Ocean & Coastal Management 148 (2017) 182–194

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

The effects of small-scale coastal development on the eelgrass (*Zostera marina* L.) distribution along the Swedish west coast – Ecological impact and legal challenges

Louise Eriander [a,*], Kristjan Laas [b], Per Bergström [a], Lena Gipperth [b], Per-Olav Moksnes [a]

[a] Department of Marine Sciences, University of Gothenburg, S-40530 Gothenburg, Sweden
[b] Department of Law, University of Gothenburg, S-405 30 Gothenburg, Sweden

ARTICLE INFO

Article history:
Received 7 March 2017
Received in revised form
6 July 2017
Accepted 12 August 2017
Available online 23 August 2017

Keywords:
Eelgrass
Small-scale development
Ecological impact
Large-scale effects
Legal challenges

ABSTRACT

Anthropogenic impacts on coastal areas have led to an increased degradation of marine environments globally. Eelgrass ecosystems are particularly susceptible to human induced stressors as they are sensitive to low light conditions and usually grow in shallow protected areas where pressure from coastal development is high. The extensive decline in coverage of eelgrass along the Swedish Northwest coast since the 1980s has largely been attributed to the effects of coastal eutrophication and overfishing. However, the impact on eelgrass from small-scale coastal development (docks and marinas) has never been investigated in this area. The aim of this study was to assess the local and large-scale effect of shading by docks and marinas on eelgrass habitats along the Swedish NW coast and to investigate the decision process behind small-scale exploitation to identify problems with the current legislation, which allows for continued exploitation of eelgrass. Through field assessments of eelgrass around docks and analysis of available data on eelgrass and dock distribution along the coast, the present study demonstrates that shading from docks reduced eelgrass coverage with on average 42–64% under and adjacent to the docks, and that floating docks affected larger areas and caused a much stronger reduction in eelgrass coverage (up to 100% loss) compared to docks elevated on poles (up to 70% reduction in coverage). The total eelgrass area negatively affected by docks and marinas along the NW coast was estimated to approximately 480 ha, an area corresponding to over 7% of the present areal coverage of eelgrass in the region. The analysis of decisions for dock construction showed that eelgrass was generally not assessed or considered in the decision process and that 69–88% of the applications were approved also in areas where eelgrass was present. Furthermore, marine protected areas only marginally reduced the approval of applications in eelgrass habitats. The continued small-scale development along the Swedish NW coast constitutes a significant threat to the already decimated coverage of eelgrass along the coast and changes in the management practices are needed in order to achieve both national and international goals on environmental status.

1. Introduction

Marine coastal ecosystems have suffered extensive damage globally due to anthropogenic impacts (Lotze et al., 2006; Halpern et al., 2008). Some of the key factors behind this deterioration are overexploitation of marine resources, increased discharge of nutrients and sediment to coastal waters, and coastal development (Lotze et al., 2006). These factors can all be related to the increasing human population, of which a majority work within or inhabit coastal areas (Vitousek et al., 1997).

Seagrasses constitute one important coastal ecosystem that has suffered extensive degradation and loss globally (Green and Short, 2003; Lotze et al., 2006; Waycott et al., 2009). Human development activities within coastal areas together with negative effects on water quality from nutrient and sediment pollution are considered two of the major reasons for the global decline (Short and Wyllie-Escheverria, 1996; Orth et al., 2006). Coastal development structures such as docks and marinas can have a significant impact on seagrass ecosystems. Building of these structures is often associated with dredging activities that involve a direct loss of habitat

* Corresponding author.
E-mail address: louise.eriander@gu.se (L. Eriander).

http://dx.doi.org/10.1016/j.ocecoaman.2017.08.005
0964-5691/

(Erftemeijer and Lewis, 2006) and can further lead to reduced water quality due to turbidity and an increased likelihood of sediment resuspension (Onuf, 1994; Schoellhamer, 1996; Erftemeijer and Lewis, 2006). The light requirement of seagrasses is high (on average around 11% of the surface irradiance; Duarte, 1991) and docks and other structures built over the marine bottoms constitute a permanent shading of the sediment surface underneath, which can have negative effects on seagrass coverage (Shafer, 1999; Burdick and Short, 1999; Beal and Schmit, 2000).

Eelgrass (*Zostera marina* L.) is the dominating species of seagrass in the northern hemisphere (den Hartog, 1970) and a foundation species within shallow coastal areas, where it provides many important functions and services valuable to humans, such as increased fish production and uptake of carbon and nitrogen (McGlathery et al., 2012; Lilley and Unsworth, 2014; Cole and Moksnes, 2016; Röhr et al., 2016; Duarte and Krause-Jensen, 2017). Large losses of eelgrass have occurred in many areas of Northern Europe (Waddens Sea; Giesen et al., 1990; Denmark; Frederiksen et al., 2004, Poland; Kruk-Dowgiallo, 1991; Germany; Munkes, 2005; Sweden; Baden et al., 2003). In response to these losses, regional marine conventions such as HELCOM and OSPAR have included references to eelgrass protection specifically and coastal environments in general (OSPAR, 2012; HELCOM, 2010). Furthermore, several directives commissioned by the European Union (EU), which aim at achieving good environmental status of the marine environment, directly or indirectly aid in the protection of eelgrass. In the Water Framework Directive (WFD; 2000/60/EC), the abundance of angiosperms or marine flowering plants (e.g. eelgrass) is one of the determinants for ecological status of coastal and transitional waters and in the Marine Strategy Framework Directive (MSFD; 2008/56/EC) eelgrass is mentioned as an important environmental indicator. Furthermore, the protection of eelgrass is also in line with the EU Biodiversity Strategy (European Commission, 2011) and the Habitats Directive (92/43/EEC), with the latter being responsible for the establishment of the Natura 2000 network of areas protected against detrimental exploitation.

Along the Swedish northwest coast, extensive losses of the eelgrass have occurred since the 1980s (>60%; Baden et al., 2003; Nyqvist et al., 2009; Moksnes et al., 2016), which has led to an estimated loss of ecosystem services worth >350 million US$ (based on three ecosystem functions; fish habitat, carbon and nitrogen uptake; Cole and Moksnes, 2016). These losses have largely been attributed to the effects of coastal eutrophication and overfishing (Moksnes et al., 2008; Baden et al., 2010, 2012). However, the impact on eelgrass from small-scale coastal development, such as docks and marinas, has received little attention and the effects of docks on eelgrass coverage have never been investigated along the NW coast of Sweden. Considering that eelgrass in this area mainly grows in sheltered bays, commonly targeted by this type of exploitation, the number of meadows impacted might be substantial. And, although small docks and marinas exert a more locally restricted pressure compared with the effects of eutrophication and overfishing, the sheer number in itself might add up to a significant cumulative impact when a larger proportion of the coastline is considered. Studies on the effect of dock structures on eelgrass are globally rare (Fresh et al., 2006), however, previous studies from USA have demonstrated that shading by docks can lead to complete loss of eelgrass or reduced shoot density of meadows under and adjacent to docks (Fresh et al., 1995, 2006; Burdick and Short, 1999). The assessment of eelgrass coverage around docks could have important implications for management, with regards to minimizing local dock impact and improving the current decision process for approval of dock construction.

In Sweden, marine coastal habitats located less than 100 from the shoreline are protected against exploitation (Swedish Environmental Code (SEC); chapter 7, Section 13–18). Most types of construction in the water need to be granted an exemption from this shore protection and construction plans needs to be notified to the authorities. Approximately 50% of the present eelgrass distribution along the NW coast of Sweden is further protected against exploitation as they are located within protected areas (i.e. national parks, nature reserves and Natura 2000 areas; Moksnes et al., 2016), where exemptions from the shore protection should normally not be granted (SEPA, 2012). Furthermore, national environmental goals decided by the parliament, such as the goal of '*A balanced Marine Environment, Flourishing Coastal Areas and Archipelagos*', aims at maintaining ecosystem services and high biodiversity within shallow coastal environments and promotes restoration of degraded habitats (Anonymous, 2012). However, despite the presence of national and international goals, the coastline along Sweden has slowly been exploited by an increasing number of coastal constructions (e.g. road banks, housings, docks and marinas). An inventory made in 2008 found around 7000 recreational docks and 600 larger marinas on the Swedish west coast alone, and those numbers have since then been increasing (Pettersson, 2011). The fact that exploitation and damage of eelgrass habitats is allowed to continue, also in areas which have experienced large and ongoing losses, such as the southern parts of the Swedish Northwest coast (Baden et al., 2003; Nyqvist et al., 2009; Moksnes et al., 2016), indicates that the present Swedish legislation is insufficient in protecting eelgrass. This situation is not in line with the demands posed by the EU WFD and MSFD to achieve and maintain good ecological status. Neither is it compatible with Swedish obligations under the above-mentioned OSPAR- and HELCOM-conventions.

In order to improve management of eelgrass along the Swedish Northwest coast, an interdisciplinary approach was applied, investigating ecological impacts and legal challenges relating to small-scale exploitation. The aim of this study was to assess the local and large-scale effect of shading by docks and marinas on eelgrass habitats along the Swedish NW coast. Furthermore, the legal process behind this physical exploitation was investigated to identify problems with the current legislation, which allows for continued exploitation, with the specific aim of determining how the presence of eelgrass and areal protection of the coast affect the approval of dock construction.

2. Materials and methods

2.1. Study area and geographic data

The study was carried out in the county of Västra Götaland, Sweden (from here on denoted as the NW coast of Sweden; Fig. 1A). This county stretches from the northern to the central parts of the Swedish west coast, and consists of 12 coastal municipalities. Within 5 of these municipalities (Strömstad, Lysekil, Uddevalla, Stenungsund and Kungälv; Fig. 1B) inventories of eelgrass have been performed through field surveys in the 1980s, 2000, 2003 and 2004 (Baden et al., 2003; Nyqvist et al., 2009) and through satellite image analysis in 2008, 2013 and 2014 (Lawett et al., 2013; Envall and Lawett, 2016) which also covered the remaining parts of the NW coast. The data on eelgrass distribution recorded from these studies were available as GIS polygons, which were used in the present study to determine the overlap between small-scale exploitation and historical and present eelgrass habitat. The distribution of docks and marinas along the Swedish west coast was available from mapping and analysis of physical structures along the coast, performed by the Swedish Environmental Protection Agency (SEPA, 2010). Tides in this area are semidiurnal with a small amplitude, normally <0.3 m (Queiroga et al., 2002) and have little influence on the light environment for eelgrass.

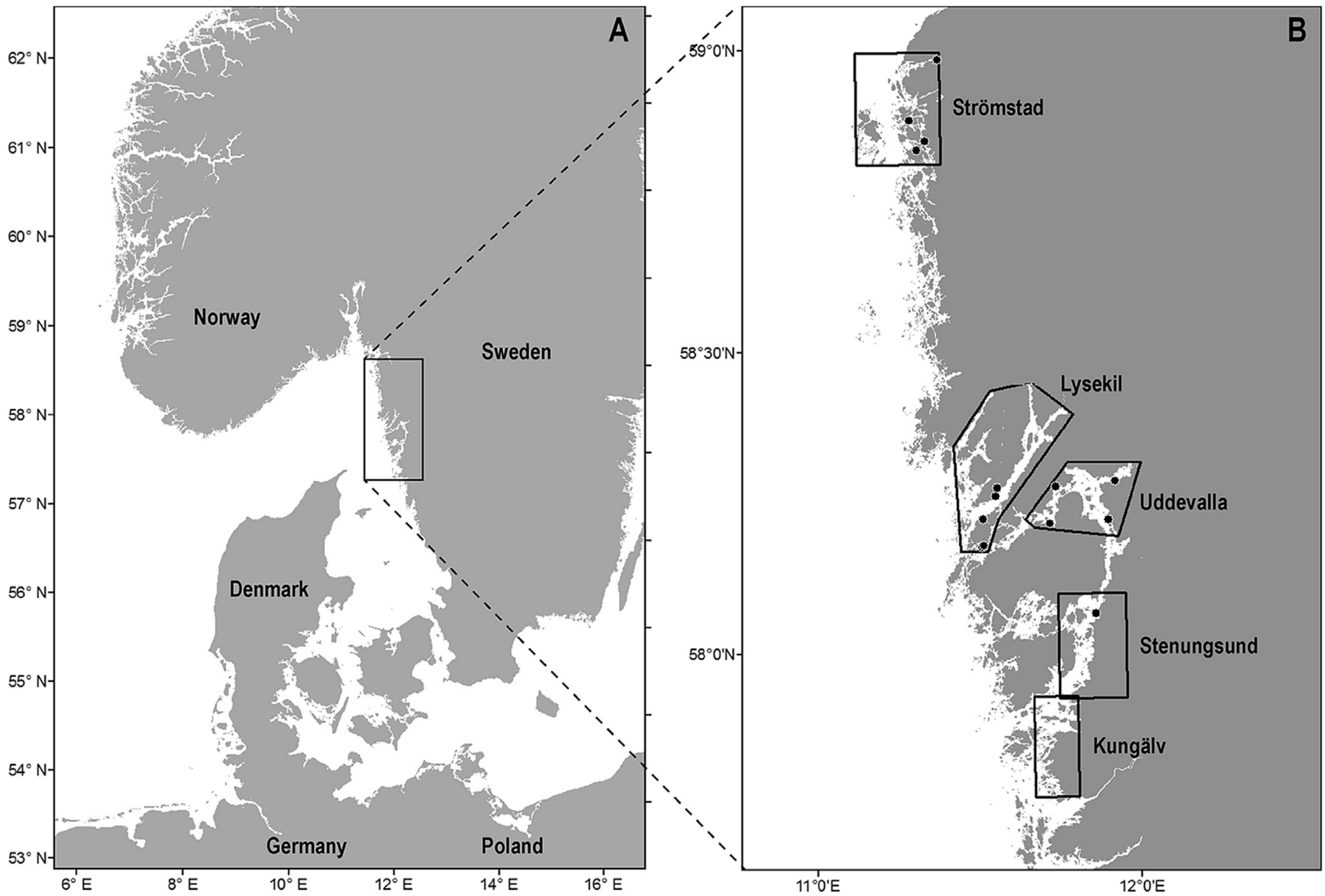

Fig. 1. The study area showing A) the Northwest coast of Sweden and the county of Västra Götaland inside the box B) a detailed map of the 5 municipalities in which extensive eelgrass monitoring have been performed (Baden et al., 2003; Nyqvist et al., 2009) and the 14 docks examined in the field assessment, indicated by dots.

Table 1
Characteristics of the 14 docks and 4 marinas with associated eelgrass examined in mid-June of 2014. For marinas, the mean length of docks and the number of docks are given under length (length/no. of docks).

Municipality	Site	Floating/Elevated (Fl/E)	Light measurements	Length (m)	Length over eelgrass (m)	Width (m)	Thickness (cm)	Height over water surface (cm)	Height over eelgrass bottom (cm)	Boat moorings (no.)	Mean eelgrass coverage below dock (%)
Docks											
Strömstad	1	E		11.0	9.4	1.6	4	165	229	2	5.3
Strömstad	2	Fl	YES	22.0	17.0	2.4	40	0	120	13	0.0
Strömstad	3	Fl	YES	20.4	9.4	3.0	21	18	118	2	0.0
Strömstad	4	Fl	YES	43.0	30.0	2.4	20	10	83	24	0.0
Lysekil	5	E		6.5	1.5	1.2	3	130	167	1	100.0
Lysekil	6	E		74.0	50.0	1.8	66	95	168	9	51.7
Lysekil	7	E		54.5	44.5	2.5	20	120	254	0	43.3
Lysekil	8	E	YES	54.0	25.0	1.9	30	50	203	0	33.3
Lysekil	9	E	YES	33.0	30.0	1.8	57	57	254	20	5.0
Uddevalla	10	Fl	YES	161.9	161.9	2.0	22	5	242	82	0.0
Uddevalla	11	E		8.8	5.0	0.8	5	90	147	1	26.3
Uddevalla	12	E	YES	55.0	26.0	2.8	30	80	200	5	0.0
Uddevalla	13	E	YES	32.0	26.0	2.1	71	55	217	20	22.8
Stenungsund	14	E		22.9	15.0	1.7	4	157	290	0	0.0
Marinas											
Strömstad	A	Fl		63.5/11		2.5				311	0.0
Lysekil	B	Fl		39.5/7		2.6				51	0.0
Uddevalla	C	Fl		68.7/7		2.5				262	0.0
Stenungsund	D	Fl		64.7/7		3.1				244	0.0

2.2. Local effects of docks

In order to determine the local effects of shading on eelgrass coverage, field sampling was carried out during mid-June of 2014, around 14 docks and 4 marinas. The docks and marinas sampled in this study were randomly chosen within the 5 municipalities amongst those overlapping with the eelgrass distribution in the 2003 and 2004 survey (Nyqvist et al., 2009). However, no

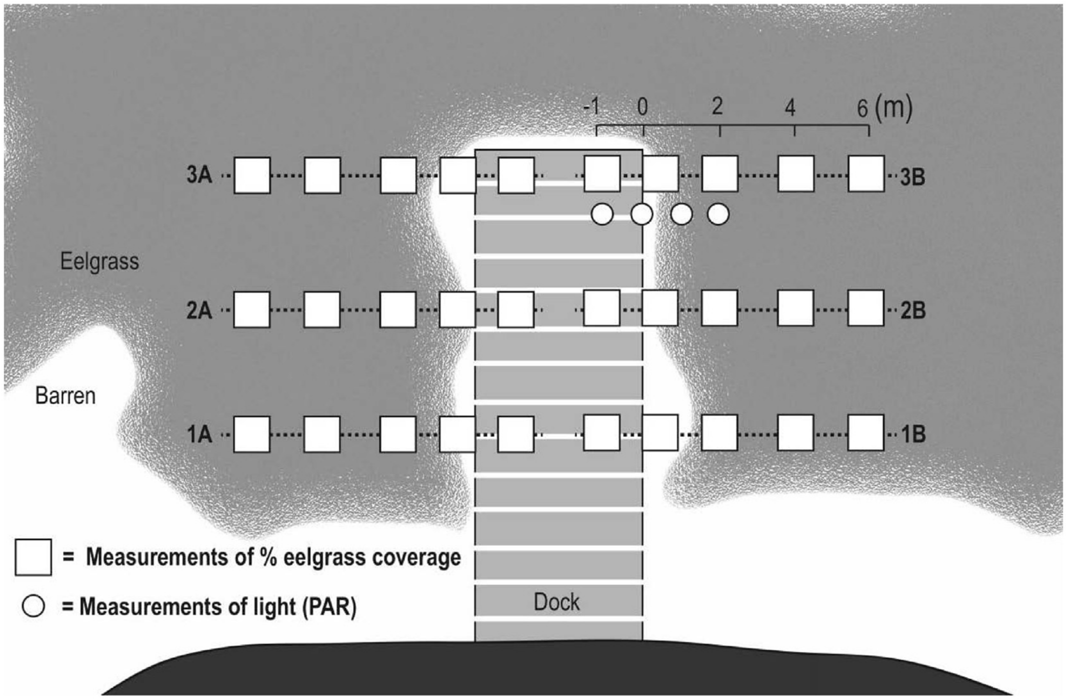

Fig. 2. General sampling design applied to each dock. Eelgrass was sampled at 5 distances from the dock (Under, Edge, 2, 4 and 6 m from the dock edge) along 6 transects (1A, 1B, 2A, 2B, 3A, 3B) perpendicular to the dock and light (PAR) measurements were collected at two depths (just below the surface and at 2 m depth) at 4 distances from the dock (Under, Edge, 1 and 2 m from the dock edge).

overlapping docks or marinas could be found within the most southern municipality of Kungälv (Fig. 1B; Table 1), where large losses of eelgrass have occurred since the 1980s (Baden et al., 2003).

Marinas were in this study defined as a collection of docks covering a total area (including space in between docks) of >2500 m^2 (Pettersson, 2011). The month of June was chosen as the sampling period since eelgrass in this area has a high biomass and shoot density in June (Baden and Pihl, 1984; Eriander et al., 2016), but the boating activity around docks is still low enough to allow safe sampling by snorkelling. At each dock, a number of physical characteristics of the dock was measured and recorded (Table 1) and six transects were established perpendicular to docks. Along each transect the percent coverage of eelgrass was visually estimated inside 0.25 m^2 quadrates placed at 5 fixed distances along each transect line: under the dock, edge of dock, 2, 4 and 6 m from the dock edge (Fig. 2). The distance from the dock to where 100% coverage was reached was noted. However, in some sites, the characteristics of the bay in which the dock was located did not allow for eelgrass to reach 100% coverage perpendicular to the dock. In those cases, the percent coverage around docks was related to the density present at the farthest measurement point from the dock. The mean percent coverage at each sampling distance was calculated for each dock (from the 6 transects). Two dock designs were identified during field visits; floating docks and dock elevated on poles (Table 1), which were analysed separately since previous studies have observed large differences between floating and elevated docks with regards to their effect on eelgrass coverage (Burdick and Short, 1999).

Since shading created by docks was believed to be the major factor affecting eelgrass coverage, light measurements were collected with a PAR-meter (Apogee MQ-200) around 8 of the visited docks at 4 distances from the dock: under the dock, edge of the dock, 1 and 2 m from the edge of the dock (Fig. 2; Table 1). At each distance the photosynthetically active radiation (PAR; μmol photons m^{-1} s^{-1}) was measured just below the surface and at 2 m depth. Measurements were performed during constant weather conditions and the percentage of surface light reaching 2 m depth was calculated at each distance. Light was sampled mid-day over the course of two days, to obtain a representative and comparable sample from each dock. The light attenuation coefficient (Kd; m^{-1}) in the water was calculated for each dock based on the light data collected at 2 m from the dock (to make sure the light sensor was not covered by any dock structures), using the Beer-Lambert equation (e.g. Dennison et al., 1993).

At each marina, descriptive measurements of dock design, number of boat spots and eelgrass coverage was collected. Because of heavy boat traffic no transects were performed within marinas, as a safety precaution. However, the eelgrass coverage underneath and at the dock edge was determined visually using aqua-scope. When water clarity allowed, the coverage of eelgrass between docks was determined from the surface. In the present study, marinas were treated as a collection of docks, and only the effects of shading from the docks and moored boats were assessed in this study.

Statistical analyses were performed using SPSS 23.0 statistical software. Homogeneity of variance was tested using Levene's test. The percent of surface light and mean percent eelgrass coverage from the 6 transects were analysed as the dependent variables in two-way analyses of variance (ANOVAs) with dock design (floating and elevated on poles) and sampling distance from dock (under, edge, 1 and 2 m from edge for light and under, edge, 2, 4 and 6 m from edge for eelgrass coverage) as fixed independent variables. Where appropriate, post-hoc tests were performed using the Tukey's HSD procedure. In order to determine how light affected coverage of eelgrass, a simple linear regression analysis was performed between percentage of surface light at 2 m depth and percent coverage of eelgrass at the overlapping sampling distances from the dock.

According to earlier studies in other regions, deck height above the marine bottom and deck height above the water surface have been shown to affect light and seagrass coverage under docks (Burdick and Short, 1999; Shafer and Robinson, 2001; Garrison et al., 2005). Furthermore, within the decisions regarding dock construction issued by the County Administrative Board in Sweden (see below), requirements to decrease the thickness of elevated docks were found, in order to reduce the negative impacts from shading. Therefore, the effect of height above the bottom, height above the water surface, water depth and deck thickness were assessed using simple linear regression analyses for each dock-characteristic separately against the coverage of eelgrass underneath the dock. Since depth differed between transects the eelgrass coverage under the dock from each transect was used as the dependent variable for these analyses. Transects where no coverage of eelgrass was observed 6 m from the dock edge were removed from the analysis, since zero coverage underneath the dock could be due to other effects than shading.

2.3. Dock characteristics

All docks in the area investigated consisted of permanent constructions used for boat keeping or seasonal leisure activities (e.g. bathing and fishing). The floating docks consisted of wooden platforms with a mean board space of 1.0 cm, supported by pontoons or concrete floats that were fixed to the shoreline and the bottom substrate through mooring chains and vertical metal poles. The elevated docks consisted of wooden platforms with a mean board space of 1.2 cm, supported by poles embedded in the bottom substrate. Of the 14 docks sampled in this study, 71% consisted of docks elevated on wooden poles and 29% were floating docks. The floating docks had on average > 5 times as many boat moorings around them compared with elevated docks (Table 1), and boat moorings were often separated by metal booms resting on small pontoons. The mean length and width of docks assessed in the study were 43 and 2 m respectively. The proportion of the dock standing above eelgrass was on average 67%, but varied between docks (23–100%; Table 1). The average height of docks was 1.9 m above the bottom and the average height above the water surface was 1 m and 0.08 m for elevated and floating docks, respectively (Table 1).

All marinas visited in this study consisted of groups of floating docks (on average 8 docks per marina), where the majority of docks were arranged perpendicular to the shoreline. The length of each dock-segment was on average 59 m, and the width 2.7 m (Table 1). The docks within marinas were primarily used for boating activities, with an average of 217 moorings per marina (Table 1).

2.4. Large-scale effects of docks and marinas

The shading impact of dock on eelgrass found in the field study was extrapolated to assess the large-scale impact of docks along the whole NW coast of Sweden. This was done by using data on size and distribution of docks in relation to eelgrass and soft sediment bottoms in the study area. The impact from the average sized dock on eelgrass was calculated separately for floating and elevated docks based on their effects on eelgrass coverage obtained in the field study. For floating docks, which never displayed any eelgrass growth underneath the dock structure, the average eelgrass area lost (m^2) per dock was calculated. The average area negatively affected by a dock (m^2) was based on the mean distance from the dock where 100% shoot coverage was found in the field assessment for floating and elevated docks. For each dock design, the average reduction of eelgrass coverage within the affected area was also estimated, based on the eelgrass coverage at different distances from the docks found in the field study.

To get a better estimate of the average size of docks and marinas along the Swedish NW coast, length and width of an additional 52, randomly selected docks and 10 marinas were measured from geometrically corrected aerial images (orthophotos; Lantmäteriet/Metria 2014) within the 5 studied municipalities (Fig. 1B). The average surface area of a dock standing over eelgrass in the study area was estimated using the average proportion of the dock length standing over eelgrass from the field study (Table 1). The same estimate was used for marinas, where the length of docks located perpendicular to the shore was adjusted according to the average proportion standing over eelgrass before the average surface area of a marina was calculated. Based on the results from the 5 marinas visited in the field, which all consisted of floating structures, the impact from marinas, were treated as equivalent to the impact observed for floating docks.

The total, large-scale impact from docks and marinas on the NW coast of Sweden was calculated according to two different scenarios (1) *maximum total impact on soft sediment* areas, and (2) *total impact on areas with historical or present eelgrass* distribution. Since eelgrass could potentially grow on all soft sediment bottoms at the depth included in the calculation (0–10 m depth), the former scenario represents an estimate of the maximum impact from docks on eelgrass. The second scenario is based on the overlap between docks and where eelgrass has been found since the 1980s, and represents a more conservative estimate.

To estimate the number of docks and marinas standing on soft sediment in the study region, GIS-analyses were carried out, using the distribution of docks and marinas and marine geological maps of the region, with aerial photographs to adjust the prediction of the geological maps. To estimate the number of docks and marinas that overlap with the present and historic distribution of eelgrass beds GIS-analyses using data on the distribution of docks and marinas and eelgrass from all the historic surveys in the 5 study areas/municipalities (1980–2014; Fig. 1B) were carried out. Since each dock was only marked by one position in the GIS-material, a 50 m buffer zone was given to each dock when estimating the number of docks overlapping with eelgrass. Making the assumption that these 5 study areas are representative for the whole study region, the proportional overlap between docks/marinas and soft sediment and docks/marinas and eelgrass were subsequently used to estimate the total number of docks/marinas that overlap with soft sediment and eelgrass along the whole NW coast of Sweden. These estimates of the total number of docks and marinas located on soft sediment or on eelgrass habitats were then separated into estimated number of floating and elevated docks, according to the proportion observed in the field assessment of docks. These numbers were subsequently multiplied with the calculated mean area of impact for floating and elevated docks respectively. For floating docks and marinas, the total area of lost eelgrass was also calculated.

2.5. Legal requirements and decisions for dock construction

In order to examine the legal protection of eelgrass from coastal exploitation in Sweden and to assess the outcome of this legislation, a legal study of decisions on dock construction was carried out along the NW coast of Sweden. In Swedish environmental law research, an established methodology is to analyse the relationship between environmental objectives, legal requirements and enforcement (Gipperth, 1999; Westerlund, 2003). The present study focuses on the outcome of primary decisions in order to acquire an understanding of how the enforcement part of the legislation is applied. This provides an opportunity to examine not only the legal protection of marine environments in theory but also the result in safeguarding eelgrass, when applying this legislation.

2.5.1. Background to relevant legislation and procedures

Dock building is restricted under Swedish legislation in two ways; by the shore protection and the regulation of water operations. The purpose of the shore protection is to secure access to the water for the general public and to preserve the living conditions for plants and animals on and around the shoreline. Along parts of the coastline the shore protection is abrogated, normally because of development that was already present before the shore protection was introduced in the 1950's, or because of municipal planning decisions. In areas with shore protection, exemptions can be granted either by the municipality or the County Administrative Board (SEC; chapter 7, section 13–18) if the proposed project does not negatively affect the purpose of the protection. According to the Swedish Environmental Protection Agency's (SEPA) handbook for shore protection, the application for a shoreline exemption should always include an assessment of the consequences of a project, e.g. impact on eelgrass or other valuable habitats (SEPA, 2012). For shore protection in protected areas, such as nature reserves or Natura 2000 areas, the SEPA handbook states that exemptions should generally not be granted, unless it is obvious that the purpose of the shore protection is not harmed (SEPA, 2012).

For minor water operations (e.g. docks <3000 m^2) it is sufficient to notify the County Administrative Board before starting the construction (SEC; chapter 11, section 9b, Ordinance on water operations; section 19). For water operations to be allowed, the benefits of public and private interests should be greater than the cost of damage associated with the water operation (SEC; chapter 11, section 6). Notifications of water operations are examined by the County Administrative Board and should contain information regarding the construction; including drawings, maps and technical descriptions, needed to assess the consequences of the project (Ordinance on water operations; section 20). In order to retrieve this information from the applicant the County Administrative Board uses a standard document, which requires information on dock design and size, potential negative impacts on the environment and actions taken to minimize these impacts. After examining the information given, the County Administrative Board can decide to either prohibit the construction of the dock or allow it to proceed, with or without specific conditions.

2.5.2. The study of applications and decisions for dock construction

In order to investigate if the presence of eelgrass was taken into account in the decision process and whether the presence of eelgrass or protected areas affected the decisions, a study of applications and decisions of exemption from shore protection and notification of water operations was performed. All decisions between 2011 and 2015 from 8 municipalities along the NW coast of Sweden were identified by searching for the Swedish word for dock ('brygga') in the digital records of the County Administrative Board. The cases included in this study are only those received by the County Administrative Board, hence cases where the municipalities have rejected the applications of exemption from the shore protection are not included. Statistics on how many applications are rejected at the municipality level is generally lacking, but according to a report from SWECO (2013), less than 25% of applications received by municipalities in 2012 were rejected. The municipalities in question were chosen to cover the same geographical area as where the impact of docks was studied. In each case the type of construction (new dock, modification of dock or reparation of dock), dock design (floating or elevated on poles), size of the dock and the mentioning of eelgrass was noted. If the case was rejected, the explicit cause for rejection was sought in the decision. Furthermore, the distribution of eelgrass from recent satellite inventories (2008–2014; Lawett et al., 2013; Envall and Lawett, 2016) was layered with the position of the docks (including a 50 m buffer zone) in the applications. Also, the location within any type of protected area (i.e. national parks, nature reserves and Natura 2000 area) was noted for each case, by overlapping the position of the dock with GIS-maps of different protected areas. The proportion of approved and rejected exemptions and notifications inside and outside of protected areas was then compared with information regarding eelgrass presence and the type of dock construction.

An in-depth analysis was performed on the complete records preceding the decision of 10 approved and 9 rejected cases for construction of new docks in areas were eelgrass was present according to the satellite data. These cases were studied in order to gain a better understanding of the material required by the County Administrative Board before making decisions of approval or rejection, and to further investigate if bottom characteristics or eelgrass was assessed.

3. Results

3.1. Local effects of docks

Analyses of light and eelgrass coverage around docks suggested large effects from shading. Eelgrass coverage increased significantly with distance from the dock for both type of dock designs, and was significantly higher around elevated compared to floating docks at all distances (Table 2; Fig. 3A). Eelgrass coverage underneath floating docks was always zero. At elevated docks, the mean coverage under the dock varied substantially, between 0 and 100%, with an average coverage of 29%. At 6 m from the edge of the dock, the mean eelgrass coverage was 57 and 82% for floating and elevated docks respectively (Fig. 3A). The average distance from the dock edge where 100% eelgrass coverage was reached was 7.3 and 5.7 m for floating and elevated docks, respectively. Elevated docks showed a more gradual increase in eelgrass coverage with distance from the dock, whereas floating docks showed a more distinct border between low coverage and 100% coverage at between 7 and 8 m from the edge of the dock. Marinas, which all consisted of floating docks, displayed a similar effect on eelgrass coverage as single floating docks. All marinas had 0% coverage of eelgrass under and at the edge of the dock, and reached 100% coverage (as estimated from visual inspection from the surface) at between 5 and 10 m from the dock edge, with an average distance of 7.5 m.

Light levels around and under the docks displayed a similar pattern as did eelgrass coverage, where light levels increased significantly with the distance from the dock for both type of dock designs, and with significantly lower light levels around floating compared to elevated docks at all distances (Table 2; Fig. 3B). Light levels at 2 m depth underneath floating docks was only 3.7% of the surface light on average, and increased to 13% at the edge and 21% 2 m from the dock. For elevated docks, the light levels increased from on average 13% of surface light under the dock to 36% at 2 m from the dock edge (Fig. 3B). The lower light conditions for floating docks, 2 m away from the dock was surprising and indicate on average poorer light conditions around floating compared to elevated docks (average light attenuation coefficient, Kd, at 2 m distance from the docks were 1.0 and 0.55 m^{-1} for floating and elevated docks, respectively). That the negative effect on eelgrass around docks was mainly due to shading was supported in the regression analysis which showed a significant positive relationship between light and eelgrass coverage around docks (Table 3; Fig. 4).

The dock characteristic that showed the strongest correlation with coverage of eelgrass underneath docks was height above the water surface, which was positively correlated with eelgrass coverage (Table 3; Fig. 5A). Furthermore, water depth showed a significant negative correlation with eelgrass coverage (Table 3; Fig. 5B). However, neither dock height above the sediment surface, or the dock thickness showed a significant correlation with eelgrass coverage under docks (Table 3).

Table 2
Two-way ANOVA tables of mean % eelgrass coverage and mean % of surface light at 2 m depth, testing for difference between dock design (floating and elevated), the sampling distance relative to the dock (Under, Edge, 2, 4 and 6 m from dock edge for eelgrass coverage and Under, Edge, 1 and 2 m from dock edge for light) and the interaction between them.

	Source	df	MS	F	P
% Eelgrass coverage	Dock type	1	10,775.4	12.40	0.001*
	Sampling distance	4	5230.4	6.017	0.000*
	Dock type x Sampling distance	4	164.4	0.189	0.943
	Error	58	869.3		
% Surface light	Dock type	1	1259.0	10.41	0.004*
	Sampling distance	3	684.1	5.654	0.004*
	Dock type x Sampling distance	3	40.4	0.334	0.801
	Error	24	120.0		

3.2. Large-scale effects of docks and marinas

The average length and width of docks along the NW coast of Sweden, as measured from aerial images and field sampling was 34 and 3.4 m, respectively, or 116 m^2 surface area, of which 78 m^2 was standing over eelgrass bottom on average. The average total length and width of all docks within marinas was 489 and 3.2 m, respectively, covering 1594 m^2 of bottom, and 1122 m^2 of eelgrass, on average.

The estimated area of eelgrass negatively affected around floating and elevated docks was on average 522 m^2 and 447 m^2, respectively. The reduction in eelgrass coverage within these areas was 64 and 42%, respectively. The area negatively affected around the average marina was 6165 m^2. The area of complete eelgrass loss under floating docks was on average 78 m^2 per dock and 1122 m^2 per marina.

The proportion of docks standing over soft sediment bottoms was on average 96% in the 5 regions assessed. Out of those, 74% were standing over bottoms where eelgrass was present at some point between 1980 and 2014 (Supplementary Table 1). The same percentage of overlap with soft-bottom was used for marinas, and 91% of marinas were standing over historical or present eelgrass bottoms (Supplementary Table 1). Assuming that these 5 regions are representative for the entire coastline of NW Sweden, the total number of docks located over soft sediment bottoms was 6210, and the number of those located over historical or present eelgrass bottoms was 4621 (Supplementary Table 1). The total number of marinas located over soft sediment was 468, and the number of those located over historical or present eelgrass bottoms was 428 (Supplementary Table 1).

Table 3
Results from simple linear regression analyses between percentage of surface light at 2 m depth and the coverage of eelgrass (%) and between four dock characteristics (height above water surface, height above sediment surface, water depth and dock thickness) and eelgrass coverage (%) underneath the dock.

Dependent variable	Independent variable	$F_{1,22}$	P	R^2
% eelgrass coverage	% surface light at 2 m depth	17.3	0.0004*	0.44
Dependent variable	**Independent variable**	$F_{1,53}$	**P**	R^2
% eelgrass coverage under dock	Dock height above water surface (cm)	19.8	<0.0001*	0.27
	Dock height above sediment surface (cm)	0.238	0.6279	0.0045
	Water depth (cm)	9.53	0.0032*	0.15
	Dock thickness (cm)	0.286	0.5954	0.0054

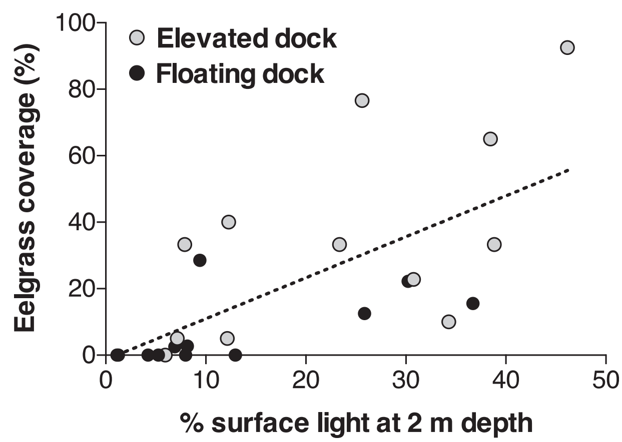

Fig. 4. Eelgrass coverage (%) plotted against percentage of surface light reaching 2 m depth.

Based on 71% of docks being elevated and 29% being floating and on all marinas consisting of floating docks, the total area of soft sediment negatively affected by small-scale coastal exploitation along the NW coast of Sweden was 579 ha, and the total area of historical and present eelgrass area affected was 480 ha, with a mean potential reduction in eelgrass coverage between 42 and 64% (Supplementary Table 2). The total loss of potential eelgrass under floating docks were 14 and 10 ha for soft sediment and historical eelgrass sediments, respectively, and the total loss of eelgrass by marinas was 53 and 48 ha for soft sediment and historical eelgrass sediments, respectively (Supplementary Table 2).

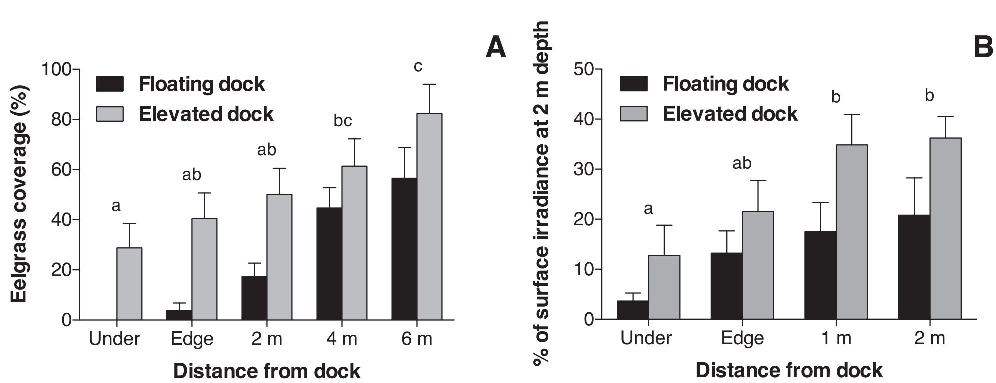

Fig. 3. A) mean % eelgrass coverage (±SE) at the different distances relative to the dock (Under, Edge, 2, 4 and 6 m from dock edge) and B) mean % of surface light at 2 m depth (±SE) at the different distances relative to the dock (Under, Edge, 1 and 2 m from dock edge) for the two dock designs (floating and elevated). Different letters above bars indicate significant differences in coverage or light levels between the different sampling distances (Tukeys HSD P < 0.05).

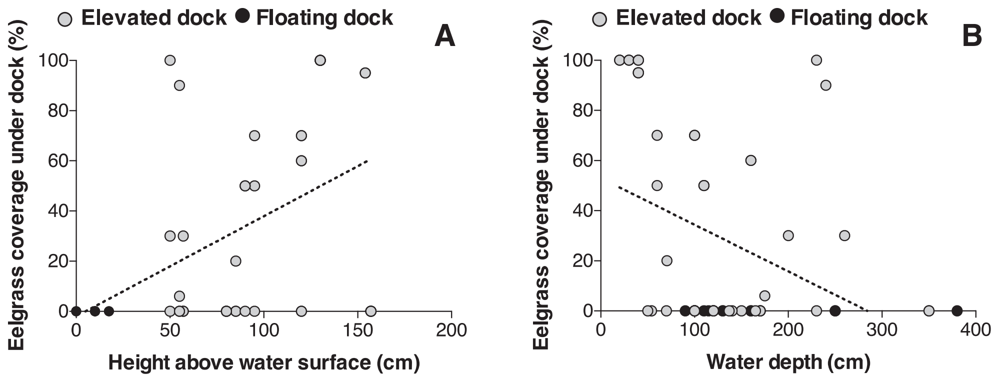

Fig. 5. Eelgrass coverage (%) underneath the docks, plotted against A) the dock height above the water surface and B) the water depth.

3.3. Eelgrass assessment and consideration within decisions for dock construction

A total number of 142 unique cases were identified from the digital records of the County Administrative Board from the 8 municipalities between the year 2011–2015, which fulfilled the criteria (final decision present, information on dock design and type of construction present) necessary for the analysis. In 69 of the cases, decisions involved both applications for the exemption from the shore protection and notification water operations. In 67 cases, only notification of water operations was involved. In these cases, the shore protection was either abrogated, or exemptions were not deemed necessary due to the small impact of the proposed dock. In 6 cases decisions involved only exemptions from the shore protection, which all consisted of docks being built unlawfully and where exemption was applied for after the construction was established. The results below are based on all cases, if not otherwise stated and 'applications' hereafter denotes both application and notifications.

Overall, 75% of the cases were approved (here meaning that they got an exemption from the shore protection and/or the notification of water operations allowed the construction to proceed). A majority of the approved cases consisted of modifications of existing docks (57%), while 26% considered new docks. When comparing cases where both an exemption and a notification was needed with those were only a notification was needed, the proportion of approved cases were 59% and 94%, respectively.

Out of the total number of 54 applications for building new docks, 65% considered floating docks and 35% elevated docks (Fig. 6). Although a higher proportion of elevated docks were approved for new construction in comparison to floating docks (Fig. 6), a greater total number of floating docks were approved and out of the 28 approved cases for building new docks, 17 consisted of floating docks. Furthermore, amongst the 69 applications to modify existing docks, 16 concerned the replacement of an elevated dock with a floating dock. These applications were approved in all but one case. The most common reason for rejection of dock applications was referral to the general shore protection law (56%) and in a smaller percentage of cases the rejection was based on chapter 11, section 6 in the SEC (11%), which states that the benefits of public and private interests should be greater than the cost of environmental damage associated with the water operation. In the remaining cases, the reason for rejection was not specified.

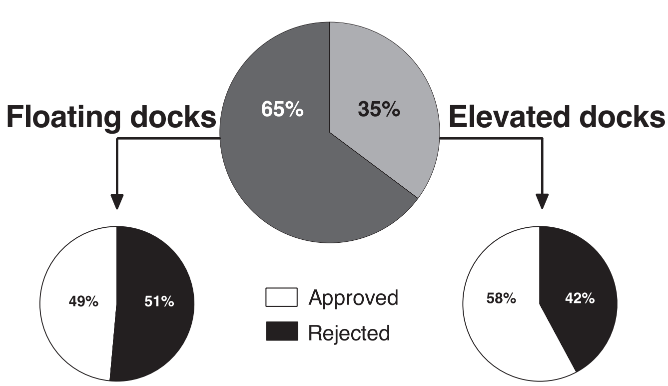

Fig. 6. Descriptive presentation of all decisions regarding construction of new docks, showing the percentage of applications concerning floating and elevated docks in the top pie and the percent approved and rejected applications for each type of dock in the lower pies.

Out of all cases analysed, 49% were located inside some type of areal protection (i.e. Nature reserve, national park or Natura 2000 area; Fig. 7). The overall approval rate of cases inside and outside of protected areas was 59% and 90%, respectively. A majority (88%) of cases in eelgrass outside protected areas were approved. This number was only marginally reduced inside protected areas, where 69% of cases in eelgrass were still approved, which is higher compared to areas without eelgrass inside protection (49%; Fig. 7). Out of the approved cases 22% and 29% considered the construction new docks, inside and outside of protected areas, respectively.

The analysis of the decisions indicates that eelgrass was generally not assessed or considered in the decision process. Only in 12 out of the total 142 cases, was eelgrass explicitly mentioned as being present, and in areas where satellite inventories indicate eelgrass only 12% of cases mention eelgrass as being present. However, the fact that 26% of all approved cases were required to perform the construction outside of the growth season suggests that impacts to the marine life were considered in some cases. In the 12 cases where eelgrass was mentioned, 9 cases were still approved, which consisted of 3 new docks and 6 modifications or reparations of existing docks. Two of the approved docks in eelgrass were located within Natura 2000 areas.

The in-depth analysis strengthened the view that very few cases contained information regarding the bottom type at the place of construction and that impact on eelgrass was rarely considered. Although the standard form used for water operations does require information regarding the conditions and estimated negative impact on the bottom, depth and bottom type were mentioned only in 26% of the examined cases. An indication that bottom conditions had been investigated at the site of construction was present only in 16% of the cases. Within the rejected cases, nature value or bottom conditions were mentioned in 78% of applications, while for approved cases these conditions were only mentioned 30% of applications. There was no mentioning of negative impacts on the environment in any of the examined applications. The County

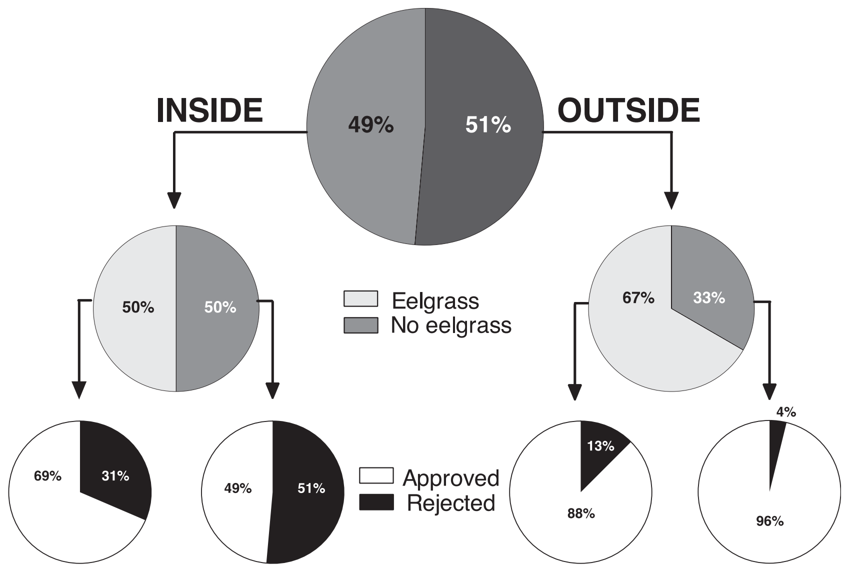

Fig. 7. The proportion of all decisions inside and outside of protected areas in the top pie, the percentage with and without eelgrass inside and outside of protected areas in the mid pies and the proportion of approved and rejected applications within each category in the bottom pies.

Administrative Board demanded supplement material in 58% of the cases, but only in one case was information on bottom conditions requested. Eelgrass was explicitly mentioned within the records of 4 applications (2 where the case was approved and 2 where it was rejected). Two of the new docks approved for construction (with the size of 455 and 24 m^2) were floating docks situated within Natura 2000 areas with eelgrass. In all ten approved cases the surroundings were described as exploited, whereas 56% of the rejected cases were located in areas described as unexploited.

4. Discussion

Small-scale, cumulative impacts to habitats have long been a concern for conservation and management of coastal ecosystems (Panek, 1979; Odum, 1982), but there still is a lack of attention of their potential large-scale effects among policy makers and managers (Peterson and Lowe, 2009). The present study demonstrates that small-scale impacts from shading by docks and marinas post a significant threat to the remaining eelgrass along the NW coast of Sweden. The lack of assessment and consideration for eelgrass in decisions regarding dock constructions, also in protected areas, demonstrate that the theoretical legal protection of important marine habitats, such as eelgrass, are not functional in safeguarding eelgrass against exploitation. These results suggest that there is a need to improve the management practices in Sweden and to consider large-scale cumulative effects during management of small-scale exploitation to avoid further losses of eelgrass and other coastal habitats. The described cumulative impacts from docks and marinas, and the identified issues in the Swedish environmental regulations and management are likely applicable also to other countries.

4.1. Local effects of docks

The positive correlation between eelgrass coverage and light observed in the present study suggests that shading by docks is the major factor driving the significant reduction of eelgrass around docks. Several studies have confirmed the shading properties of docks (Shafer, 1999; Burdick and Short, 1999; Beal and Schmit, 2000; Garrison et al., 2005) and losses of seagrass under docks have in many studies been attributed to a reduction in light (Fresh et al., 1995; Shafer, 1999; Burdick and Short, 1999; Shafer and Robinson, 2001; Gladstone and Courtenay, 2014). In the present study eelgrass was absent underneath 43% of the docks assessed, and the overall reduction in eelgrass coverage under docks compared to 6 m adjacent was 78% (Fig. 3A). Burdick and Short (1999) reported similar losses, with eelgrass absent under 43–62% of docks, and an average reduction in shoot density between 82 and 89%.

The present study demonstrates large differences between floating and elevated docks. All floating docks (single docks and docks within marinas) had zero coverage of eelgrass underneath, while elevated docks showed a larger variation, with a mean coverage of 29%. This is likely explained by differences in shading created by the two dock designs. Floating docks generally had a stronger shading effect of the bottom underneath, and the average reduction in light at 2 m depth moving from the edge to underneath the dock was 72% and 41% for floating and elevated docks, respectively (Fig. 3B). This resulted in 3.7% and 13% available surface light at 2 m depth below floating and elevated docks, respectively. Previous studies have demonstrated similar shading properties by elevated docks (Shafer, 1999; Shafer and Robinson, 2001) and that floating docks substantially decrease the coverage or cause a complete loss of eelgrass on the bottom below (Fresh et al., 1995, 2006; Burdick and Short, 1999). The fact that floating docks stand closer to the water surface compared to elevated docks (0.08 and 1.0 m, respectively) and have floating elements at which no light reach the water surface through the board space is likely the explanation to the larger reduction in light and therefore, the absence of eelgrass underneath. This is also supported by the observed significant positive correlation between height above the water surface and eelgrass coverage under the dock, seen in the present study. However, the present study found no significant relationship between eelgrass coverage underneath the dock and dock height above the sediment surface, which have been observed in other studies (Burdick and Short, 1999). This could possibly be due to the significant negative correlation between eelgrass coverage and depth.

Eelgrass coverage was also reduced at 6–8 m from the dock edge, displaying that the area negatively affected by a dock was greater than the actual area of the dock. Eelgrass coverage and light was significantly lower adjacent to floating docks compared with elevated docks. This could be explained by the observed difference in human activity and water quality between the two dock designs. Shading by boats was not assessed in this study, since light levels adjacent to the dock was measured in locations without overhead dock structures. However, boats, which were >5 times more abundant around floating docks compared with elevated docks, are likely to have caused shading of the marine bottom, which could explain the larger reduction in eelgrass coverage adjacent to floating docks. Elevated docks were more often associated with a single private owner, with few boats and more of a recreational function in order to access the water. That boats are responsible for creating these differences in coverage is further supported by the observation that eelgrass coverage increased more gradually around elevated docks while a distinct border between low coverage and 100% coverage was seen around most of the floating docks, at a distance of 7–8 m, which coincides with the length of booms situated between boat mooring and the length of the majority of moored boats. That moored boats can increase the shading footprint and/or disturb the area adjacent to docks is supported by previous studies on eelgrass from USA (Fresh et al., 1995; Burdick and Short, 1999). Furthermore, the attenuation of light in the water (Kd) was higher around floating docks, which led to a smaller percentage of surface light reaching 2 m depth compared with elevated docks. This difference was surprising, and could possibly result from a greater boating activity around floating docks that create more turbid conditions in the water, through resuspension of bottom sediments (Yousef, 1974). Furthermore, floating docks, which move up and down with waves have been seen to create a pumping effect that increases sediment resuspension (Abul-Azm and Gesraha, 2000; Kelty and Bliven, 2003). The effect of dock design and boating activity on shading and water quality needs to be further investigated in the study region.

4.2. Large-scale effects of docks and marinas

As a result of eutrophication and overfishing, over 60% of the eelgrass along the NW coast of Sweden has been lost since the 1980s (Baden et al., 2003, 2012; Moksnes et al., 2008), equivalent to a loss in the order of 10 000 ha (Moksnes et al., 2016). In comparison with these losses, the 480–580 ha of eelgrass negatively affected by docks, as determined by the present study, may not seem substantial. However, in comparison to the present eelgrass distribution along the Swedish NW coast, estimated to approximately 6300 ha (E. Lawett, unpubl. data), the area of eelgrass negatively affected by docks represent 7.6–9.2% of the total area of eelgrass remaining today. Moreover, in areas that have suffered more extensive losses of eelgrass, docks can impact a considerable area relative to the remaining eelgrass. This is particularly true for the municipality of Kungälv, which has lost more than 98% of the eelgrass coverage present in the 1980s (Moksnes et al., 2016). Thus, it is critical to evaluate information about the present and historic distribution of eelgrass in a region, when assessing the relative impact of a dock or marina on the local eelgrass populations.

The results from the present study demonstrates the importance of considering large-scale cumulative effects when assessing the impacts of small-scale exploitation. This has been demonstrated also in a study from the Swedish east coast, which estimated that approximately 40% of important fish habitats had been degraded as a result of coastal construction between 1960 and 2005 (Sundblad and Bergström, 2014). The number of docks used to estimate the total impact on eelgrass in the present study came from inventories performed in 2008, which also found that the number of constructions along the Swedish west coast had increased with approximately 200 docks and 9 marinas between 2003 and 2008 (SEPA, 2010; Pettersson, 2011). That the impact from dock construction is increasing was supported also in the present study of dock application, where 28 new docks, and 16 replacements of elevated docks for floating docks were approved along the NW coast of Sweden between 2011 and 2015. Thus, the total impact of docks on eelgrass today is likely greater than what was estimated in the present study. The study might further underestimate the actual negative impact by small-scale exploitation since only the direct effect of shading was quantified. Several other factors, which were not assessed in this study, such as dredging, propeller scarring and mooring chains, have been shown to create negative effects on seagrass coverage (Walker et al., 1989; Fresh et al., 1995; Burdick and Short, 1999; Shafer and Robinson, 2001; Erftemeijer and Lewis, 2006). Furthermore, landscape effects e.g. from fragmentation were not assessed. This suggests that the total effect of docks and marinas could be substantially higher within the study region.

4.3. Dock design within applications and decisions

The applications and decisions for dock construction analysed in the present study showed that floating docks were the most common design within applications to build new docks and amongst new constructions. Furthermore, 23% of all modifications of docks consisted of changing elevated docks into floating docks, indicating a preference and increasing trend for this type of dock design. This was also supported by the fact that all marinas visited in the present study consisted of floating docks. Considering that the negative impact on eelgrass coverage from floating docks was over 60% higher than from elevated docks, a trend towards more floating docks is worrisome. Due to the detrimental effects from floating docks on eelgrass, general guidelines in the USA concerning dock construction issued by the U.S. Army Corps of Engineers state that floating docks should be avoided if possible (Shafer and Lundin, 1999). To decrease the impact from docks on eelgrass, the recommendation and common design of docks in the USA today is to place floating docks only at water depths which exceed the natural maximum depth distribution of eelgrass in the area, and to use an elevated dock as a walkway out to the floating dock (Burdick and Short, 1999; Landry et al., 2008). Based on the results of the present study, these recommendations would be valid also for Sweden (and likely also elsewhere).

4.4. Eelgrass assessments and considerations in decisions for dock construction

One of the most apparent concerns relating to the protection of eelgrass, was the general absence of eelgrass assessment in the applications and decision processes concerning dock construction. Eelgrass was only mentioned in 12% of the cases where the satellite inventory indicated a high likelihood of eelgrass presence. According to the Swedish Environmental Code (chapter 2, section 1), the responsibility to provide sufficient information about the location aimed for construction lies with the applicant. However, the authorities have the ultimate responsibility to make sure that decisions are based on good grounds, and that the information is sufficient for determining the consequences of a dock (Michanek and Zetterberg, 2012). The lack of eelgrass assessment is not in line with guidelines on shore protection from the SEPA, where eelgrass habitats are explicitly described as a habitat that should be considered when making decisions regarding exemptions from the shore protection (SEPA, 2012). Instead it appears that the applicant is, in most cases, left in charge of determining the negative impacts caused by the proposed construction. Most applicants did not provide any information about environmental impacts. This is problematic, both since the applicants likely lack the knowledge required to make this conclusion, but also because they might be inclined not to report negative impacts that could hinder the approval of the application. Furthermore, the in-depth analysis indicated that the mentioning of any type of nature value or bottom conditions increased the rejection rate of the applications. The fact that this information, similar to the negative impacts, is also provided by the applicant is worrisome. The study further demonstrates that the confirmed presence of eelgrass within the applications had little influence on the decision, since 75% of the decisions were still approved. The reason behind these results are not clear, but could possibly be a result of lack of consideration amongst administrators at municipalities and the County Administrative Board for the cumulative effects from many small dock constructions, for the guidelines regarding protection of habitats within protected areas, and the value of eelgrass habitats also in areas with previous exploitation.

4.4.1. Lack of consideration for cumulative, large-scale effects

One explanation to why small-scale coastal development is allowed to continue and why the confirmed presence of eelgrass had little influence on decisions could be the present approach of assessing each individual case separately without taking into account the cumulative, large-scale impacts on eelgrass habitats. This would entail that the lost value of ecosystem services provided by eelgrass is only related to the individual exploitation case, projecting a relatively innocent nature of each and every dock. If this is the case, it could explain the lack of proper investigations of impact, since the demand for information could be seen as proportionate to the severity of the impact. This approach allows for small-scale coastal development to continue, despite the overall non-negligible total effect on eelgrass demonstrated in the present study. Furthermore, it could also be discussed if the impact from a single dock should be considered negligible in itself. The mean size of docks accepted for construction were on average 80 m^2, and as the present study has shown, the negative impacts from docks reach beyond the actual area of the dock. As a comparison, in California, USA, all impacts on eelgrass larger than 10 m^2 require compensation under the U.S. Clean Water Act through restoring eelgrass habitats (NOAA, 2014).

Local habitat alterations from small cryptic impacts such as boat scarring of seagrass, dock shading, bulkheading of intertidal marshes, levee building, pier development, dredging, etc. are problematic because they are often not immediately noted and build up over time to produce a more substantial impact (Peterson and Lowe, 2009). Although the importance of cumulative impacts has long been recognized (Panek, 1979; Odum, 1982), policy makers and managers have generally failed to consider their large-scale impacts, resulting in regional-scale environmental changes and fragmentation of coastal landscapes (Peterson and Lowe, 2009). Odum (1982) used the term “the tyranny of small decisions” to describe how a lack of considering cumulative effects resulted in a large number of small management decision regarding e.g. exploitation of marshlands or building of drainage canals, which in the end caused extensive losses of coastal wetlands along the east coast of the United States and the reduction of annual surface flow into the Everglades national park, respectively. In order to avoid a slow but continuous degradation of important coastal habitats, managers must consider large-scale cumulative effect of small-scale exploitation such as constructions of docks and marinas.

4.4.2. Lack of consideration for protected areas

One of the most worrying results from the present study of dock applications was the high rate of approvals (59%) for construction of docks located inside protected areas (i.e. national parks, nature reserves and Natura 2000 areas). This is in conflict with the guidelines for shore protection, which states that exemptions should normally not be granted inside such areas (SEPA, 2012). Furthermore, eelgrass is also pointed out in the guidelines as a habitat in which exemptions should normally not be granted (SEPA, 2012). The fact that 69% of the dock applications inside protected areas with eelgrass presence were still approved is in clear conflict with these guidelines. The high approval rate within protected areas is further surprising since the protection was clearly acknowledged within the decisions, meaning that no information gap exists regarding protected areas, as could be stated for the presence of eelgrass. That Swedish nature reserves and Natura 2000 areas provide a very weak protection against coastal exploitation is further supported by an earlier study performed in one of the municipalities in NW Sweden, where no difference was seen in the increase of docks built inside and outside protected areas between 1988 and 2008 (Hellström, 2007). The reason for these results could be that Swedish protected areas that include marine habitats were created mainly to protect habitats on land (Moksnes et al., 2016). Therefore, it may be important to revise the regulations for some protected areas to ensure it provides eelgrass and other important marine habitats with protection from destructive human activities.

4.4.3. Lack of protection in areas with previous development

Although the Swedish shore protection legislation appears to give eelgrass some protection against coastal exploitation, the shore protection is abrogated along parts of the Swedish coast, largely because the area is affected by earlier exploitation, or because of municipal planning decisions. These areas with abrogated shore protection, where only a notification of water operations is required, appear to have a very weak protection against further exploitation as 94% of the cases of docks constructions were approved.

The in-depth analysis of docks built inside protected areas also indicated that previous development in the target area had a large influence on the decision. For example, one case that considered the building of floating docks with a total area of 455 m^2 on eelgrass habitat inside a Natura 2000 area. The decision to approve the construction was justified by arguing that the new dock was placed in an area already exploited in such a way that it was not of any value to the purpose of the shore protection. The construction was also deemed necessary for the marina to remain functional, which overweighed the interest of protecting plants and animals. If previous exploitation in an area is considered a valid reason to grant an exemption from the shore protection, also within protected areas, it is alarming since it would allow coastal exploitation to spread unimpeded. Furthermore, it could be strongly questioned if a habitat adjacent to an existing dock or marina has no value to the purpose of the shore protection, which is not only to secure access to the water for the general public, but also to preserve the living conditions for plants and animals on and around the shoreline (SEC; chapter 7, section 13). As the present study has shown, eelgrass meadows with high coverage can grow within 10 m from docks and marinas, which provide a number of important ecosystem functions to the area, such as increasing the local biodiversity and water clarity (e.g. Cole and Moksnes, 2016). Moreover, studies along the Swedish NW coast have shown that when an eelgrass meadow is lost, the water transparency can decrease with over 1 m due to increased sediment resuspension, preventing eelgrass from growing in the area (Moksnes et al., 2016). Such changes likely occur at a threshold size of the meadow, when it becomes too small to stabilize the sediment, after which the remaining eelgrass is quickly lost by the decreasing water quality (Duffy et al., 2014; Maxwell et al., 2016). Thus, in areas where the eelgrass has already suffered large losses and is presently fragmented, such as along the Swedish NW coast, a relative small-scale exploitation of eelgrass may push the system over the tipping-point, causing an accelerating loss of eelgrass in the area.

4.5. Conclusions and suggestions for improving eelgrass management in Sweden

Considering the range of ecosystem functions that eelgrass provide, the loss over time and space is not only of pure ecological importance, but also of societal interest, since the loss could lead to e.g. decreased water clarity and recreational value, beach erosion and loss of fish production and biodiversity (Bos et al., 2007; Van der Heide et al., 2007; Bilkovic and Roggero, 2008; Cole and Moksnes, 2016). The present study demonstrates a large-scale effect on eelgrass by small-scale coastal constructions, and indicates that without any measures to fully compensate for these losses, it will not be possible to achieve national and international goals of protection and no-net loss of eelgrass habitats (Anonymous, 2012; OSPAR, 2012; HELCOM, 2013), nor to achieve the environmental status required by EU-directives. Furthermore, in Sweden, national managers are presently planning extensive restoration of eelgrass habitats to compensate for historical losses (SwAM, 2015). Considering that the amount of eelgrass planned to be restored (120 ha to a cost of approximately 11.5 million Euro), is less than the amount presently being negatively affected by docks in NW Sweden alone (480 ha), it could be considered contra productive to allow coastal exploitation of eelgrass to continue while at the same time demanding costly measures to be taken in order to restore these habitats.

The guideline by the Swedish Environmental Protection Agency clearly identifies eelgrass habitats and protected areas as environments where exemptions from the shore protection should generally not be granted, unless it is obvious that the purpose of the shore protection is not harmed (SEPA, 2012). In order to fulfil this recommendation there is a need for authorities to increase the demand on the information provided by the applicants, e.g. regarding bottom conditions, where all negative impacts on eelgrass should be reported. It is also important that Swedish authorities are restrictive in giving exceptions from the shore protection and approving dock constructions when eelgrass habitats are present, particularly along the Swedish NW coast where large losses of eelgrass have occurred. In the decision process, it is critical that the authorities consider the ecological value of eelgrass also if the area have earlier developments, and in particular consider the cumulative, large-scale impact of all small-scale exploitations in the area and how it would affect national and international environmental objectives and commitments. Thus, managers on local and regional levels should apply a landscape perspective to coastal management and relate each small-scale project to the spatial distribution of natural resources and other human activities along the coast. This type of *marine spatial planning* is gaining considerable importance all around the world where various countries use it as a tool to achieve sustainable use of marine resources (Douvere, 2008).

In the cases when the construction has been approved and alternative locations were missing, it is important to use compensatory restoration of eelgrass to fully compensate for all ecosystem services lost. This is important to prevent the continuation of net-losses of eelgrass habitats along the Swedish coasts. Based on the successful California eelgrass mitigation policy (NOAA, 2014), a guideline for compensatory restoration of eelgrass in Sweden was recently developed, which recommend to use compensation for all exploitation cases where more than 100 m^2 of eelgrass is negatively affected (Moksnes et al., 2016). There is also a need to develop a guideline for construction of docks that minimize the negative effects from shading, and where floating docks should be avoided over eelgrass bottoms.

Finally, to handle the increasing demand for boat space along the coasts without further degrading coastal habitats, it may also be necessary to change people's habits regarding boat use. There is a need to move away from the perception that everyone in Sweden has the right to a private dock by their house or cottage, or keeping their boat in the water when it is not in use. According to the latest report on boat use in Sweden, from the Swedish Transport Agency (STA), the average boat is only used 16 days between May to September (STA, 2015) Furthermore, approximately 50% of boats are moored at private docks while less than 10% are found within marinas or at common docks. A behavioural change regarding boat usage could possibly be accomplished through information campaigns about the benefits of renting boats, or keeping boats out of the water when not in use (e.g. decreased problems with fouling), and increasing the availability of public boat ramps with parking space for trailers, or dry-stack marinas with boat storage on land and launching assistance. Such a change could decrease the pressure on coastal habitats without any negative effects on the development and the economy of small coastal communities.

Acknowledgement

This research was funded through two PhD-positions from the interdisciplinary graduate school in environmental marine research at the University of Gothenburg, and by grants to L. Gipperth and P-O. Moksnes from the Swedish Research Council FORMAS (contract no. 212-2011-758) and the Swedish Agency for Marine and Water Management (contract no. 4832-12). We would like to thank Jonas Nilsson for valuable assistance in retrieving and revising dock decisions.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2017.08.005.

References

Abul-Azm, A.G., Gesraha, M.R., 2000. Approximation to the hydrodynamics of floating pontoons under oblique waves. Ocean. Eng. 27, 365–384.
Anonymous, 2012. Svenska miljömål: preciseringar av miljökvalitetsmålen och en första uppsättning etappmål, Ds 2012:23. Miljödepartementet, Regeringskansliet, Stockholm, ISBN 978-91-38-23762-5. In Swedish.
Baden, S.P., Pihl, L., 1984. Production, abundance and biomass of mobile epibenthic fauna in *Zostera marina* meadows. Ophelia 23, 65–90.
Baden, S., Gullström, M., Lundén, B., Pihl, L., Rosenberg, R., 2003. Vanishing Seagrass (*Zostera marina*, L.) in Swedish coastal waters. Ambio 32, 374–377.
Baden, S., Boström, C., Tobiasson, S., Arponen, H., Moksnes, P.-O., 2010. Relative importance of trophic interactions and nutrient enrichment in seagrass ecosystems: a broad-scale field experiment in the Baltic–Skagerrak area. Limnol. Oceanogr. 55, 1435–1448.
Baden, S., Emanuelsson, A., Pihl, L., Svensson, C.-J., Åberg, P., 2012. Shift in seagrass food web structure over decades is linked to overfishing. Mar. Ecol. Prog. Ser. 451, 61–73.
Beal, J.L., Schmit, B.S., 2000. The effects of dock height on light irradiance (PAR) and seagrass (*Halodule wrightii* and *Syringodium filiforme*) cover. In: Bortone, S.A. (Ed.), Seagrasses: Monitoring, Ecology, Physiology, and Management, Marine Science Series, vol. 16. CRC Press, Boca Raton, pp. 49–63.
Bilkovic, D.M., Roggero, M.M., 2008. Effects of coastal development on nearshore estuarine nekton communities. Mar. Ecol. Prog. Ser. 358, 27–39.
Bos, A.R., Bouma, T.J., de Kort, G.L.J., van Katwijk, M.M., 2007. Ecosystem engineering by annual intertidal seagrass beds: sediment accretion and modification. Estuar. Coast Shelf S 74, 344–348.
Burdick, D.M., Short, F.T., 1999. The effects of boat docks on eelgrass beds in coastal waters of Massachusetts. Environ. Manag. 23, 231–240.
Cole, S.G., Moksnes, P.-O., 2016. Valuing multiple ecosystem services in Sweden: fish production and uptake of carbon and nitrogen. Front. Mar. Sci. 2, 121. http://dx.doi.org/10.3389/fmars.2015.00121.
den Hartog, C., 1970. Verh. K. Ned. Ak. Wet. Adf. North Holland Amsterdam. The Seagrasses of the World, vol. 59, pp. 1–275.
Dennison, W.C., Orth, R.J., Moore, K.A., Stevenson, J.C., Carter, V., Kollar, S., Bergstrom, P.W., Batiuk, R.A., 1993. Assessing water quality with submersed aquatic vegetation. BioScience 43, 86–94.
Douvere, F., 2008. The importance of marine spatial planning in advancing ecosystem-based sea use management. Mar. Policy 32, 762–771.
Duarte, C.M., 1991. Seagrass depth limits. Aquat. Bot. 40, 363–377.
Duarte, C.M., Krause-Jensen, D., 2017. Export from seagrass meadows contributes to

marine carbon sequestration. Front. Mar. Sci. 4, 13.
Duffy, J.E., Hughes, A.R., Moksnes, P.-O., 2014. Ecology of seagrass communities. In: Bertness, M.D., Bruno, J.F., Silliman, B.R., Stachowicz, J.J. (Eds.), Marine community Ecology and Conservation. Sinauer Associates, Inc, pp. 271–297.
Envall, M., Lawett, E., 2016. Satelitbildsanalys för uppföljning gav vegetation på grund marin botten. In: Metodtest med fältverifikation för uppskattning av utbredning av ålgräs och annan långskottsvegetation men satelitbildsanalys – jämförelse Sveriges västkust och ostkust. In Swedish. Havs och Vattenmyndighetens rapport 2015:6.
Erftemeijer, P.L.A., Lewis III, R.R.R., 2006. Environmental impacts of dredging on seagrasses: a review. Mar. Pollut. Bull. 52, 1553–1572.
Eriander, L., Infantes, E., Olofsson, M., Olsen, J.L., Moksnes, P.-O., 2016. Assessing methods for restoration of eelgrass (*Zostera marina* L.) in a cold temperate region. J. Exp. Mar. Biol. Ecol. 479, 76–88.
European Commission, 2011. Our Life Insurance, Our Natural Capital: an EU Biodiversity Strategy to 2020. European Commission, Brussels.
Frederiksen, M., Krause-Jensen, D., Holmer, M., Sund Laursen, J., 2004. Long-term changes in area distribution of eelgrass (Zostera marina) in Danish coastal waters. Aquat. Bot. 78, 167–181.
Fresh, K.L., Williams, B.W., Penttila, D., 1995. Overwater structures and impacts on eelgrass (*Zostera marina*) in Puget Sound, Washington. In: Proceedings of Puget Sound Research '95. Puget Sound Water Quality Authority, Olympia, WA, pp. 537–543.
Fresh, K.L., Wyllie-Echeverria, T., Wyllie-Echeverria, S., Williams, B.W., 2006. Using light-permeable grating to mitigate impacts of residential floats on eelgrass *Zostera marina* L. in Puget Sound, Washington. Ecol. Eng. 28, 354–362.
Garrison, P.J., Marshall, D.W., Stremick-Thompson, L., Cicero, P.L., Dearlove, P.D., 2005. Effects of Dock Shading on Littoral Zone Habitat and Communities in Lake Ripley and Rock, Jefferson County. Wisconsin Department of Natural Resources Research Report No. ISS PUB-SS-1006 2005, Madison.
Giesen, W.B.J.T., van Katwijk, M.M., den Hartog, C., 1990. Eelgrass condition and turbidity in the Dutch Wadden sea. Aquat. Bot. 37, 71–85.
Gipperth, L., 1999. Miljökvalitetsnormer: en rättsvetenskaplig studie i regelteknik för operationalisering av miljömål (Uppsala). In Swedish.
Gladstone, W., Courtenay, G., 2014. Impacts of docks on seagrass and effects of management practices to ameliorate these impacts. Estuar. Coast Shelf S 136, 53–60.
Green, E.P., Short, F.T., 2003. World Atlas of Seagrasses. California University Press, p. 310.
Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, M.P.E., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A global map of human impact on marine ecosystems. Science 319, 948.
HELCOM, 2010. Towards an ecologically coherent network of well-managed Marine Protected Areas – implementation report on the status and ecological coherence of the HELCOM BSPA network. In: Baltic Sea Environment Proceedings, No. 124B. Helsinki Commission, 148 pp.
HELCOM, 2013. Red List of Baltic Sea underwater biotopes, habitats and biotope complexes. In: Baltic Sea Environmental Proceedings No. 138.
Hellström, H., 2007. Strandexploatering I Strömstad kommuns södra skärgård. Länsstyrelsen I Västra Götalands län. In Swedish.
Kelty, R.A., Bliven, S., 2003. Environmental and aesthetic impacts of small docks and docks, workshop report: developing a science-based decision support tool for small dock management, phase 1: status of the science. In: NOAA Coastal Ocean Program Decision Analysis Series No. 22. National Centers for Coastal Ocean Science, Silver Spring, MD, 69 pp.
Kruk-Dowgiallo, L., 1991. Long term changes in the structure of underwater meadows of the Puck Lagoon. Acta Icht. Pisc XXI, 77–84. Supplement. Szczecin.
Landry, J.B., Kenworthy, W.J., Di Carlo, G., 2008. The Effects of Docks on Seagrasses with Particular Emphasis on the Threatened Seagrass, Halophila johnsonii. Report to NMFS.
Lawett, E., Olsson, A., Envall, M., 2013. Ålgräs på Västkusten – test av metoder för fjärranalys, kartering, inventering och kvalitetsklassificering. In Swedish. Länsstyrelsen Rapport 2013:84.
Lilley, R.J., Unsworth, R.K., 2014. Atlantic Cod (Gadus morhua) benefits from the availability of seagrass (Zostera marina) nursery habitat. Glob. Ecol. Conserv. 2, 367–377.
Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M., Kirby, M.X., Peterson, C.H., Jackson, J.B.C., 2006. Depletion, degradation, and recovery potential of Estuaries and coastal seas. Science 312, 1806.
Maxwell, P.S., Eklöf, J.S., van Katwijk, M.M., O'Brien, K.R., de la Torre-Castro, M., Boström, C., Bouma, T.J., Krause-Jensen, D., Unsworth, R.K.F., van Tussenbroek, B., van der Heide, T., 2016. The fundamental role of ecological feedback mechanisms for the adaptive management of seagrass ecosystems – a review. Biol. Rev. http://dx.doi.org/10.1111/brv.12294.
McGlathery, K.J., Reynolds, L.K., Cole, L.W., Orth, R.J., Marion, S.R., Schwarzschild, A., 2012. Recovery trajectories during state change from bare msediment to eelgrass dominance. Mar. Ecol. Prog. Ser. 448, 209–221.
Michanek, G., Zetterberg, C., 2012. Den svenska miljörätten. Iustus, Uppsala. In swedish.
Moksnes, P.-O., Gullström, M., Tryman, K., Baden, S., 2008. Trophic cascades in a temperate seagrass community. Oikos 117, 763–777.
Moksnes, P.-O., Gipperth, L., Eriander, L., Laas, K., Cole, S., Infantes, E., 2016. Förvaltning och restaurering av ålgräs i Sverige – Ekologisk, juridisk och ekonomisk bakgrund. Havs och Vattenmyndigheten. Rapport 2016:8, ISBN 978-91-87967-16-0, p. 148. In Swedish.
Munkes, B., 2005. Eutrophication, phase shift, the delay and the potential return in the Greifswalder Bodden, Baltic Sea. Aquat. Sci. 67, 372–381.
NOAA, 2014. California Eelgrass Mitigation Policy and Implementing Guidelines. National Oceanic and Atmospheric Administration (NOAA). West Coast Region October 2014.
Nyqvist, A., André, C., Gullström, M., Baden, S., Åberg, P., 2009. Dynamics of seagrass meadows on the Swedish Skagerrak coast. Ambio 38, 85–88.
Odum, W.E., 1982. Environmental degradation and the tyranny of small decisions. BioScience 32 (9), 728–729.
Onuf, C.P., 1994. Seagrasses, dredging and light in Laguna Madre, Texas, USA. Estuar. Coast Shelf S 39, 75–91.
Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., 2006. A global crisis for seagrass ecosystems. Bioscience 56, 987–996.
OSPAR, 2012. OSPAR Recommendation 2012/4 on Furthering the Protection and Conservation of Zostera Beds.
Panek, F.M., 1979. Cumulative effects of small modifications to habitat. Fisheries 4 (2), 54–57.
Peterson, M.S., Lowe, M.R., 2009. Implications of cumulative impacts to estuarine and marine habitat quality for fish and invertebrate resources. Rev. Fish. Sci. 17 (4), 505–523.
Pettersson, K., 2011. Hur mycket tål kusten? Västerhavet 2011, Aktuellt om miljön i Skagerrak, Kattegat och Öresund. In Swedish.
Queiroga, H., Moksnes, P.-O., Meireles, S., 2002. Vertical migration behavior in the larvae of the common shore crab *Carcinus maenas* (L.), from a micro-tidal fjord in Sweden. Mar. Ecol. Prog. Ser. 237, 195–207.
Röhr, M.E., Boström, C., Canal-Vergés, P., Holmer, M., 2016. Blue carbon stocks in Baltic Sea eelgrass (Zostera marina) meadows. Biogeosciences 13 (22), 6139.
Schoellhamer, D.H., 1996. Anthropogenic sediment resuspension mechanisms in a shallow Microtidal Estuary. Estuar. Coast Shelf S 43, 533–548.
Shafer, D.J., 1999. The effects of dock shading on the seagrass *Halodule wrightii* in Perdido Bay, Alabama. Estuaries 22, 936–943.
Shafer, D.J., Lundin, J., 1999. Design and Construction of Docks to Minimize Seagrass Impacts. WRP Technical Notes Collection (TN WRP-VN-RS-3.1). U.S. Army Engineer Research and Development Center, Vicksburg, MS.
Shafer, D.J., Robinson, J., 2001. An Evaluation of the Use of Grid Platforms to Minimize Shading Impacts to Seagrasses. WRAP Technical Notes Collection (ERDC TN -WRAP–01–02. US Army Engineer Research and Development Center, Vicksburg, MS. Available at: www.wes.army.mil/el/wrap.
Short, F.T., Wyllie-Escheverria, S., 1996. Natural and human-induced disturbance of seagrasses. Environ. Conserv. 23, 17–27.
Sundblad, G., Bergström, U., 2014. Shoreline development and degradation of coastal fish reproduction habitats. AMBIO 43, 1020–1028.
SwAM, 2015. Swedish Agency for Marine and Water Management. God havsmiljö 2020 Marin strategi för Nordsjön och Östersjön, Del 4: Åtgärdsprogram för havsmiljön. Havs- och vattenmyndighetens rapport 2015:30. In Swedish.
SWECO, 2013. Utvärdering och analys av de nya strandskyddsreglerna – sammanställning och jämförande analys av genomförda enkäter till länsstyrelser och kommuner, 2013. Report no. 3831701000. Sweco Architects AB. In Swedish. Available at: http://www.strandskyddsdelegationen.se/wp-content/uploads/Utvärdering-och-analys-av-de-nya-strandskyddsreglerna-sammanställning-och-jämförande-analys-av-genomförda-enkäter-till-länsstyrelser-och-kommuner-SWECO.pdf.
SEPA, 2010. Kartering och analys av fysiska påverkansfaktorer i marin miljö. Report no. 6376, ISBN 978-91-620-6376-4. In Swedish.
SEPA, 2012. Strandskydd – en vägledning för planering och prövning. Handbok 2009:4, utgåva 2, februari 2012, ISBN 978-91-620-0175-9. In Swedish.
STA, 2015. Båtlivsundersökning 2015 – En undersökning om svenska fritidsbåtar och hur de används. Rapport no. TSG 2016–2534, mars 2016. In Swedish.
Van der Heide, T., van Nes, E.H., Geerling, G.W., Smolders, A.J.P., Bouma, T.J., van Katwijk, M., 2007. Positive feedback in seagrass ecosystems: implications for restoration success in conservation and restoration. Ecosystems 10, 1311–1322.
Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M., 1997. Human domination of Earth's ecosystems. Science 277, 494–499.
Walker, D.I., Lukatelich, R.J., Bastyan, G., McComb, A.J., 1989. Effect of boat moorings on seagrass beds near Perth, Western Australia. Aquat. Bot. 36, 69–77.
Waycott, M., Duarte, C.M., Carruthers, T.J.B., Orth, R.J., Dennison, W.C., Olyarnik, S., Calladine, A., Fouqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Short, F.T., Williams, S.L., 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. PNAS 106, 12377–12381.
Westerlund, S., 2003. Miljörättsliga grundfrågor 2.0. Institutet för miljörätt (IMIR), Björklinge. In Swedish.
Yousef, 1974. Assessing Effects on Water Quality by Boating Activity. EPA670/2-74-072. U.S. Environmental Protection Agency.