1 Systems Engineering

Systems Engineering (SE) was the overarching methodology for selecting and developing indicators. More specific, the vee-model (life cycle model) in SE was applied. This model provided a systematic framework for the indicator set development process. The model presents more clearly the scope of the indicators and all associated requirements. One of the key stages in this model was classifying the impacts of marine macroplastic and the marine ecosystem services, in the design requirements. This was an important stage in selecting and developing indicators, as it made the connection of impacts and services more apparent. The continuously verification process also highlights strengths and weaknesses of the indicators both individually and in general. This method has made the development of the indicator set more structured, which is clearly detectable in chapter 8. It has also contributed in understanding the purpose of the thesis, and its objectives, influencing the end result in a seemingly positive way.

This thesis did not get to execute the last stage of the model, involving testing and operating, but opens up for continuing further work on the issue and on this thesis.

9.4.2 **Indicator framework**

The DPSIR-framework made it possible to classify indicators related to different impacts of marine macroplastic. It also gave several chapters in this thesis a straightforward structure. Examples of this are chapter 8.4.1 and 8.5. Classifying indicators also made it easier to compare and verify similar indicators, very evident in the verification process. The DPSIR framework illustrates the purpose of the indicators which is providing information on different elements of the plastic pollution and ultimately leading to policy responses.

10 Summary and conclusion

This thesis has examined the potential of using indicators to describe the impacts of marine macroplastic and relate them to marine ES. Three research questions were chosen to answer the assignement.

The first research question searched to identify active marine macroplastic indicators related to state, pressure and impact on the DPSIR-framework. Only one active state indicator was identified. This was the Northern Fulmar indicator, addressing mainly state of the environment due to marine plastic pollution. Other active state indicators together with impact indicators were searched for, but none were found. Indicators related to marine litter monitoring were identified and have potential for marine macroplastic conversion. These are related to beach-, floating- and benthic litter. Several pressure indicators were also identified related to input of ALDFG. Apart from these there seem to be few active indicators addressing marine macroplastic. Several proposed indicators were identified, which were proposed in relation to the Global Partnership on Marine Litter (GPML), an initiative launched by UNEP. These indicators show potential for future marine plastic indicators related to pressure, state and impact. Several of the largest and most well known environmental players also report that they are in the process of developing indicators related to entanglement and ingestion.

The second research question searched to answer how ES could be used to structure the impacts of marine macroplastic. The process of connecting the impacts to the services, is first individually classify them both. Inspiration for classifying marine ES may be found in previous published work. Classification of macroplastic impact and ES make the process of connecting the different macroplastic impacts to the marine services more apparent. The connection can highlight the relation between impacts of macroplastic and marine ES and may assist in the selection and development of related indicators. The main challenge in this process is connecting the ecological impacts of macroplastic to any direct service.

The third and last research question aimed to examine the potential of state, pressure and impact indicators to measure the impact of macroplastic on marine ES. Pressure, state and impact indicators all have the potential to convey information on social, economic and ecological impacts of macroplastic on the marine ES. This information can lead to marine policy responses. The possibilities for valuation can make the indicators more policy relevant by highlighting the economic cost of marine macroplastic. For indicators in this thesis, this is especially evident for the social and economic impact indicator (marine energy) and the GFI indicator. These indicators may be linked to direct services which can be valuated through market-based valuation. Several challenges are met with these types of indicators that should be addressed in future research. Except for determining the direct services of impacted species, measuring complex ES and impacts from marine macroplastic can offer complications and make operationalisation challenging.

Further work on these type of indicators is advised. This work should address challenges related to the indicator requirements and with determining the direct services of impacted species. Future work could also involve testing and operating of the indicators, finishing the last stage of the vee-model in this thesis and validating the indicators.

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Appendix A: ALDFG indicators

Table 8: Indicators of gear loss related to fish nets (NOAA 2015).

Region	Fishery/gear type	Indicator of gear loss (data source)
North Sea & NE Atlantic	Bottom-set gill nets	0.02–0.09% nets lost per boat per year
English Channel & North Sea (France)	Gillnets	0.2% (sole & plaice) to 2.11% (sea bass) nets lost per boat per year
NE Atlantic*	Deepwater monk fish and shark fisheries	>25,000 nets; 1,254 km sheet netting per year
	Deepwater Greenland halibut	0.14–0.17% nets per season; est. 15 nets per day
Mediterranean	Gillnets	0.05% (inshore hake) to 3.2% (sea bream) nets lost per boat per year
Baltic Sea*	Gillnets	5,500–10,000 nets lost per year
North Pacific*	Gillnets	7,000 km of net per year
NW Atlantic	Newfoundland cod gillnet fishery	5,000 nets per year
	Canadian Atlantic gillnet fisheries	2% nets lost per boat per year
Caribbean	Nets	79% of nets

Table 9: Indicator of gear loss related to traps (NOAA 2015).

Region	Fishery/gear type	Indicator of gear loss (data source)
Gulf of Aden	Traps	c. 20% lost per boat per year
ROPME Sea Area (UAE)	Traps	260,000 lost per year in 2002
Australia (Queensland)	Blue swimmer crab trap fishery	35 traps lost per boat per year
NE Pacific	Bristol Bay king crab trap fishery	7,000 to 31,000 traps lost in the fishery per year
North Pacific*	Traps	7,000– 31,600 pots per year
NW Atlantic	New England lobster fishery	20– 30% traps lost per boat per year
	Chesapeake Bay	Up to 30% traps lost per year, mainly in the hurricane season
Caribbean	Guadeloupe trap fishery	20,000 traps lost per year, mainly in the hurricane season

Appendix B: Proposed future indicators for marine plastic

Table 10: Proposed state and impact indicators related to the Global Partnership on Marine Litter (GPML) (Kershaw 2016).

Intended outcome	Indicator description	Target (2020-25)	Monitoring/verification
Reduce the quantities and impact on the environment of marine litter entering from all sources	Number of cetaceans injured or killed	Significant reduction[13]	IWC, Regional Seas Bodies, national government, municipalities and NGO reporting
	Number of turtles killed by entanglement	Significant reduction	Regional Seas Bodies, national government, municipalities and NGO reporting
	Quantity of plastic (number and mass of items) in guts of indicator species from necropsies (e.g. fish, birds, reptiles, cetaceans)	Significant reduction	Regional Seas Bodies, national government, municipalities and NGO reporting
	Number and mass of items of floating macro-litter (items km^{-2})	Significant reduction	Regional Seas Bodies, national government and NGO reporting
	Number of items of floating micro-litter, especially microplastics (items km^{-2})	Significant reduction	Regional Seas Bodies, national government and NGO reporting
	Number and mass of items of litter on shorelines - km-1 shoreline		Regional Seas Bodies, national government and NGO reporting

Table 11: Proposed pressure, state and impact indicators related to the GPML (Kershaw 2016)

Intended Outcome	Indicator Description	Target (2020-25)	Monitoring/Verification
Reduce the quantities and impact on the environment of marine litter introduced directly at sea	Quantity (volume m^3 and length km) of capture fisheries gear abandoned, lost or otherwise discarded (ALDFG) (e.g. nets, lines, pots, FADs)	Significant reduction[15]	FAO reporting (LC/LP), Regional Seas Bodies, national governments, municipalities, fisheries industry
	Quantity of other capture fisheries-related items in the environment – items km^{-2} sea surface, km^{-2} water column, km^{-2} seabed, km^{-1} shoreline (e.g. strapping bands, boxes, rope)	Significant reduction	Reporting by NGOs, Regional Seas Bodies, national governments, municipalities, fisheries industry
	Quantity (volume m^3 and length km) of aquaculture gear abandoned, lost or otherwise discarded (ALDFG) - items km^{-2} sea surface, km^{-2} water column, km^{-2} seabed, km^{-1} shoreline (e.g. floats, rope, nets, cages, poles)	Significant reduction	FAO reporting; regional reporting e.g. Network of Aquaculture Centres in Asia-Pacific (NACA), NGOs, Regional Seas Bodies, national governments, municipalities
	Quantity of litter derived from commercial shipping	Significant reduction	National governments, NGOs, Regional Seas Bodies & municipalities reporting
	Quantity of litter derived from cruise industry	Significant reduction	National reporting
	Number of turtles killed by ALDFG	Significant reduction	CBD, Regional Seas Bodies, national and NGO reporting
	Number of cetaceans injured by ALDFG	Significant reduction	FAO, IWC, CBD, Regional Seas Bodies, national and NGO reporting
	Number of fish killed by ALDFG	Significant reduction	FAO, CBD, Regional Seas Bodies, national and NGO reporting
	Number of birds killed by ALDFG	Significant reduction	CBD, Regional Seas Bodies, national and NGO reporting
	Number of containers and other cargo lost by commercial shipping	Significant reduction	National and shipping industry reporting

Table 12: Proposed indicators on social and economic impacts of marine litter, related to the GPML (Kershaw 2016)

Intended Outcome	Indicator Description	Target (2020-25)	Monitoring/Verification
Reduce the social and economic impact on the environment of marine litter entering from all sources	Number of vessels damaged or lost due to collisions or entanglement (e.g. fouled propellers or blocked cooling water intake)	Significant reduction[16]	Operators, national governments
	Loss of energy generation capacity (and income) and risk of accidental damage due to blocked cooling water intakes in coastal power stations, including nuclear power stations; loss of functioning of desalination plants.	Significant reduction	Operators, national governments
	Cost of beach cleaning	Significant reduction	Municipalities
	Number of injuries to public caused by marine litter	Significant reduction	National governments, municipalities, health authorities
	Number of call-outs of emergency services by stricken vessels	Significant reduction	National governments, emergency services, municipalities