Impacts of recreational boating in coastal seascapes and implications for management

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"Life isn't about waiting for the storm to pass.

It's about learning to dance in the rain."

- *Vivian Greene*

ABSTRACT

Kosterhavet National Park, a marine protected area on the Swedish west coast, is a popular destination for tourists and attracts over half a million visitors annually. Many of the tourists arrive by boat, and the natural harbours are frequently visited. Boat presence may affect bottom substrates through anchoring, and pollution could also occur in the form of leaching antifouling paints, fuel residue (PAHs) and litter. This thesis set out to investigate if there are any lingering impacts resulting from boat tourism in Kosterhavet and suggests management efforts in those cases there are.

Through studies using a video sled, data from two consecutive years revealed visible anchor traces on soft unvegetated bottoms, and number of traces were also linked to number of bottom anchoring boats. Furthermore, it was found that visitors engage in bottom anchoring at locations where sensitive habitats like eelgrass and oyster beds are located, which may result in harm to both habitat types.

Sediment samples taken in both natural harbours and small marinas unexpectedly showed presence of long since banned antifouling products like TBT, but also more recently prohibited biocides like irgarol and diuron. This suggests that they are still in use. Moreover, water samples from the area show that the currently used antifouling compound copper, is likely to exceed threshold values set by the Swedish Agency for Marine and Water Management (SwAM) during peak boat season. Concentrations of PAHs were found to be below threshold values for water, but they are also known to have low water solubility and are more likely to be bound to particles.

From the video data, occurrence of seafloor litter was also obtained, and data on beach litter from reference sites on the Swedish west coast was downloaded from the OSPAR beach litter database. Seafloor litter, in contradiction to beach litter, was at a much higher degree found to have an origin related to recreational activities. This suggest that beach litter stem from other activities in the park, or are brought to the area by currents.

A threat analysis based on the leisure boat related threats; anchoring, antifouling, PAHs and litter were performed. Threats were analysed with respect to their potential impact to the soft bottom values; eelgrass, oysters and blue mussels. The sum of these threats showed that eelgrass was highly impacted by anchoring, but oysters were more severely affected when all threats were considered.

This type of threat analysis can be of great value to park managers, as they need to make prioritizations regarding how to use their often limited resources.

Based on these finding, it is, among others, suggested that bottom anchoring should not be allowed at locations where eelgrass and oyster beds occur, and that bottom friendly mooring solutions should be made available to avoid negative impact on these habitats.

List of papers

The thesis is based on the following articles and manuscripts. The papers will be referred to by their roman numerals.

I. **Is leisure just pleasure? Mapping anchoring impact from recreational boats in coastal seascapes.**
Jenny Egardt, Ingela Dahllöf, Per Nilsson. (2018).
Manuscript

II. **Sediment indicate the continued use of banned antifouling compounds**
Jenny Egardt, Per Nilsson, Ingela Dahllöf. (2017).
Marine Pollution Bulletin.
https://doi.org/10.1016/j.marpolbul.2017.08.035

III. **Release of PAHs and heavy metals in coastal environments linked to leisure boats**
Jenny Egardt, Martin Mörk Larsen, Pia Lassen, Ingela Dahllöf. (2018).
Marine Pollution Bulletin.
https://doi.org/10.1016/j.marpolbul.2017.12.060

IV. **Are recreational activities a source of marine litter in Kosterhavet marine national park?**
Per Nilsson, Jenny Egardt, Jessica Lundqvist, Louisa Borthwick. (2018).
Manuscript.

CONTENTS

Abbreviations

AA-EQS	Annual Average Environmental Quality Standards
CMP	Conservation Measures Partnership
DBT	Dibutyltin
DGT	Diffuse Gradient in Thin films
DPSIR	Framework for describing interactions between society and the environment
EEA	European Environment Agency
GenS	Good Environmental Status
GES	Good Ecological Status
IMO	International Maritime Organization
LAC	Limits of Acceptable Change
MAC-EQS	Maximum Allowable Concentration Environmental Quality Standard
MBT	Monobutyltin
MSFD	Marine Strategy Framework Directive
OS	Open Standards
OSPAR	The Commission for the Protection of the Marine Environment of the North-East Atlantic
PAH	Polycyclic Aromatic Hydrocarbons
ROS	Recreational Opportunity Spectrum
SEPA	Swedish Environmental Protection Agency
SR	Silicone rubber
SwAM	Swedish Agency for Marine and Water Management
TBT	Tributyltin
WFD	Water Framework Directive

1 Introduction

1.1 Outdoor recreation and management

Tourism is projected to have an annual growth of 3.3 % globally, until 2030 (UNWTO, 2016). Marine and coastal tourism is one of the fastest growing sectors (Hall C.M. 2001, UNWTO 2011) and more pressure will be put on these environments as an increasing number of visitors will occupy the same space. Tourists often engage in outdoor recreation which can be defined as "activities in the outdoors in a natural setting without a competitive narrative". With an increase in activities in natural areas, like national parks and protected areas, came the question of how recreation should be managed in a sustainable manner, which lead to the research field of recreation ecology that studies the impacts of outdoor recreation and nature-based tourism (Liddle, 1997, Hammitt & Cole, 1998).

Several strategies exist to manage nature areas. Limits of acceptable change, LAC, was developed by the US forest service in the 1980s as a means to address wilderness areas carrying capacity (Stankey et al., 1985). The idea was that when a maximum limit of resource degradation was reached, recreation should be restricted to avoid further damage. This model builds on a concept in ROS, recreational opportunity spectrum, in which recreational opportunity classes are defined, from primitive to urban with regard to landscape and available facilities. ROS was adopted in the 1970s as a response to visitors being disturbed by logging and grazing animals (Clark & Stankey, 1979, Nilsen & Tayler, 1997).
Generally, more urban areas are located close to park entrances and with increasing distance, areas get more primitive with regards to available facilities and road access. The visitors can then choose areas based on their desired experience and not be disturbed by conflicting activities.

In Sweden, the customary "right to public access", means that everyone has the right to move freely in nature, while having the responsibility to keep nature areas unharmed. Specific areas can also be designated as a national interest for outdoor recreation by the Swedish environmental protection agency (SEPA).
A proposition from the Swedish government in 2009 on the future of outdoor recreation also set forth recreational goals (Prop. 2009/10:238). These goals include available nature for all, protection of the right to public access and protected areas as a resource for recreation.
Furthermore, in 2012, the Swedish Government assigned the Agency for Economic and Regional Growth to strengthen and develop sustainable tourist destinations and promote them on the international market (Government Decision,

N2012/508/ENT). Bohuslän on the west coast of Sweden was one of these destinations and the project proved successful as there in 2015 was an increase in almost 16 % among foreign visitors (SAERG, 2015).
Bohuslän has also been designated "one of ten last great wildernesses in the world" by CNN travel in 2013. Thus, maintaining the attractive values while simultaneously increasing the visitor pressure in the region may pose a challenge to managers.

1.2 Possible environmental impacts from recreation and tourism

When planning and developing areas for recreation, several factors that may have negative consequences for the environment have been suggested (Lal Mukherjee, 2013, EC news alert, 2007). On a larger scale in coastal areas they include;

- Coastal development and dredging - lead to habitat destruction
- Resource use - an increase in visitors also increase the demand on freshwater and energy etc.
- Pollution - sewage and waste are likely to increase
- Social disruption via commercialization and adaptation of local culture
- Depletion of fish stocks from unregulated recreational fishing
- Loss of public access due to private beaches and hotels
- **Boat tourism**

Boat tourism in Sweden
Sweden has one of the highest numbers of leisure boats per capita in the world, with fourteen percent of households owning at least one boat and an estimated number of leisure boats of around 500 000 (STA, 2015). Sweden has a large archipelago with around 16 000 islands located on the west coast alone (SCB, 2013). As an active boating country, internationally attractive, the Swedish coasts are frequently visited by leisure boats during the summer months. Coastal communities on the Swedish west coast, formerly reliant on fisheries and trade now get a large part of their revenue from tourism (www.vastsverige.com/tanum/). Tourism and boat tourism is therefore important as the communities get a financial gain, but may this come at a cost of the environment?

Impacts that can arise from boat tourism, which is the focus of this thesis, includes (Lal Mukherjee, 2013, EU Commission news alert, 2007);

- careless boating, diving etc., that can lead to degradation of habitat from touching and stirring up sediment
- noise, that may impact behaviour in organisms
- disturbed megafauna
- sewage and grey water being released into the water
- physical damage from **anchoring**
- **antifouling biocides** that leach into the water
- hydrocarbon release (**PAH** from fossil fuels)
- **litter**

These factors are directly linked to leisure boats and may pose harm to protected habitats, and as their presence oppose goals set both nationally and within the EU, four of them were chosen to be further investigated within the scope of this thesis:

Anchoring has the potential to damage seafloor habitats, e.g. eelgrass and oysters. These species are important components in marine Natura 2000 habitats (established by EU Habitat Directive, 92/43/EEC). They are also on the OSPAR list of rare and threatened habitats, making them important species for protective measures in Sweden. Physical damage is also one of two criteria to evaluate "seafloor integrity", which is a descriptor in the EUs Marine Strategy Framework Directive (MSFD).

Chemical compounds like **PAH** (polycyclic aromatic hydrocarbons) and previously used **antifouling** biocides like TBT (tributyltin) that degrade slowly contribute to why the Swedish national environmental goals such as "A Non-Toxic Environment" will not be met on time. These national goals were set by the Swedish Parliament in 1999, and amended in 2005, as a foundation for the national environmental policy with the intent to achieve them by the year 2020. PAHs as well as TBT are also considered priority hazardous substances under the Water Framework Directive (WFD, Directive 2008/105/EC, Annex II).

Marine litter is not directly described in the national goals but it is considered a source of pollution and the goal "A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos" may be affected by large quantities of marine litter. It is however one of the 11 descriptors in the MSFD, which need to be addressed to achieve good environmental status, and it is a priority issue within OSPAR.

1.2.1 Anchoring

Boats may exert direct physical pressure on its environment when moored. Grapnel- and claw type anchors are widely used for anchoring and they function by digging into the bottom substrate. On soft bottoms, this can leave holes and plow-like drag marks, as well as resuspension of sediment, which may also be transported out of the area (Osterdorp et al., 2009). Organisms in and on the substrate may be disturbed and damaged, mussels and oysters can get crush injuries and eelgrass could be uprooted. On rock substrates, the anchor may cause abrasion and can dislodge macro algae.

Two species that may be at risk from anchoring are the eelgrass *Zostera marina* and the European oyster *Ostrea edulis.* They are both common components of protected habitats in the Natura 2000 network, and are also on the OSPAR-list of protected species as they have both suffered decline in distribution.

Zostera marina

Eelgrass is a form of seagrass. It is not an alga, but instead more closely related to plants on land. It has a root-system, rhizome, which is buried in soft substrates like sand and mud, and shoots that protrude above the sediment surface. Eelgrass can form vast meadows and in temperate areas they are very productive habitats with high biodiversity. They are considered to be ecosystem engineers, creating a living environment for many other species, and serve as nursery areas for commercial fish species (OSPAR *Zostera*, 2009).

Globally, the distribution of seagrasses is declining at a rate of 7 % every year (Waycott et al., 2009), and on the Swedish west coast there has been a loss of about 60 % of the common eelgrass *Z. marina* since 1980 (Baden et al., 2003, Nyqvist et al., 2009). The main reason for this is eutrophication (Baden et al. 2003). Filamentous algae thrive in nutrient rich environments, and can grow on the surface of eelgrass leaves, thereby shading them. Eutrophication also increases the amount of microalgae in the water, which attenuates the light. As *Z. marina* is highly dependent on favourable light conditions, this attenuation has decreased the depth distribution of eelgrass, which on the Swedish west coast now mainly occur in shallower habitats of 0-5.5 m (Boström et al., 2003). The rhizomes can be severed when a buried anchor is retrieved and plants can be uprooted, leaving bare patches. Studies of anchoring in seagrass areas have revealed areal loss of seagrass and bare circles in seagrass meadows as a result of swinging chains from moored boats (Hastings et al., 1995, La Manna et al. 2015, Walker et al., 1989), and as anchors damage rhizomes, recovery is impeded (Ceccherelli et al., 2007, Milazzo et al., 2004, Montefalcone et al., 2008). If growth does not equal or exceed the physical damage done by anchors, bare patches will remain.

Ostrea edulis

The European oyster, *O. edulis,* is an oyster native to Europe, but it has been introduced for cultivation in North America, Australasia, Japan and South Africa (FAO, 2017). In Sweden it occurs on the northern west coast, at a depth ranging from 0 to 6 meters (OSPAR *Ostrea,* 2009). These oysters will not grow in waters colder than 5 ° C, and need warmer waters (ca 15 ° C) to spawn (SEPA, 2009). For spawning to occur water conditions need to be favourable with respect to both salinity and temperature for a prolonged period. This does not happen on a yearly basis in Sweden, and recruitment is therefore slow. Like eelgrass, it is considered a keystone species that create three-dimensional structures on the bottom that other organisms may utilise and both also stabilizes sediment (OSPAR *Ostrea,* 2009).

According to the International Council for the Exploration of the Sea (ICES, 2002), the naturally occurring stocks of the *O. edulis* have declined which is attributed to, among others, overexploitation and habitat loss from destructive harvesting, but also deceases and severe winters (FAO, 2017).

Damage caused in these habitats is most often from fishing equipment (Woolmer et al., 2011), but as anchors impact the bottom, abrasion and crush injuries is not unlikely. Because of its importance as a species and its´ declining natural occurrence it has been placed on the OSPAR list of threatened habitat/species (OSPAR *Ostrea,* 2009).

1.2.2 Antifouling biocides

Biocides are toxic substances used to prevent proliferation of unwanted organisms, in agriculture they are used to protect crops against pests like weeds or insects.

Antifouling paints contain biocides to prevent organisms like barnacles and algae to attach to boat hulls in aquatic environments. However, the biocides used in paints are not only toxic to the organisms settling on a hull, aka target-organisms, they are also potentially toxic to all other organisms in the vicinity. A barnacle settling on the hull of a boat is a target organism. A barnacle on a cliff nearby is a non-target organism, but it is just as sensitive as the fouling barnacle (target organism) and will be affected if exposed to the same toxic substance. Most antifouling paints used today are self-polishing (Buskens et al., 2013), and leach its active ingredient continuously into the water. Therefore, many different types of non-target organisms run the risk of being exposed and affected.

TBT

In the 1960s the compound TBT (tributyltin) replaced lead in antifouling paints, and became very popular since it was highly efficient in preventing fouling. In the late 80s however, TBT was linked to the declining oyster populations in Arcachon Bay, France, where the oysters suffered failed reproduction and abnormal shell development (Alzieu et al., 1986). TBT is also known to cause a condition known

as imposex in gastropod molluscs (snails), in which females develop masculine characters. As reproduction is affected, exposed populations will be impacted for generations. The severe effects on the environment lead to a ban on recreational vessels < 25 m in length in countries like France, the UK and Sweden in the late 80s, but it wasn't until 2003 that the international maritime organisation (IMO) put forth a global ban which did not come into effect until 2008.
Unfortunately, TBT is highly persistent in nature. It degrades slowly, and can be stored in anoxic sediments for decades (Fent, 2006). Although the degradation products, DBT and MBT (di- and monobutyltin), which also persist in sediments (Sarradin et al., 1995), are not as toxic as the parent compound, they are still a cause for environmental concern (Hoch, 2001).

Irgarol and diuron
Herbicides have been added to antifouling paints to make them more efficient, as some algae are tolerant to heavy metals (Reed & Moffat, 1983). Irgarol and diuron are two examples of so-called booster biocides, and they both function by inhibiting photosynthesis. Irgarol have been used in Swedish antifouling paints (KemI, pesticides register, 2017) but no new permits have been issued since 2010 and the EU Commission decided not to continue the authorization of irgarol as an antifouling product (Commission Implementing Decision (EU) 2016/107) in 2016. Diuron on the other hand has never been permitted in antifouling products for leisure crafts in Sweden, but it has been allowed within the EU (Price & Readman). Diuron was phased out during 2008 (Commission Decision 2007/565/EC), and is considered a priority substance under the water framework directive (Directive 2008/105/EC, Annex I).
Irgarol and diuron are both photosynthetic inhibitors, subsequently affecting all organisms that perform photosynthesis, and may therefore also have negative effects on non-target organisms. Studies have shown community level effects on periphyton when exposed to environmentally occurring concentrations of irgarol, and also induced selection towards more tolerant communities (Dahl & Blanck, 1996, Blanck et al., 2009). Irgarol and diuron have also been shown to have effects on non-photosynthesising organisms, such as species of nematodes (Gallucci et al., 2015).
Irgarol degrade slowly with a half-life of around 200 days (Zhang et al., 2008), and can have a long residence time in marine systems (Ranke, 2002). Diuron is more short-lived with a half-life of 14 days in anaerobic conditions. However, diuron associated with paint particles showed little degradation over 42 days, and it is also considered relatively persistent in the water column (Thomas & Brooks, 2010).

Metals

Heavy metals like lead, mercury and copper have been used in antifouling paints as they reduce growth rate and reproduction of fouling organisms but they can also be lethal in high concentrations. Lead and mercury are no longer allowed due to their high toxicity, but copper is the most common heavy metal used as a biocide (Thomas & Brooks, 2010). Copper is an essential metal, and thus all organisms need it to function properly. In too high concentrations however, it can cause neurologic damage in higher organisms and cause growth and reproductive deficiencies in many organisms (Flemming & Trevors, 1989, Manto, 2014). Other heavy metals associated with antifouling paints are zinc, which is not a biocide but instead used for its polishing properties, and chromium and cobalt that have been used for pigmentation.

As even essential metals can become toxic, concentration limits have been set for a variety of toxic substances, including toxic metals, which should not be exceeded. These limits, environmental quality standards (EQS) (Directive 2008/105/EC) exist for several chemicals, not only heavy metals but also PAHs and diuron, as a safety margin above which the environment is at risk of negative impact. Copper and zinc are not considered in this EQS Directive (2008/105/EC), unlike cadmium, lead, mercury and TBT, but instead there are national EQSs set by the Swedish Agency for Marine and Water Management (SwAM).

1.2.3 PAH

PAHs are hydrophobic compounds, made up of two or more fused benzene rings (Cerniglia, C.E., 1992). They can be pyrogenic or petrogenic in origin, where pyrogenic are formed by incomplete combustion of organic matter and fossil fuels, and petrogenic are natural components of coal and crude oil. PAH exposure may have serious consequences to several organisms as some forms are considered mutagenic (Abdel-Shafy & Mansour, 2016), which is why PAHs are listed as priority hazardous compounds in the WFD (Directive 2008/105/EC, Annex II).

Outboard engines emit both exhaust fumes and uncombusted fuel directly into the water, thereby releasing PAHs. The amount of uncombusted fuel emitted depend on the engine type. Two-stroke engines have the highest emissions, and even newer models of two-stroke engines wash out 20 % fuel uncombusted. Four-stroke engines on the other hand emit ten times less uncombusted fuel compared to the newer two-strokes and are therefore considered more environmentally friendly (Alin & Astnäs, 2001).

In Sweden, no new sales of the older two-stroke model have been allowed since 2007 (Lindgren, 2015), and yet about one third of all boats in Sweden have this type of engine (> 25 years old) (STA, 2015).

Most outboard engines run on conventional gasoline, but by switching to alkylated gasoline, there may be up to 90 % less emission of PAHs (Lindgren, 2015).

1.2.4 Litter

Marine litter has got much attention lately as it is an environmental problem (Lachmann et al., 2017) (UNEP, 2016), and it has its' own descriptor for good environmental status (GEnS) in the Marine Strategy Framework Directive (MSDF). The focal point of marine litter is often plastic, but it can be composed of many different materials. In marine protected areas (MPAs), litter may be a problem not only for conservation values (e.g. Fossi et al, 2017) but also for social and economic objectives as recreational activities are often part of the motive for establishing an MPA. Activities like sunbathing and boating are suggested as two important sources of marine litter, and as people do not like the sight of littered beaches (Marin et al., 2009), its mere existence may cause harm to the social aspects of the MPA.

The effects of marine litter on a population level is not fully understood, although individual organisms can be harmed through entanglement and ingestion (Werner et al., 2016).

In Kosterhavet National Park, two of the main activities for visitors are beach activities and recreational boating. Marine litter is definitely an economic problem for the national park: beach cleaning cost the park management authorities > 100 000 € per year, which amounts to ten percent of their annual budget. To what extent it is also an environmental/conservation problem is part of the analyses in this thesis.

1.2.5 Management tools

Open standards

Several factors that need to be addressed, like the ones described above, often exist at the same time and it is up to managers to prioritize among them. One way to accomplish this is by means of a model known as Open Standards (here forth abbreviated OS). It was created by the Conservations Measures Partnership, CMP, which was born out of the Society for Conservation Biology (CMP, Open Standards, 2012). The CMP is made up by well-established conservation NGOs e.g. WWF, Conservation International, and other wildlife foundations and conservation networks. With their experiences, questions and concerns regarding conservation and how success should be measured and monitored they created the OS model in 2004, and it has since been revised twice. The intent with the OS model was to, initially, assure that conservation managers "spoke the same language". Other

existing conventions on conservation use different words when describing the same thing. For instance, three of the most common approaches use the words; source, direct threat and pressures (EPA risk assessment, FOS Framework, WWF RAPPAM framework, respectively, Salafsky et al., 2003) to define the same feature. This complicates collaborations and learning from other projects and the OS model therefore suggests a common taxonomy and descriptions to facilitate exchanges between conservation practitioners.
One part of an OS conservation project is identifying critical threats.
By evaluating the impact of specific threats to conservation values, a threat rank matrix is created, which indicates the most important overall threats and the most sensitive values. Based on information from this matrix, managers can decide where to put their resources. If one threat is overwhelmingly important that can be chosen for management efforts, or if a value of great importance is threatened, efforts can be put forth to save that value.

DPSIR

In Sweden, the DPSIR framework (Drivers, Pressures, State, Impact, Response) established by the European Environment Agency (EEA, 2018) is used to describe the interactions between society and the environment based on specific indicators. The different parts of DPSIR regarding this thesis would be Drivers = leisure boat tourism, Pressures = effects from leisure boats, such as anchoring, chemical pollution and littering, State = state of environment, presence of species, concentrations of pollutants etc., Impact = changes in environmental quality such as habitat fragmentation, damage to bottom substrate, toxic concentrations of pollutants affecting species, Response = societies response to the impact in the form of behavioural changes or legislation to prevent impact.

The threat rank from the OS model relate to this framework as it allows for a measurable connection between state and impact. The threat rank evaluates possible impact depending on how widespread a threat is in the conservation area and also combine effects of threats to pinpoint (if possible) the largest impact of the pressures and thus help in finding an appropriate response.

2 Aim

The overarching aims of this thesis were to assess;

a) the impact of leisure boats to values designated in Kosterhavet National Parks management plan, and

b) what threats pose the highest risk to conservation values, and propose actions to alleviate impact

The values in the Kosterhavet National Park management plan are divided into eight main categories based on, among others, depth and substrate and include shallow soft and hard bottoms (SEPA, 2009). Values also include "the pelagic" and specific species. Conservation values are specific species and habitats associated with the above mentioned values (see below, *Values,* p. 17).

To address the first aim, four specific studies were carried out;

1. Video transects (Paper I, Paper IV). Video data give information on habitat types present in the area (mud, sand, rock), and presence of OSPAR and Natura 2000 protected species like eelgrass (*Zostera marina)* and the European oyster (*Ostrea edulis)*. From this data occurrence of litter and traces from anchors have also been quantified.
2. Boat counts and visitor interviews (Paper I-III). Boat counts were made to test if a correlation existed between, for instance, bottom damage and amount of litter and visitor number. Interviews were carried out to estimate what the preferred antifouling products were, and how often they were applied.
3. Sediment sampling. Sediments were analysed for current and prohibited antifouling paint components, referred to as biocides (Paper II).
4. Water sampling. Passive sampling devices were used to measure concentrations of dissolved metals from antifouling paints as well as PAHs from fuel (Paper III).

In order to address the second part of the aim, a model to prioritise threats from different types of impacts is suggested, based on the findings from the above mentioned studies.

All studies were carried out in Kosterhavet National Park, located on the Swedish west coast, this marine area consists of two major islands (North- and South Koster) and an archipelago (Fig. 1). The area is a very popular destination for recreation during the summer months, June-August, and has been for long before the area was given a national park status. Boat tourism has occurred since at least the 70ies and today it is estimated that more than half a million people visit every year (NV, 2015).

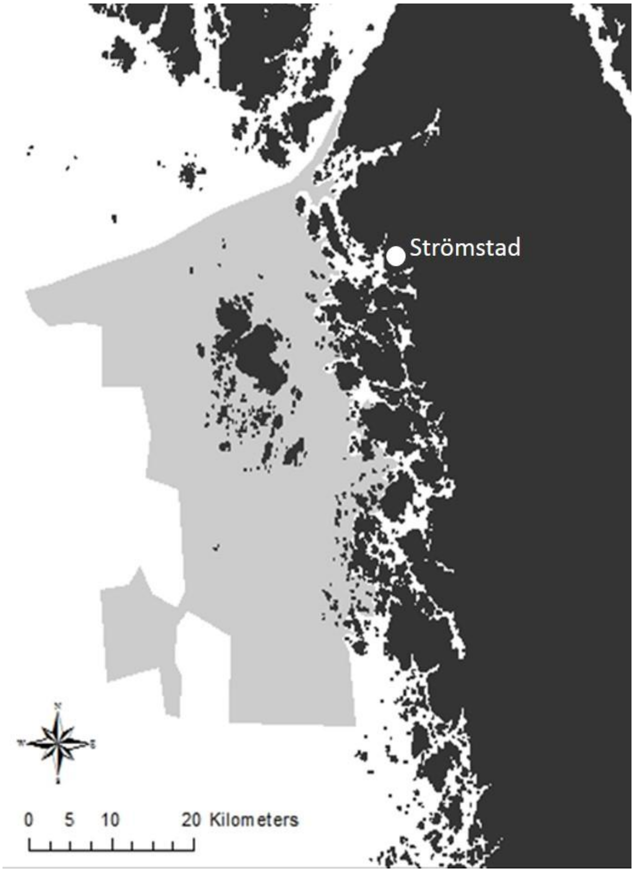

Figure 1. Map of Kosterhavet National Park, including the main Koster Islands and archipelago. The national park area in grey.

The national park (Fig. 1) was inaugurated in 2009 and is 98 % marine, that is, most of the land area of the islands in the archipelago are not part of the national park. They are however under management of the same county administrative board as Kosterhavet, largely as nature reserves. The national park was established due to its, for Sweden, unique characteristics. Oceanic bottom water run along the Norwegian trench and provide an influx of highly saline water enabling deep sea organisms to flourish. A large number of for Sweden rare and threatened organisms occur in the

the area, for example, the sea pen *Kophobelemnon stelliferum* has its only known record in Swedish waters in this area. In the shallower regions, where most of the outdoor recreation take place, species like *Zostera marina* and *Ostrea edulis* are present.

3 Methods

3.1.1 Video (Paper I, IV)

Video transects were obtained by slowly towing a sled along the bottom. A camera was mounted on the sled frame, facing perpendicular to the bottom. Transects were made in shallow (0-12 m depth) areas around islands in the archipelago during the summer of 2013-2014, in areas that were known mooring sites and in locations known to be less attractive to leisure boats.

Still frames from the video data from 2013-2014 were taken every 20 s of each transect and were assessed for habitat type. The European Nature Information System (EUNIS) habitat codes were used to the second level, and A3.2 (rock), A5.1 (coarse sand), A5.2 (fine sand), A5.3 (mud), A5.4 (mixed sediment) and A5.5 (macrophyte dominated) substrates were designated (Fig. 2). Percent of eelgrass cover on the still frames were assessed, when present, to estimate density and cover in the surveyed area.

Full length transects were used to assess anchor impact, occurrence of *O. edulis* and presence of litter.

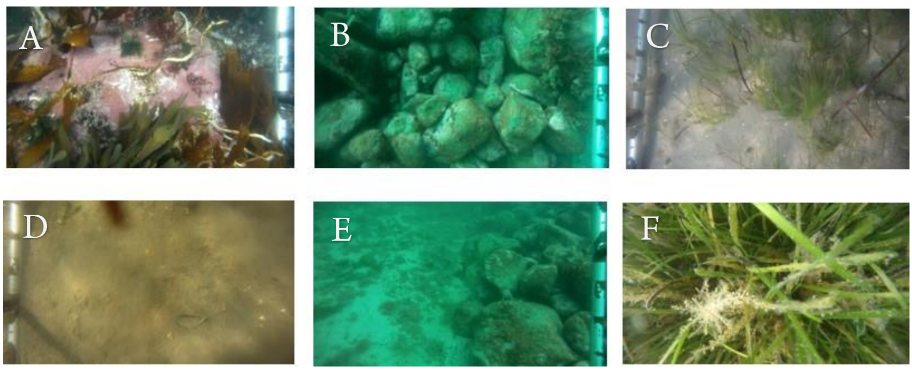

Figure 2. Habitat types in Kosterhavet. A) Rock (A3.2) B) Coarse sand, gravel (A5.1) C) Fine sand (A5.2) D) Mud (A5.3) E) Mixed sediment (A5.4) F) Macrophyte dominated (A5.5)

This method proved good for habitat mapping on softer substrates, but on rock bottoms the sled would occasionally get stuck in crevasses and between rocks. The method was also useful for surveying litter-, and anchor traces on unvegetated substrates. The downward facing camera helped in determining type and size of litter (Fig. 3 A-C) and anchor trace.

The method was less suitable for finding anchor traces in vegetated habitats, specifically dense eelgrass areas with high shoots. As the sled moved through the eelgrass, the leaves would bend under the frame and cover the bottom facing camera making inspection of the bottom virtually impossible. However, in less vegetation dense areas bottoms were visible, and although typical anchor traces like plow-marks and pits were not detected in eelgrass areas, anchor presence was confirmed (Fig. 3 D).

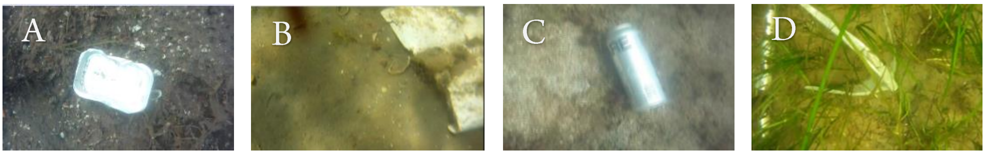

Figure 3. Still frames from downward facing camera. A) Disposable barbeque B) Plastic sheet C) Metal can D) Anchor in eelgrass

3.1.2 Boat counts and visitor interviews (Paper I-III)

Boat counts were made manually by driving around in the archipelago recording where boats were moored, the boat type (motor vs sail), size as well as preferred style of anchoring. Anchoring generally occur alongside a cliff or by use of a bottom anchor, either from the bow, which allow the boat to drift around the anchor, or by attaching the bow to an object (jetty, cliff) and cast an anchor from the stern. Visitor interviews were carried out to try to establish antifouling paint preferences as well as knowledge concerning paints. Visitors were asked if they knew what paint they used, why that paint was chosen and how often they needed to re-apply.

Data on where and how people anchor was used to answer if more bottom damage could be seen at sites where visitors preferred to use bottom anchors (Paper I). The number of boats per location and type and size of those boats (motor or sail, and length), where used to evaluate the potential chemical imprint (Paper II, III).

Total number of boats was used to compare concentrations of antifouling compounds in sediments between sites (Paper II), and the boat sizes were used to estimate how much copper from antifouling paints could potentially leach into the natural harbours (Paper III). Information regarding paint use was used to discuss results in Papers II and III.

3.1.3 Sediment sampling (Paper II)

Sediment was sampled once, at ten locations in the national park (Paper II, Fig. 1). Four of the sampled locations were natural harbours, an additional four were considered leisure boat waterways and the remaining two were small marinas. A

Kajak corer (Fig. 4) was used to get a sediment core with an undisturbed sediment surface, and the top 2 cm of the core were sampled and sent for analysis. Several cores were taken at each location, to get sufficient amount of material for the analysis. Two cores were pooled for the organotin and metal analysis, two cores were pooled for analysis of diuron and irgarol and material from one core were taken for loss-on-ignition (LOI) analysis (Fig. 4).

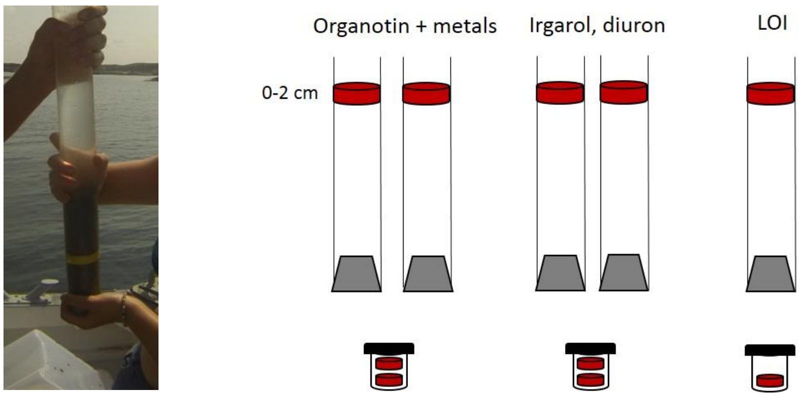

Figure 4. Kajak corer to the left, showing sediment and water column in the collecting tube. Top 2 cm of the cores was pooled from two cores for organotin analysis/metals and irgarol/diuron respectively. Material from one core was used for loss on ignition, LOI.

Sediment was freeze dried prior to all analysis. Organotins, metals and LOI were analysed from all ten locations, and irgarol and diuron were analysed from six locations including two natural harbours, two waterways and two marinas.

3.1.4 Water sampling (Paper III)

Samples were taken in the water column at the same locations as the sediment samples (Paper II). Passive samplers were used to collect the dissolved fraction of metal ions and PAHs. DGT-samplers (Diffusive Gradient in Thin films) were used for metal sampling and SR- (silicone rubber) sheets were used to sample PAHs. The SR sheets were spiked with performance reference compounds (PRCs) that leach at the same rate as other PAHs are collected, and hence the water volume sampled by the membrane can be calculated (see methods section Paper III).
Sampling for both metals and PAHs was done twice, at peak season when maximum number of boats were present, and at post season, when few or no boats were occupying the area.

3.1.5 Marine litter (Paper IV)

Video transect data on litter was obtained during the 2013-2014 investigations, but were also collected in related investigations in 2011, 2012 and 2017. The same video sled system was used, however surveyed locations differ between all the additional years as those data originate from different field studies. Data from 2011, 2012 and 2017 were collected using a forward facing camera, with a 27-degree forward angle, and in the depth range of 0-30 m. Litter data was calculated to items/km^2 and was assigned to litter types in accordance with a protocol used to assess litter (ICES, 2014). Additional information on beach litter from OSPAR reference beaches from the Swedish west coast was downloaded (www.mcsuk.org/ospar) and used in the analysis.

3.1.6 A systematic approach to prioritize among threats

The individual studies described above give information on the potential threat from a given activity. In a real management situation, there are often many threats and a limited budget for actions plans, and resources need to be allocated where they are of best use. The possibility to prioritize among threats is therefore essential. For the aim b) "to analyse what threats pose the highest risk to the conservation values, and actions to alleviate impact", the Open Standards model was used as it;

- can make a prioritizations based on common transparent rules
- can incorporate information of different quality (quantitative and qualitative)

Open Standards

The concept of Open Standards (OS) help to assess and prioritize among threats, as described earlier. It also brings a systematic approach to planning, implementing and monitoring large conservation initiatives.

It divides a conservation project into 5 different parts;

1. Conceptualize project. Here you list; the initial project team; define scope, vision and target; **identify critical threats**; and make a situation analysis.
2. Plan actions and monitoring. In this step, strategic, monitoring and operational plans are developed.
3. Implement actions and monitoring. A short-term work plan and budget is developed and implemented.
4. Analyse, use, adapt. Data is prepared and analysed. Project plan is adapted based on results.

5. Capture and share learning. In this step, key results and lessons learned are documented. Reports are made to stakeholders and key audiences and evaluations are made and successes and failures can be shared with other project teams.

To rank the different impacts from leisure boats on values in Kosterhavet National Park and subsequently prioritize among them, the threat prioritization sub step from step 1, "Conceptualize project" was used.
In order to **identify the critical threats**, values and threats need to be specified.

Values
Values for the shallower regions (< 30 m) in Kosterhavet National Park (SEPA, 2009) where leisure boating takes place and may affect the environment;

- Shallow soft bottoms (< 30 m)
    - Eelgrass meadows (*Zostera marina*)
    - Blue-mussel banks (*Mytilus edulis*)
    - Horse-mussel banks (*Modiolus modiolus*)
    - Oyster beds (*Ostrea edulis*)
    - Gravel and shell gravel
    - Sand and shell sand
    - Diversity hotspots
- Shallow hard bottoms (< 30 m)
    - Diversity hotspots
- The pelagic
- Fish and shellfish
- Seals and seabird

Three other values are mentioned in the management plan, but they refer to deeper areas;

- Deep soft bottoms (> 30 m)
- Deep hard bottoms (> 30 m)
- Corals

Conservation values (here forth values) chosen for the threat rank assessment in this thesis are **eelgrass meadows, blue-mussel banks and oyster beds**. Soft bottoms are by far the most common habitat in the surveyed area (Paper I) and these three chosen values are all sessile and will therefore be directly affected by threats occurring where they are located.

Threats
Threats are defined as effects from leisure boats studied within the scope of this thesis;

- Anchoring
- Heavy metals
- Booster biocides
- TBT
- PAH
- Litter

Direct threats should be lumped together if they are "caused by the same actor" or "require similar strategies" according to the OS guide. Antifouling compounds will however be evaluated separately, since booster biocides and metal-antifoulants act in different ways, and TBT and heavy metals are separated in time as TBT has been forbidden since the late 1980s.
In paper IV, data on litter from a number of years are assessed. However, to make comparison with other treats more relevant, only the litter found on transects from the 2013-2014 study will be used here in the threat matrix on the three chosen soft bottom values (eelgrass, blue-mussels and oysters).

Prioritizing threats
The threat analysis of Open Standards builds on the concept of risk assessment, but with the ability of the environment to recover added as a third component. Therefore, each combination of value and threat are evaluated separately based on three factors; scope, severity and irreversibility according to the OS model.

Scope
This is the extent of a threat on a value, for instance, how much of the surveyed eelgrass areas in the defined area (Kosterhavet) are subject to a specific threat, such as anchoring. Categories range from low to very high depending on the overlap between threat (anchoring) and value (eelgrass) and can be as follows;

Very high: > 71 % of the locations containing the value experience the threat.
High: 31-70 % of the locations containing the value experience the threat.
Medium: Threat is located in several locations with value, >1 location - 30 % of locations.
Low: Threat is local, one location with value experience threat.

Severity
This factor defines how severe the threat is to the value, e.g. how much damage is done to the value by the threat.

Again, using eelgrass and anchoring as an example;

Very high: Where the threat occurs (anchor), all of the value is destroyed. A bare patch is left where the anchor was deployed. Plow-marks are present as result of dragging the anchor at retrieval and rhizome is damaged.
High: Value is partly destroyed. Some plants are uprooted where anchor was present, but no plow-marks. Rhizome is damaged.
Medium: Plants are damaged where anchor was deployed. Leaves are removed from plants but none are uprooted and rhizome is intact.
Low: Plants are temporarily covered and flattened by anchor, but there is no visible damage to leaves and rhizome.

Scope and **Severity** are then combined to **Magnitude** as follows,

Table 1. Magnitude matrix. Adapted from Open Standards Guidance (CMP, Open Standards 2012).

		Scope			
		Very High	High	Medium	Low
Severity	Very High	VH	H	M	L
	High	H	H	M	L
	Medium	M	**M**	M	L
	Low	L	L	L	L

If **scope** is set to high (H), and **severity** to high (H), the **magnitude** will be high (H);

Magnitude: H * H = H

Severity can bring down the total estimation (Table 1), as even if a scope is very high, if the threat is not severe, it is not judged to have a high impact. But in the example with eelgrass and anchoring, both scope and severity will be high (Appendix A).

The magnitude thus bears a similarity to the standard concepts of risk. However, in the OS system, to achieve a **threat rank** of the threat to the value, irreversibility has to be taken into account.

Irreversibility
This last factor sets a time frame for how reversible the effects of the threat will be, provided that the threat ceases to occur;

Very high: No recovery where the damage occurs within 6 years.
High: Damage is partly recovered (some re-growth) in 6 years where damage occurred.
Medium: Damage is completely recovered, full re-growth of damaged area within 6 years.
Low: Full recovery within one growth season.

Magnitude and **Irreversibility** are then combined in a new matrix;

Table 2. Threat rank matrix. Adapted from Open Standards Guidance (CMP, Open Standards 2012).

		Irreversibility			
		Very High	High	Medium	Low
Magnitude	Very High	VH	VH	VH	H
	High	VH	H	H	M
	Medium	H	M	**M**	L
	Low	M	L	L	L

As **magnitude** was previously determined to be H, a medium (M) **irreversibility** will return a threat rank;

Threat rank: **H * M = H**

The timeframe according to the OS model is generally set to 10 years, here a 6-year time frame was chosen as it is the reporting cycle for the Water Framework Directive (WFD), in which all EU member states strive to achieve good ecological status (GES). The general definition for GES is defined as "The values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions" (Directive 2000/60/EC, Annex V).

The three factor analysis (scope, severity and irreversibility) is made for all combinations of values and threats and the final threat ranks are combined in a matrix where all threats and values are summed up to indicate which threats will have the highest overall impact and which of the values are most sensitive (see Table 3 in main findings).

4 Main findings

Paper I

Mud was found to be the most common bottom substrate in the surveyed areas of Kosterhavet National Park, followed by macrophyte dominated soft substrate. The most common substrate was also where most of the anchor traces were found. When comparing eelgrass density with the different anchoring classes (no-always) between the two studied years it was found that the proportion of 0 % eelgrass cover decreased when anchor pressure was low and increased when anchor pressure was high, which is in line with what to expect if anchoring affects eelgrass density. This was however, not statistically significant. There was a significant correlation between number of bottom anchored boats and anchor traces on soft substrates. No traces was found on hard- or vegetation covered substrates, and it is likely that the method used was unsuitable for investigation of anchoring on these substrates. Anchoring was found to occur in eelgrass, and since there was a significant correlation between anchoring boats and traces on soft vegetation free bottoms, effects of anchoring is probably underestimated. There was also an overlap with bottom anchoring boats and presence of both eelgrass and European oyster, which may be cause for concern.

Paper II

The banned antifouling compound TBT was found in nine out of ten sampled locations. Degradation products were found in relatively low concentrations indicating recent deposit. The concentrations found were significantly above threshold limit of 1.6 µg/kg dw for all location types. Marinas had significantly higher concentrations than natural harbours, but there was no significant difference between marinas and waterways or waterways and natural harbours.
The previously used booster biocides diuron and irgarol were found at all sampled locations, but in the case of diuron, never in concentrations of toxic concern. Irgarol on the other hand had significantly higher concentrations when compared to Norwegian threshold limits for the location type marina.
Copper and cadmium were the only heavy metals found to be above background levels for all locations sampled, but there was no difference between any of the location types.

Paper III

During post season there was a short-term shift in type of PAH, which could be attributed to location type (mainland/marina or archipelago). Archipelago locations had more of the two-ringed PAHs, and near mainland and marinas have less of these and instead more of three- and four-ringed types. The locations were sampled at different times, with the archipelago sampled in April and the other locations in May. One of the archipelago locations was sampled both in April and May and this shift in PAH type also occurred at this location.

The difference in types of PAHs, but also a higher total PAH concentration (especially in marina 2) generated a significant difference between archipelago and the other two types of locations. This difference between types of locations did not occur during peak season.

Surprisingly, there were higher concentrations of heavy metals during post season when compared to peak season. This however, is likely due to heavy biofouling on the membranes during peak season. The pattern seen with PAHs during post season, with higher concentrations in near mainland and marina locations compared to archipelago holds true also for heavy metals, mostly due to high concentrations of zinc.

AA-EQS for Cu was exceeded at 1 location and Zn at 5 locations during post season, however mostly not statistically significant due to large deviation within locations.

Paper IV

We found substantial amounts of litter on the seafloor, approximately 3900 items per km^2. Litter was found in 20 % of the 390 surveyed transects. A large part of the items may be attributed to recreation: (42 %) using a list of recreation indicator items produced by OSPAR, and 51% using a likelihood attribution method. We found larger amounts of items on the seafloor during and after the tourist season, compared to before the tourist season. Litter densities were found to be higher on soft sediments than on hard bottoms, but we did not find a significant correlation with the number of boats anchored in different areas. Most items found on the seafloor were typically heavy items (glass, metal), suggesting that they are of local origin. This is in contrast with what was found on the OSPAR reference beach where the number of items found was higher in spring than in summer or autumn. On the beach only a small part (<7%) of items found were classified as typical recreation-related items using the OSPAR indicator list, while 44-48 % of items were attributed to recreation using the likelihood method, with a higher proportion of recreation-related items found in winter-spring, i.e. outside the tourist season.

Prioritised threats with Open Standards

The results from the different individual investigations I-IV were then compared, using the OS system as described above. Total threat ranks (low-very high) for each value and threat are combined according to a basic rule: 7 L = M, 5 M = H, 3 H = VH (Table 3). At least two of same rank are needed for that value to be confirmed, for instance, ∑threat rank for organotin is 3M and hence the total threat rank is M. The horizontal summary then tells us which threat is most important, or have the highest degree of negative impact on the listed values aka “summary threat rating”. The vertical summary gives information about which of the values are most sensitive, aka “threat status for value” (each individual value and threat analysis are provided in supplementary material, Appendix A).

Table 3. Threat rank matrix from OS analysis.

	Z. marina	*M. edulis*	*O. edulis*	Summary threat rating
Anchoring	H	L	M	**L**
Heavy metals	L	M	M	**M**
Booster biocides	M	L	M	**M**
Organotin	M	M	M	**M**
PAH	L	L	L	**L**
Litter	M	M/L	M	**M**
Threat status for value	**M**	**L**	**H**	

Z. marina, has the highest effect of a single threat (anchoring), but *O.edulis* (having 5 M) will get the highest overall rank and therefore deemed the most threatened value. It should however be noted, that the matrix (Table 3) is not large enough for the 7*5*3-rule to be applied.

5 Discussion - Implications for management

In the management plan of Kosterhavet National Park (SEPA, 2009), a general Open Standard (OS) was conducted. It covers all types of activities and impacts that may affect the values in the national park like eutrophication, litter, dredging and introduction of invasive species. This general OS (here forth abbreviated G-OS) has been done in broad strokes regarding impact on the environments listed on page 17. The OS in this thesis was based on specific impacts (here forth abbreviated S-OS) from a specific category (leisure boats) on specific conservation values (eelgrass, oysters etc.). The conservation values chosen for this OS are indicated in the management plan (SEPA, 2009) as species for which distribution and areal cover should not decrease over time. Considering the vast overlap of the environments in which these values exist and leisure boats visiting the area, there is a risk that the environments are negatively impacted by boat presence. Therefore, the results from this thesis may prove helpful in order to conserve these values according to the management plan.

The impacts studied in this thesis were previously evaluated as follows in the management plan, G-OS;

Table 4. Comparisons between general OS (G-OS) from management plan and specific OS (S-OS) from this thesis.

	General OS (G-OS)		**Specific OS (S-OS)**
	Impact	*Trend*	*Threat rank*
Anchoring	Low	Rising	Low
Antifouling	Low/ Medium	Unchanged	Medium
Two-stroke fuel (PAH)	Medium	Rising	Low
Litter (ocean)	Medium	Unaltered/ Declining	Medium
Litter (beach)	?	Declining	

In the G-OS, anchoring and litter (ocean) is stated as “may have local effects”, and both fuel and antifouling also have the annotation “can at some places and certain times of year have significant impact”.

Effects of **anchoring** on the three chosen values (eelgrass, oysters and blue mussels) based on the S-OS evaluation, is given a low summary threat rating (Table 4) which is consistent with that of the G-OS (Table 4). Studying the effect of anchoring on specific values, however, reveals that although the overall threat is low, the effects on eelgrass is high in the S-OS (Table 3). Although there was no evidence of anchor traces in eelgrass areas, anchor presence was noted (Paper I, Fig. 4a) and there was an overlap in locations with bottom anchoring boats and eelgrass presence.

Growth of eelgrass is dynamic (Olesen & Sand-Jensen, 1994), and a longer time-scale is therefore needed to assess future losses and gains of *Z. marina*. What was notable was that none of the surveyed transects containing eelgrass formed large areas of continuous cover, but all were fragmented.

As fragmentation is a proven effect of anchoring (Ceccherelli et al., 2007, Milazzo et al,. 2004, Montefalcone et al., 2008) and anchoring has been going on for decades in Kosterhavet, the fragmented eelgrass areas surveyed in Paper I may be a result of this.

Anchoring had a medium impact on *O. edulis*, another of the specific values in the S-OS (Table 3). Quantification of *O. edulis* proved difficult from the video transects, but presence was noted (Paper I, Fig. 5b). At one location in the national park (Paper I), the density was > 5 oysters m^{-2}, qualifying them as oyster banks (OSPAR *Ostrea*, 2009), and as bottom anchoring boats also occur in this area (Paper I, Fig. 5b), oysters therefore run the risk for crush injuries. Oysters also have the highest overall threat status for value and is at risk from impact from several leisure boat related sources (Table 3).

Anchoring on soft substrates can result in resuspension of the sediment. Fine particles may then be removed by currents and settle elsewhere, changing the bottom substrate to coarser fractions that remain in the area (Ostendorp et al., 2009). Increased resuspension may also re-introduce toxic compounds bound to sediment particles and in pore waters (see below).

The **sediments** contained measurable concentrations of both old and new **antifouling components**. TBT, irgarol, diuron and heavy metals were found at several locations (Paper II), where they may pose a threat to benthic organisms. Resuspension of sediment make these compounds available to more organisms than in-fauna, and specifically filter feeders are at risk as they ingest particles as well as dissolved fractions.

Impacts of antifouling was considered to be low-medium in the G-OS, with certain places being more affected certain times of year.

Booster biocides, TBT and heavy metals were all given a medium threat rank (Table 3) in the S-OS analysis which again is in line with the G-OS. Finding TBT still present above threshold levels (Paper II, Fig. 3) in the surface sediments is cause for great concern. No evident land based sources are present in the archipelago, and its origin is therefore probably related to leisure boats. The low concentration of degradation products in relation to the parent compound also indicates the deposition was recent.

Finding the booster biocide diuron was surprising as it has not been allowed in antifouling paints sold on the Swedish market, although it has been used in other countries within the EU (Price & Readman). Diuron never exceeded threshold values (Paper II, Fig. 4), and is unlikely to cause negative effects where found. Irgarol however, has been used in Sweden and the compound was found above Norwegian threshold levels for irgarol in sediments.

Metals in the sampled sediments mostly did not deviate from background concentration (Paper II, Fig. 2) with the exception of Cu and Cd. These two compounds were significantly above background concentrations at all locations.

All sampled antifouling compounds were found to overlap with the chosen values, and therefore an effect cannot be ruled out.

Both **anchoring** and **antifouling** is in this thesis suggested to impact soft bottom substrates and their associated flora and fauna.

Seafloor integrity is part of the Marine Strategy Framework Directive (MSFD) (descriptor 6, D6), and as two of the main pressures are *mooring* and *pollution* (http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-6/index_en.htm) it is important to evaluate the effects of leisure boats.

The two criteria to look at in D6 are *physical damage* and *condition of the benthic community*. The first criterion aims at pointing out the most sensitive substrate with regard to physical damage. Abundance, areal extent and biomass should be known and the extent to which substrate types are affected by physical damage. This was partly attempted in Papers I and II, as anchoring on different substrates and their distribution was mapped and presence and concentration of antifouling compounds was assessed. The second criterion deals with the condition of the benthos. This is not addressed within the scope of this thesis, but compounds have been found that may have serious effects on the benthic community.

As for the **antifouling compounds found in the water column**, heavy metals, the AA-EQS for Cu and Zn were exceeded at post season (Paper III, Fig. 5). The addition of Cu and Zn are likely to be much higher during peak-season when boats are present and the AA-EQSs are therefore likely to be exceeded at several locations during the summer. This may affect organisms that inhabit the pelagic, and national environmental goals as well as good ecologic status set by the WFD will not be reached if this continues. The DGT membranes only samples dissolved metal ions and not those that are complex bound or bound to particles, and the overall concentration of metal ions is therefore likely to be higher in the water column. As with the benthos, an actual response in the environment has not been evaluated, but thresholds that were set to avoid a negative impact (AA-EQS) are highly likely to be exceeded during the peak boating season in Kosterhavet.

Fuel, in the form of **two-stroke fuel** was considered to have a medium impact, but rising trend in the G-OS analysis.

PAHs, being components of fuel, were evaluated in the S-OS analysis, but only for the water column. As concentrations were much lower than what is required to be considered toxic, summary threat rating for the analysed values was low (Table 3). PAHs are more likely to be bound to particles and only truly dissolved fractions are taken up by the SR-membranes, and the total concentration is therefore underestimated. One of the PAHs (benzo(g,h,i)perylene) was found close to its individual MAC-EQS threshold and this particular PAHs is considered very toxic to aquatic life. As PAHs have low water solubility they are likely to exist as droplets or bound to particles. Filter feeders may be at risk as they can ingest both particle-bound and dissolved fractions and may therefore be exposed to higher concentrations. This is also true for benthic organisms as PAHs are likely to end up in the sediment.

Exceedance of individual EQSs and threshold values for several different compounds have been shown in this thesis (Paper II, III). The compounds that do not exceed EQS, should however also be given consideration. Combination effects of chemicals are well known, as mixtures of compounds present below their individual effect levels yield an effect when combined (Backhaus et al., 2011), and many toxic substances are known to co-occur in nature (Gustavsson et al., 2017). Yet, when thresholds are set, only a compounds individual toxicity is considered although many compounds are known to interact.

Litter was listed to have medium or unknown impact for ocean and land based litter respectively, but likely to decline in the G-OS. As only the data from 2013-14 was used for the litter evaluation, effects of this may have been underestimated in the S-OS where it was given a medium threat status, agreeing with the G-OS.
42 – 51 % of the seafloor litter are considered to originate from recreational activities (Paper IV), which suggest a quite large input from tourism. This may impact the benthos depending on the type of the litter, and may also remain on site for an unforeseeable amount of time. With regards to the beach litter, fewer items were considered recreation related, and thus suggest that the main input of this type of litter come from other activities in the national park (e.g. shipping or commercial fishing etc.) or are brought to the area from land or other sea areas by currents.

To conclude; although the specific OS, which utilises the results from the studies in this thesis, often agrees with the general OS, the G-OS lacks depth due to its general nature. Therefore, it fails to register impacts that may be severe on specific values. Hence, more specific evaluations may be needed for individual values as not to miss impacts that could have detrimental effects on the environment we intended to conserve.

Information types and needs for management

There is often a mismatch between the needs of environmental managers and the type of investigations and data produced by scientific investigations. The suspected threats to the environment may require studies of questions/phenomena that do not have a great scientific height, but which have large actual consequences for the local environment. While science commonly strive for strict protocols and cautious interpretation of generic studies, managers are often required to take immediate action and thus need "the best available information", preferably specific for the local setting. The studies forming this thesis are made in the junction between these different needs. I study several partly unrelated issues (physical disturbance, marine litter, toxic substances) but with a common potential root in the same human activity, recreational boating. Some of the studies use established protocols and experimental designs, while others use new or relatively untried methods, and combines several investigations with different designs. There is a certain similarity in this to the situation that managers are commonly confronted with.

Several studies, several potential threats, several formulations of harm. How can a manager choose where to focus actions? How can a scientist give advice to do this but not that? To make sense of this, I choose to use two different management models to link my scientific studies to the need of managers. The DPSIR model helps to relate different types on information (e.g, visitor frequency, the number of boats, the concentration of chemicals, the frequency of anchor traces, mode of anchoring) and show how these form parts of an environmental management problem. In my view, the DPSIR framework helps the manager and the scientist to design both management actions and monitoring programmes to evaluate the effects of such actions.

However, the DPSIR framework do not solve the problem of when to act and when not to act, or to prioritize among actions. As stated previously in this thesis, OS allows a systematic approach to assess connections in the DPSIR framework, especially in the links between pressures to states and from states to impacts, using many types of information available (scientific and otherwise). Ideally all parts in these links should be established for each combination of threat and value, but this is commonly not the case. This is not always the case in the studies forming this thesis either. Let us look at some of these links, and what information I have been able to add.

I did detect anchor traces and, for unvegetated bottom substrates, also found a link to number of boats. Hence pressure (anchoring boats), is linked to state (anchor traces) which is also damage (impact) on the bottom as cavities and drag marks are created. For this combination of pressure-value the links seem to hold. For eelgrass we didn't find this link- notably we could not find any impact in our study (Paper I).

Measuring eelgrass growth is complicated and requires monitoring over time, which may be a luxury that managers cannot afford. We instead propose that managers measure the pressure, e.g., the number of anchored boats in locations with known occurrence of eelgrass. This means that we temporarily accept a direct link from pressures to impact. The motivation could be that since the pressure-state-impact chain is established for anchoring on unvegetated bottoms we suggest to instead measure pressure (counting bottom anchoring boats is quite easy and cost efficient) and assume impact on eelgrass.

Chemical monitoring is different, as it requires considerable resources to evaluate the state and the impact. Methods for assessing the state exist, and has been used in papers II and III, but they are costly and thus the geographical and temporal resolution will be low. The impact can be assessed in controlled laboratory studies, but probably not in the field. This is problematic as there is no direct link between boats and a specific site, although presence of boats do increase concentrations of pollutants in a general area. Here a link could be drawn from pressure to response (see next section, "suggestions and future studies").

For litter, assessing the state is comparatively straightforward, at least in regard to macroscopic items. There may however be more difficult to monitor pressure: Litter may have both diffuse and direct sources. Heavier objects made of glass and metal often sink to the bottom directly while plastic objects may drift away and be deposited elsewhere. Litter may also have sources far from the investigated area as many objects drift with currents from shipping lanes etc. As with chemical pollution, links may be drawn from pressure or state, to response.

The diffuse sources, chemical pollution and litter, may have their solutions outside the realm of the national park. They can be addressed locally but since sources are not just local, and for litter they can be global, response must also be in the form of legislation and decisions on an international level.

The anchor study did not find a direct causal link between anchor pressure and eelgrass distribution, probably mostly due to an unsuitable method. The litter survey uses a compilation of data sets with different designs. This weakens the results and affects the conclusions that can be drawn from them. However, scientific studies are often conducted independent of each other and together create a larger dataset, even though there are monitoring studies carried out in a standardised fashion. Managers don't have the luxury to wait for a perfectly designed study with an appropriate time scale (even if such a study would be financed) but have to rely on the material at hand. Available data, albeit not perfectly designed should be used as long as the analyses of that data are interpreted with caution.

I have found that applying both the concepts of DPSIR and the Open standards method help to assess to what extent the results from my studies can be used to inform management, and what parts are missing and need to be developed further. This is why I feel results from this thesis, if data is interpreted cautiously, could be of help to form a basis for decisions regarding conservation efforts in Kosterhavet National Park.

6 Suggestions and future studies

As stated earlier, the problems with using illegal antifouling paint need to be dealt with, and as legislation already exists, it needs to be enforced. However, my suggestion is to put effort into information. People need to understand that this is still an issue, and possibly a serious one at that.
Many of the problems found in the studies in this thesis can be remedied with information, as it is a change in behaviour that is necessary.
The facilities for alongside anchoring already exist in several places in the national park as permanent mooring wedges to attach to occur in many of the natural harbours. More may be necessary, and where alongside mooring is not possible, other solutions should be considered. Adding anchor free zones in areas where sensitive species overlap with bottom anchoring boats is here considered necessary. The concept of zones already exists in the park, so this will simply be an addition for the most sensitive areas.

As for antifouling, boat washes can be made available in the area, thereby scrubbing the boat clean of fouling organisms instead of painting with biocidal paint. As for PAHs, two of the closest marine service stations in the Koster area do not provide alkylated fuel. It is available as cans in Strömstad, but not on tap at the stations, which makes it difficult to choose the more environmentally friendly option. Four-stroke engines with alkylated fuel is the best combination with regards to minimizing release of PAHs, but a reduction in PAHs also occur with alkylated fuel in two-stroke engines and this type of fuel should be made more available in the area.

With litter, much may be accidental as item fall over board, but surely not all. An exhibition at the Naturum, showing litter found on the seafloor may increase awareness in the visitors. With regards to beach litter, much of the items seem to be out of scope for management when considering pre-emptive measures as items may not originate in the national park. The current beach cleaning activities is one active local measure that should be continued. Internationally there are many suggested methods to also clean the water column and the seafloor from litter, but the environmental effects of such methods are not yet evaluated.

As for future studies, apart from monitoring anchoring effects on sensitive species, the shallow soft bottoms in Kosterhavet are not the only areas where pollutants can accumulate and have an impact. The deeper areas, the true accumulation bottoms that also contain unique species, may also be accumulating toxic substances. But to what extent? And are they exerting pressure on the organisms?

7 Summary

The studies that form the basis for this thesis show that leisure boats, while being an essential part of the recreational use of Kosterhavet National Park, may also negatively impact environmental conservation values. My studies show that leisure boats can impact the environment in Kosterhavet National Park in several ways.

Drag-marks and cavities from anchors occurred in several habitats. This suggest that anchoring may injure bivalves such as mussels and oysters, damage eelgrass and potentially change the bottom substrate from fine fractions to coarser material.

Antifouling paints leaching from boat hulls occurred in high enough concentrations to potentially impact biota, and compounds from antifouling paint in the sediments may also have an effect. TBT was still found in surface layers, and the concentrations are higher than threshold levels set by the Agency for Water Management. Through resuspension, both TBT and heavy metals like copper in the sediment may be re-introduced to the water column, especially the water directly overlying the seafloor.

PAHs in the water column did not exceed their individual EQS values, but PAHs have low water solubility and will more likely be associated with particles. Particle bound PAH was however not measured in my investigations, nor was its presence in sediments.

Litter on the seafloor was found in 20% of the surveyed transects. 42-51 % of the seafloor litter is likely to originate from recreational activities, which suggest a quite large input from tourism. This may impact the benthos depending on the type of the litter, and may also remain on site for an unforeseeable amount of time. With regards to the beach litter, 7-48 % of items (depending on source allocation method) were considered recreation related, but with higher amounts outside the main tourist season. This suggest that the main input of litter on beaches is from other activities in the national park (e.g. shipping or commercial fishing etc.) or are brought to the area from land or other sea areas by currents.

One suggested approach to manage several of the negative environmental effects of leisure boat related impact is information to the public. A behavioural change is needed as illegal paints is still used. Increasing the amount of boats that moor alongside a cliff as opposed to with a bottom anchor, and a shift to a different, less polluting fuel source are other suggestions that can come about with a change in visitor behaviour.

Creating anchor free zones where the use of bottom anchor is not allowed, to protect sensitive values like eelgrass and European oyster and provide mooring structures where alongside mooring is not applicable are other management suggestions.

Populärvetenskaplig sammanfattning

Kosterhavets nationalpark är Sveriges första marina nationalpark, och ett mycket populärt resmål för både svenska och utländska besökare. Ungefär en halv miljon människor uppskattas besöka området årligen, och då främst sommartid. Många besökare kommer i egen båt för att bl.a. kunna lägga till i de många naturhamnarna i nationalparkens skärgård.

Merparten av besökarna förtöjer med ett ankare mot botten, vilket kan påverka de djur och växter som lever där. Ålgräs har rötter som ligger nedgrävda i bottnarna och dessa kan kapas, och ålgräsplantor lossna när ankaret tas upp. Ostron är en annan art som lever på botten och som kan skadas av ankare. Om ankare faller på dem kan de få krosskador och bitar kan lossna från deras skal. Båda dessa arter anses vara extra skyddsvärda då de i Europa minskat kraftigt i utbredning och försvunnit från vissa platser. Det står också inskrivet i nationalparkens skötselplan att dessa arters utbredning inte långsiktigt får minska i Kosterhavet, så det är viktigt att undvika påverkan av dem.

Båtar kan påverka miljön även på andra sätt. Båtbottenfärger läcker främst tungmetaller för att undvika påväxt på båtbottnarna, och bensindrivna motorer läcker bränsle. Den mest kända ingrediensen från båtbottenfärger man brukar prata om är TBT, tributyltenn. Den förbjöds i slutet av 80-talet i Sverige för användning på fritidsbåtar, men fortfarande hittas den i ytskiktet på havsbottnarna vilket tyder på att den fortfarande används. TBT är mycket giftig för speciellt snäckor och musslor, som blir missbildade och får svårt att reproducera sig. TBT bryts också ner väldigt långsamt och stannar därför kvar länge där det släpps ut och kan påverka under lång tid. Idag används främst koppar i de vanligaste båtbottenfärgerna. Koppar är en livsnödvändig metall för snäckor och tång såväl som oss människor, men i för höga halter kan det få negativa konsekvenser. Om många båtar ligger förtöjda på samma ställe och läcker koppar från båtbottnarna, och vattnet inte blandas om ordentligt så kopparen späds ut, skulle halterna av koppar kunna bli högre än bestämda gränsvärden. Dessa gränsvärden är satta för att skydda livet i havet, och om de skulle överskridas kan en del organismer påverkas negativt.

Avgaser och bränsleläckage innehåller s.k. PAHer, polycycliska aromatiska kolväten. De är sammansatta av två eller flera bensen-ringar (ringformade kolvätemolekyler) varav en del av dem kan vara bl.a. cancerogena.

Friluftslivet i stort kan också bidra med ökade mängder skräp, där en del säkert är omedvetet tillfört då det ramlar överbord. Beroende på typen av skräp kommer det att transporteras till olika platser. Tunga saker som glasflaskor tenderar att sjunka till botten direkt medan lättare plastobjekt kan flyta längre och antingen sjunka till botten en bit ifrån där det föll i eller flyta tills det når land och spolas upp på en strand.

I denna avhandling studeras dessa olika delar; ankring, båtbottenfärger, PAHer och skräp och en rangordning av deras grad av påverkan på bevarandevärden från nationalparkens skötselplan utförs. Bevarandevärdena som valts ut är de tidigare nämnda inhemska ostronen och ålgräs, men också blåmusslor då dessa nämns specifikt i skötselplanen. Att kunna rangordna på det här sättet kan underlätta när åtgärder ska sättas in. Då kan man se var den största påverkan sker och vilka de allvarligaste hoten överlag är och på sätt använda sina resurser där de behövs mest.

Besöksdata har också samlats in, där antalet båtar i skärgården räknats, men också deras storlek och ankringssätt har också noterats. Båtar kan ankra på olika sätt, de vanligaste sätten i Kosterhavet har varit "längs med", då ankring sker längs en klippvägg vilket medför att ankare inte används, eller med förtöjning med fören mot en klippa och ett bottenankare från aktern. Intervjuer med besökare har också utförts, främst för att få en bild av vilka de vanligaste båtbottenfärgerna som används är.

Resultaten från när alla studerade påverkansfaktorer lagts samman visar att den enskilt största påverkan är ankring på ålgräs, men de sammanlagda effekterna av ankring, båtbottenfärger, PAHer och skräp gör att det inhemska ostronet bedöms vara mest påverkat.

Med hjälp av denna information kan nationalparksförvaltningen agera för att minska påverkan på dessa arter. De kan t.ex. skapa ankringsfria zoner, där bottenankring inte är tillåtet, för att undvika krosskador på ostron och uppslitna ålgräsplantor. Man kan också satsa på information gällande t.ex. båtbottenfärger, ankring och bränsle så att besökarna kan göra mer miljövänliga val. Att byta bränsle från vanlig- till alkylatbensin t.ex. minskar utsläppen av PAHer med upp till 90 %.

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Appendix A

Open standards, value – threat combinations

<u>COMBINATION:</u> *Zostera marina* * anchoring

Scope: High (H)
60 % of surveyed locations with value (*Z. marina*) in Kosterhavet national park are also subject to bottom anchoring boats.

Categories
Very High: Threat exists at > 71 % of locations with value
High: Threat exist at 31-70 % of locations with value
Medium: Threat exist in several locations (>1 location to 30 % of locations)
Low: Threat is local

Severity: High (H)
Impact not proven with camera sled method, but anchors have been seen in eelgrass habitats and plow marks and pits were seen on soft unvegetated substrates. Since the majority of anchors used in area are of claw and grappnel type that dig into substrate, they will damage rhizome when anchor is retrieved.

Categories
Very High: Where threat occur, value is destroyed. A bare patch is left were anchor was deployed, plow marks are present and rhizome is damaged.
High: Value is partly destroyed. Some plants are uprooted where anchor was present, no plowmarks present but rhizome is damaged.
Medium: Plants are damaged where anchor was deployed, leaves are removed but rhizome is intact.
Low: Plants are temporarily covered and flattened by anchor, but no visible damage to leaves and rhizome.

Magnitude: H * H = H

Irreversibility: M
Z. marina has an average rhizome growth of about 16 cm / year (Olesen & Sand-Jensen 1994). Anchors used in area affect a larger area than 16 cm and hence irreversibility is set to medium.

Categories
Very High: No recovery for 6 years (where damage occurred).

High: Damage is partly recovered in 6 years from when damage occurred. Some regrowth.
Medium: Damage is completely recovered, full regrowth in 6 years.
Low: Full recovery within a growth season.

Threat rank : H * M = H

<u>COMBINATION:</u> *Z. marina* * heavy metals

Scope: H
Heavy metals exist throughout the national park, both in sediment and water. It is above background levels, and ERL (effect range low) for sediments, meaning there is potential for effect. Water concentrations was only in few instances above EQS for copper and zinc but as the overlap of threat and value is hig, scope is set to high. Worth noting; water concentrations are only dissolved fraction, total concentration is likely higher.

Categories same as for anchoring.

Severity: L
The concentrations at which *Z. marina* is affected by heavy metals are higher than the ones measured in Kosterhavet. Growth can be inhibited at 0.32 mg/L Cu, and 10 mg /L Hg, and visible effects (blackening of plant leaves) can be seen within a few days (Lyngby & Brix 1984). Decreased photosynthesis have been seen after 10 h exposure to concentrations 0.1-1 mg/L for Cu and Zn (Macinnis-Ng & Ralph, 2002). Sublethal effects from chronic exposure cannot be ruled out but that requires further study.

Categories
Very High: All plants affected by threat die
High: Some individuals die
Medium: Sublethal effects, growth is affected.
Low: Negligible effects

Magnitude: H * L = L

Irreversibility: L or M
Metals in sediments can be available for several years through re-suspension and leaching into pore waters. However, MarLIN (http://www.marlin.ac.uk/species/detail/1282) states species is not sensitive to heavy metals and recoverability is very high if exposed to contamination.

Same categories as anchoring.

Threat rank: L * L (M) = L
Regardless of irreversibility is L or M or even H, threat rank will be Low.

<u>COMBINATION:</u> *Z. marina* * booster biocides

Scope: H
Biocides are present in sediment of two sampled locations where value is also present (33 %).

Same categories as heavy metals.

Severity: M
The concentrations in sediments exceed limits set by Miljødirektoratet in Norway for irgarol, which implies ecological effects may be occuring. Irgarol is an s-triazine which is primarily taken up by roots in land-based plants which zostera is related to and therefore this pathway for uptake is likely. Atrazine, another s-triazine can cause severe growth inhibition and mortality in *Z. marina* when exposure is 100 ng/L over 21 days (Davison & Hughes, 1998), and low concentrations of irgarol and diuron, 0.5 and 1.0 μg/l respectively, can initiate decrease in Fv:Fm which indicate that photosystem II affected and not fully functional (Chesworth et al. 2004). Sublethal effects are considered possible and severity set to medium.

Same categories as heavy metals.

Magnitude: H * M = M

Irreversibility: H
The half-life of irgarol is 200 days, but can remain in sediment for > 10 years (Ranke et al. 2002)
As biocides can be present for a long time and continue to leach, effects may continue for more than one year and irreversibility therefore set to high.

Threat rank: M * H = M

<u>COMBINATION:</u> *Z. marina* * TBT

Scope: M

TBT occurred in 20 % of sampled locations where *Z. marina* was present. Scope is therefore medium.

Categories same as before.

Severity: M
Photosynthetic activity and relative growth rate in *Ruppia maritima* was affected by similar sediment concentrations as those measured in Kosterhavet (Jensen et al. 2004), and sub-lethal effects cannot be ruled out and severity is set to medium.

Categories same as before.

Magnitude: M * M = M
If scope set to high as TBT is likely to occur in more locations where *Z. marina* is present, magnitude is the same.

Irreversibility: H
The half-life and residence time of TBT are both extensive and the compound will remain where deposited for a long time. Irreversibility set to high.

Threat rank: M * H = M

<u>COMBINATION:</u> *Z. marina* * PAH

Scope: H
PAHs were detected at all sampled locations, in the water column. PAHs in sediments were not measured and cannot be assessed. The concentrations in the water column were only in one instance close to EQS, but as presence of PAH was detected everywhere it was sampled, scope is considered high.

Categories same as before.

Severity: L
No or negligible effects of PAHs on *Z. marina*. High levels, or oil spill can affect by smothering which will have adverse effects but that is not the case here.

Same categories like before.

Magnitude: H * L = L

Irreversibility: L

PAHs have low solubility in water, and will not remain if threat ceases to occur. Will be associated with particles and sediment.
PAHs in sediment can be persistent, but as this is not measured it cannot be assessed.

Threat rank: L * L = L

Combination: *Z. marina* * litter

Scope: H
62 % of all locations with zostera also have litter

Severity: L (if object is small)
H (if object is large, like a plastic sheet)

Magnitude: H * L = L
H* H = H

Irreversibility: L (if object is large plastic, it is likely to be swept away)
VH (smaller plastic, metal and glass objects will remain for a long time)

Threat rank: L * VH = M
H * L = M

COMBINATION: *Mytilus edulis* * anchoring

Scope: Very High
Only three locations in the area have the value present, however this is modelled data and not visible inspection. All locations are subject to anchoring and scope is therefore very high.

Severity: M
As anchoring is a direct type of damage as opposed to chemicals, the anchor need to land directly at the value to inflict damage. If an anchor lands directly on mussels, they are likely to get crush-injuries but not necessarily die.

Magnitude: VH * M = M

Irreversibility: L

Larval recruitment to area is likely, and annual recruitment can give a rapid recovery. Larsen & Risgård 2016, saw newly settled mussels in May had grown to 30 mm in November. Not considered sensitive to abrasion according to MarLIN (http://www.marlin.ac.uk/species/detail/1421).

Threat rank: M * L = L

<u>COMBINATION</u>: *Mytilus edulis* * heavy metals

Scope: H
None of the locations with modelled mussels had heavy metal measurements. However, as heavy metals where present above background levels in all sampled sediments (Cu Cd) and both Cu and Zn did exceed MAC-EQS during post season (and is therefore likely to exceed at additional locations where boats are present during peak season), heavy metals are likely to be present at all these locations since they all experience boat presence. Scope is conservatively set to high.

Severity: M
5.8 µg/L Cu can lead to abnormal larval development in *M. edulis* larvae (Martin 1981) and adult bivalve mortality can occur at exposure to 1-10 µg/L Cu (Crompton, T.R. 2007) The highest post season concentration of Cu was 4,7 µg/L. Since it is reasonable to believe that peak season concentrations are higher due to the presence of boats leaching antifouling paint, and *M. edulis* have two larval spawning periods (one in late May and a second one in August-September) it is not unreasonable to assume that there may be abnormal larval development as larvae are likely to overlap with boat presence. Poorly flushed locations may temporarily experience heightened Cu concentrations when boat number is high which may also affect the adult mussels. The measured concentrations are also only dissolved fraction and total concentration available for filter feeders are likely to be higher. Severity is set to medium.

Magnitude: H * M = M

Irreversibility: H
Water concentrations of heavy metals will decrease if threat stops but resuspended heavy metals may generate high enough concentrations for negative effects. Hill et al. (2009) found water concentrations of 7-8 µg/L from resuspended sediments with 55 µg/kg dw Cu (concentrations in this range exist in Kosterhavet, Paper II).

Threat rank: M * H = M

COMBINATION: *Mytilus edulis* * booster biocides

Scope: M
Biocides were not sampled at any of the locations with modelled *M. edulis*. Irgarol, however were detected at all sites it was sampled for. Two of the locations with *M. edulis* are fairly close to two locations where Irgarol were detected. Scope is set to medium.

Severity: L
As there is distance to the sampled locations, severity is considered to be low. Most molluscs also seem to be quite unsensitive to booster biocides. Mussels have been reported to have reduced growth and mortalities from 1-10 µg/L of Irgarol (Finnegan et al. 2009) (samped sediment 0,9 µg/kg at the most). Acute toxicity is at mg/L, and chronic can be above 0.1 µg/L.

Magnitude: M * L = L

Irreversibility: H
Due too long half-life in sediment, irreversibility is set to high.
Threat rank: L * H = L

COMBINATION: *M. edulis* * TBT

Scope: M
None of locations with modelled *M. edulis* were sampled for TBT. But two locations are fairly close and TBT was found in 9 out of 10 locations sampled. Thus likely to be present but scope is conservatively set to medium.

Severity: M
Concentrations of 0.5 µg/L can affect adult mussels (Hagger et al. 2005) and haemocyte function was affected after 4 days exposure to 1 ng/L (St Jean et al., 2002 MEPS). Resuspended sediment can be directly ingested by filter feeders and they may be exposed to concentrations causing sublethal effects. Severity is therefore set to medium.

Magnitude: M * M = M

Irreversibility: H
As TBT is highly persistent in sediments, threat will remain and may be resuspended for a long period of time.

Threat rank: M

COMBINATION: *M. edulis* * PAH

Scope: H
PAHs were detected at all sampled locations, in the water column. PAHs in sediments were not measured and cannot be assessed. The concentrations in the water column were only in one instance close to EQS, but as presence of PAH was detected everywhere it was sampled, scope is considered high.

Severity: L
Immuno-response in *Cerastoderma edule* and *Mytilus edulis* occur with 50-400 μg/L phenanthrene and death in *C. edule* and *Enses silique* occur at 400 μg/L (Wootton et al, 2003). Mussels seem quite insensitive to PAHs.

Magnitude: H * L = L

Irreversibility: L to M
Water concentrations will be diluted between seasons but addition could be made through resuspension of sediment as PAH tends to bind to particles.

Threat rank: L * L (M) = L
Threat rank will be low regardless of irreversibility is low or medium.

COMBINATION: *M. edulis* * litter

Scope: M
3 locations of modelled mussel presence contain litter, several more locations of modelled mussels do not have litter present.

Severity: L (if object is small)
H (if object is large, like a plastic sheet)

Magnitude: M * L = L
M* H = M

Irreversibility: L (if object is large plastic, it is likely to be swept away)

VH (smaller plastic, metal and glass objects will remain for a long time)

Threat rank: L * VH = M
M * L = L

<u>COMBINATION</u>: *Ostrea edulis* * anchoring

Scope: M
18 locations were modelled to have *O. edulis*. All these have anchoring boats. However, eight of these 18 have bottom documentation from video transects. 2/8 have confirmed oyster presence. Hence 25 % can be extrapolated to contain oysters and scope in set to medium.

Severity: H
As with mussels, anchors need to land directly on the organism for damage to occur. Some of the locations are heavy boated and this is not unlikely. Oysters can be sensitive to siltation, especially the newly settled spat. They live close to the bottom, and are therefore more flat than musselbeds and more susceptible to effects of siltation. They also may experience reduced growth as an effect of cloudy water(http://www.marlin.ac.uk/species/detail/1146). MarLIN also list specie as highly sensitive to abrasion.

Magnitude: M * H = M

Irreversibilty: H
Larvae is spawned once or twice per season, and growth is rapid the first 18 months, but oyster recruitment has been slow in Swedish waters, and recruitment varies. Estimation of up to five years for good recruitment.

Threat rank: M * H = M

<u>COMBINATION</u>: *Ostrea edulis* * heavy metals

Scope: H
Three of locations with modelled oyster have measurements of heavy metals. All of them are above background values for sediment but not above EQS in water during post season. This is however likely to change during peak season and several locations are likely to exceed EQS for Cu and Zn in water. Heavy metals were also found everywhere when sampled.

Severity: M
Crassostrea gigas, another oyster had abnormal larval development at 5.3 µg/L Cu (Martin et al 1981). Sublethal effects may exist on larvae.

Magnitude: H * M = M

Irreversibility: H
See *Mytilus edulis.*

Threat rank: M * H = M

<u>COMBINATION</u>: *Ostrea edulis* * booster biocides

Scope: M
All sampled sediment contained booster biocides, only one location was directly were oysters were modelled to be present. Others were sampled in the vicinity of modelled oyster and it is therefore likely that more than one site with *O. edulis* overlap with booster biocide presence.

Severity: M
Embryotoxicity can occur in as low doses as 0.01 and 0.04 µg/L fir irgarol and diuron respectively in the pacific oyster, *Crassostrea gigas* (Mai et al. 2012). Diuron is likely to be associated with the water phase, and since it is present in the sediment it is not unlikely that it is also present in the water column.
If compounds leach from sediments, oysters may experience sublethal effects.

Magnitude: M * M = M

Irreversibility: H
The long half-life of biocides, irgarol up to 200 days and longer associated with paint flakes and sediment make it likely for these biocides to remain in the area. Irreversibility is set to medium.

Threat rank: M * H = M

<u>COMBINATION</u>: *Ostrea edulis* * TBT

Scope: H
TBT was found in all but one sampled location. Three of these overlapped with modelled oyster presence, and an additional four locations with TBT presence were in the vicinity of modelled oyster habitats. Hence 7 out of 10 are likely to be exposed.

Severity: M
Effects of TBT are sublethal, with reproductive difficulties as a consequence since it causes imposex, a masculinization of female bivalves and gastropods. Population decline as a result of low or no reproduction has been seen historically (Alzieu et al. 1986).

Magnitude: H * M = M

Irreversibilty: H
TBT is a highly persistent compound in sediments, and re-suspension may occur for many years. As *O. edulis* is a filter feeder it will ingest particle-associated TBT and not just dissolved fractions and are thus likely to be exposed for as long as TBT containing sediment is re-suspended. TBT will be degraded over time and levels may not be high enough to cause effect but as it is toxic is small doses, irreversibility is set to high.

Threat rank: M * H = M

<u>COMBINATION</u>: *Ostrea edulis* * PAH

Scope: H
See *Mytilus edulis.*

Severity: L
PAHs can accumulate in bivalve tissue and affect growth rates in juveniles and adults. This however occur at much higher concentrations than measured (embryo toxicity in C. gigas on the scale of PAH in sediment of g/L, Geffard et al 2003). Sediment concentrations are not measured. Previous study by Eklund et al 2016, while sampling in the area showed concentrations in sediments of 0.01-0.2 mg/kg dw of ∑16PAH.

Magnitude: H * L = L

Irreversibility: L
Sediment re-suspension may expose individuals to PAHs, but concentration in sediments are not measured.

Threat rank: L * L = L

COMBINATION: *Ostrea edulis* * litter

Scope: VH
All location with confirmed oyster presence as well as some modelled contained litter.

Severity: L (if object is small)
H (if object is large, like a plastic sheet)

Magnitude: VH * L = L
VH* H = H

Irreversibility: L (if object is large plastic, it is likely to be swept away)
VH (smaller plastic, metal and glass objects will remain for a long time)

Threat rank: L * VH = M
H * L = M

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