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Climate change can cause complex responses in Baltic Sea macroalgae: A systematic review

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ABSTRACT

Estuarine macroalgae are important primary producers in aquatic ecosystems, and often foundation species providing structurally complex habitat. Climate change alters many abiotic factors that affect their long-term persistence and distribution. Here, we review the existing scientific literature on the tolerance of key macroalgal species in the Baltic Sea, the world's largest brackish water body. Elevated temperature is expected to intensify coastal eutrophication, further promoting growth of opportunistic, filamentous species, especially green algae, which are often species associated with intensive filamentous algal blooms. Declining salinities will push the distributions of marine species towards south, which may alter the Baltic Sea community compositions towards a more limnic state. Together with increasing eutrophication trends this may cause losses in marine-originating foundation species such as *Fucus*, causing severe biodiversity impacts. Experimental results on ocean acidification effects on macroalgae are mixed, with only few studies conducted in the Baltic Sea. We conclude that climate change can alter the structure and functioning of macroalgal ecosystems especially in the northern Baltic coastal areas, and can potentially act synergistically with eutrophication. We briefly discuss potential adaptation measures.

Contents

1. Introduction: Climate change impacts in marine ecosystems

In the recent decade anthropogenic climate change has been recognized as a global biodiversity threat, motivating extensive research on its biological impacts (Wernberg et al., 2012). However, the majority of research has focused on terrestrial ecosystems, and detailed knowledge of impacts in marine ecosystems is lagging behind (Rosenzweig et al., 2008).

Coastal macroalgae are important foundation species providing biomass and structurally complex habitats important for coastal biodiversity (Airoldi et al., 2008; Eriksson et al., 2006). Macrolgal beds are

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highly productive environments comprising an important carbon sink (Chung et al., 2011). Climate change has caused extensive poleward shifts of macroalgal distributions including range contractions as species are tracking their thermal niches (Nicastro et al., 2013; Wernberg et al., 2011), and more extensive shifts have been projected for the future (Jueterbock et al., 2013; Müller et al., 2009). Macroalgae have been proposed to benefit from ocean acidification (OA) (Hall-Spencer et al., 2008; Koch et al., 2013) but so far experimental evidence remains mixed (Hurd et al., 2009).

In this study we review climate change impacts on key Baltic Sea macroalgae species. As shallow inland sea, the Baltic is particularly prone to warming, and observed rates of warming at the end of the 20th century have been highest in all of the world's large marine ecosystems (Belkin, 2009). We utilize both studies that have been conducted with climate change focus, as well as studies that have been conducted on environmental tolerances of key species.

The Baltic Sea is a large, shallow brackish water epeiric sea heavily impacted by human activities. Allegedly one of the biggest threats to the Baltic ecosystem during the 21st century is climate change with predicted declines in salinity and elevated temperatures (Meier et al., 2012a). As the brackish water environment is challenging for both marine and limnic species, the Baltic Sea ecosystem is relatively species-poor, and the species distributions are controlled by a steep salinity gradient. Low salinity and seasonal temperature oscillations cause many species to exist at the edges of their geographic distribution (Hällfors et al., 1981), and towards the northern areas in the Baltic Sea the conditions become more severe in form of shorter growing season, longer ice cover, and declining salinity (Fig. 1a).

In the Baltic coastal zones, the habitat-forming macroalgae are the foundation species in rocky shore ecosystems, which are the prevalent shore types in the northern and western archipelago areas (Hällfors et al., 1981, Fig. 1b). The vertical zonation of algal species creates a structurally complex habitat, which is important for both juvenile fish and small invertebrates, thus harboring a large fraction of biodiversity in the Baltic coastal ecosystems (Hällfors et al., 1981; Kautsky et al., 1992). Especially the perennial, habitat-forming species have suffered from coastal eutrophication, causing declines in abundance and depth penetration during the 20th century (Kautsky and Kautsky, 1986). Eutrophication has also favoured fast-growing, filamentous species, which has culminated in the emergence of drifting, decomposing algal mats destroying soft-bottom communities (Norkko and Bonsdorff, 1996).

While in oceanic areas climate change has been projected to cause northward shifts in macroalgal distributions (Müller et al., 2009), the patterns are different in the Baltic. Declining salinities (Meier et al., 2012a) may counteract the general trends, pushing the distributions of marine-originated species towards south (Vuorinen et al., 2015). This, together with other interacting human impacts makes the Baltic macroalgae particularly interesting study organisms for climate change ecology. As the northern and western shores and archipelagos of the Baltic contain large fraction of the suitable shores for macroalgae, we focus our review on dominant species occurring in these areas.

2. The changing abiotic conditions in the Baltic Sea

The sea surface temperature (SST) of the Baltic has warmed rapidly during recent decades. Siegel et al. (2006) observed warming of 0.8 °C over 15 years, in good agreement of unprecedented warming of 0.6 °C between 1985 and early 2000 reported by MacKenzie and Schiedek (2007), who also reported increased frequency of extreme temperatures. MacKenzie and Schiedek (2007) observed the warming of the Baltic and North Sea to be three times higher than the global average. The BACC I report (BACC Author Team, 2008) states warming of air temperatures by 1 °C from the beginning of the 1980s to 2004, while Lehmann et al. (2011) identified warming of 0.5 °C per decade for the northern Baltic, which seems to be warming more rapidly. Finally, Belkin (2009) reported observed warming of SST of 1.35 °C (1982–2006), which was higher than in any other Large Marine Ecosystem in the world, and seven times higher than the observed global warming rate (Belkin, 2009).

Salinity conditions in the Baltic depend on riverine inflow of fresh water and stochastic inflow of saline water through Danish straits (Leppäranta and Myrberg, 2009). No clear long-term trend in salinity has been observed for the last hundred years (Fonselius and

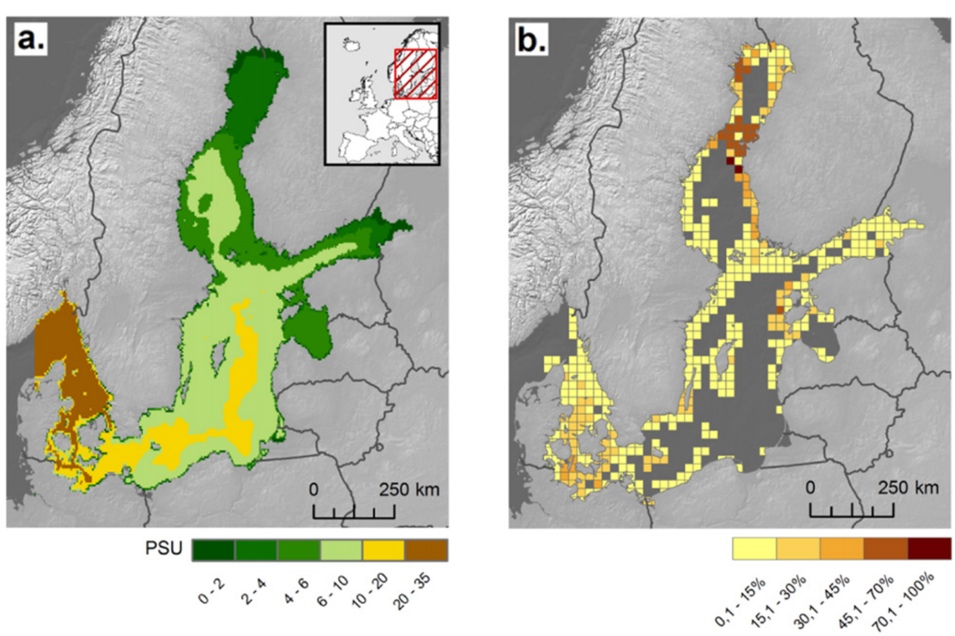

Fig. 1. a) Current salinity distribution of the Baltic Sea b) abundance of photic hard bottoms, the potential habitat for the macroalgae. Values are percentages of photic hard bottoms in relation to total bottom area.
Data source: a) EUSeaMap (Cameron and Askew, 2011) b) Benthic biotope complexes in the Baltic Sea (HELCOM, 2010).