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

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## 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 (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

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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.

### 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 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