Name of indicator	2.15 Reed belt extent – the NDVI approach via high resolution satellite images
Type of Indicator	State indicator
Author(s)	Hanna Piepponen, Meri Koskelainen and Kirsi Kostamo
Description of the indicator	The indicator expresses the extent of coastal reed belts, using information from remote sensing and exposition-depth data. The reed belt extent in the archipelago of South-western Finland, in the MARMONI 3FIN study area, was examined from high resolution satellite images dating from September 2009 (RapidEye, 5m by 5m resolution) and July 2013 (WorldView, 2m by 2m resolution). For verifying the results, data from Kotka located in South-eastern Finland was used. The Kotka satellite images dated from July 2011 (RapidEye, 5m by 5m resolution) and September 2012 (WorldView, 2m by 2m resolution). The indicator is a combination of Normalized Difference Vegetation Index (NDVI) and the exposition-depth data (Isaeus & Rygg 2005, Tolvanen 2010) that shows the optimum growing area for reed vegetation. The indicator demonstrates the local extent of reed communities very well in the two test areas. NDVI calculated from satellite images shows the actual extent and location of reed communities in sheltered areas. A temporal aspect is possible to attain by comparing seasonal changes in reed vegetation, provided that suitable satellite images are available. However, both the temporal and spatial coverage of the indicator is still fairly restricted due to a lack of available high resolution satellite images, and for a better coverage of reed vegetation information in the Gulf of Finland a higher number of high resolution satellite images are needed. Images of a coarser resolution are not useful for local scale reed belt extent studies because they do not provide reliable spatial information for the calculation of the size and shape of the reed belt by the NDVI. Coarse resolution Landsat (30m by 30m resolution) satellite images were tested but the results are too rough for closer examination of changes in reed belt extent. The lack of high resolution satellite images also prevents comparing temporal changes in coastal areas in a long time scale, so the development of the index requires further studies with upcoming satellite images. Availability of usable high resolution satellite images is not certain because the weather conditions and scanning time limit the use of all available images from a study area. Summarizing the above, high resolution satellite images of sufficient spatial and temporal frequency are requisite for the indicator.
Relationship of the indicator to marine biodiversity	Common reed, *Pharagmites australis* (Cav.) Trin. Ex Steudel, is an erect perennial grass growing in lakes, trenches, shore and bog meadows in Northern Europe (Hämet-Ahti *et al*. 1998). It often forms dense and more or less monospecific patches or areas consuming all available growing space. Both the number and coverage of reed patches has increased in many areas both in disturbed and forested sites in Northern America (McCormick *et al*. 2010). Common reed is a rapidly expanding species which can reproduce both clonally and sexually. Even though it forms very dense patches, negative effects of shading on plant biodiversity have not been established (Güsewell & Edwards 1999). Furthermore, it has been discovered that the species richness does not decrease as a result of an increase in reed biomass (Grime 1973, 1979, Güsewell & Edwards 1999), but changes from aquatic macrophytes towards species occurring in the geolittoral (Munsterhjelm 1997). Furthermore, high reed biomasses may alter the proportion of species so that the plant community will develop so that light-demanding species from nutrient-poor sites are replaced by more shade-tolerant and more nutrient-demanding species. In light of these results, it is also likely that an increase in eutrophication may affect the plant community composition (Tilman 1982, 1987, Olff 1992, Eek & Zobel 1997). Since the light interception by common reed follows a clear seasonal pattern and is negligible until June, its impacts on species developing in spring or early summer are likely to be strongly reduced by phenological separation (Güsewell & Edwards 1999). Therefore species, growing until the end of the summer, are more likely to be influenced by *P. australis* than species that complete their annual growth in early summer or which are at least capable of doing so if light conditions decline. The relationship between species richness and reed biomass is further complicated by the different types of wetland communities (Güsewell & Edwards 1999). Thus the coexistence of other wetland species and succession of species composition can increase the biodiversity of the reed communities.
Relevance of the indicator to different policy instruments	EU Marine Strategy Framework Directive: descriptor 1 Biodiversity, 1.5 Habitat extent, 1.5.1 Habitat area. HELCOM Baltic Sea Action Plan ecological objective for 'natural marine and coastal landscapes'. Habitats Directive: state of the coastal habitats and protected species.
Relevance to	1.5. Habitat extent

commission decision criteria and indicator	1.5.1. Habitat area
Method(s) for obtaining indicator values	The coverage of common reed was estimated by using information provided by satellite remote sensing (RapidEye 5m by 5m resolution and WorldView-2 2m by 2m resolution). The reed vegetation presence was determined from the images by calculating the Normalized Difference Vegetation Index (NDVI), which was calculated from the band relations between red and infrared bands. NDVI areas were extracted to water areas by clipping the data by shoreline as we assumed that all the vegetation in water is reed vegetation. The threshold value of the NDVI was set in both summer and fall images to 0.2 to avoid errors caused by highly reflecting objects such as sailboats. In general, the reflection from vegetation was more moderate in fall compared to summer when the reflection intensity was the highest and shows the maximum vegetation cover. The indicator utilizes depth-exposition data to determine the potential growing area of reed belts. Used depth-exposition data covers the shoreline from 0 to 2m in depth (Luther 1951a, 1951b) and exposition of less than 100 000 (sheltered and moderately sheltered areas, Munsterhjelm 1997, 2005); these conditions were considered to be the optimum growing area for reed vegetation. Over 95% of NDVI areas were included in depth-exposition area showing that the optimum area for reed vegetation is coherent. Cloudy areas on each used data were removed for reducing errors and the pixel size of each data was resampled to the same size (4m by 4m). In addition to satellite remote sensing, the maximum extent of reed belts was confirmed by local field measurements during summer 2013 in Tammisaari. A comparison of summer and fall images revealed that it is possible to use both late summer and early fall satellite images for determining reed belt extent. Spring images (April, May) are not useful in Finnish coastal areas especially when growing season starts late due to elongated winter because the reed coverage reaches its maximum extent only in late June or July. Fall images (September) are usable but they underestimate the reed belt extent by about 10%. This was verified by calculations in Kotka, South-eastern Finland, from satellite images in July 2011 and in September 2012. The assumption was that reed vegetation has not changed during one year, and therefore, the reed extent in fall and summer images should be the same. As the reed extent in fall was smaller than in summer we derived a coefficient of 10% of underestimation for fall images. After adding 10% to reed vegetation data in fall 2009 in Tammisaari in the MARMONI 3FIN study area, we concluded that the reed belt extent has expanded by 1% during the period 2009–2013.
Documentation of relationship between indicator and pressure	The main pressures affecting the extent of the reed belts are land use and eutrophication. In the coastline of the Northern Baltic Sea, also land uplift influences the reed extent through a series of succession stages resulting from geological succession of the shoreline (Munsterhjelm 1997, 2005). Disturbance of upland habitats and eutrophication of estuaries have been shown to be positively correlated with the abundance of common reed (Bertness *et al*. 2002, Silliman & Bertness 2004, King *et al*. 2007, Chambers *et al*. 2008). A higher level of disturbance in developed watersheds can create open spaces for seedling emergence and rhizoid settlement and establishment and thus facilitate dispersal of this species (Kettenring et al. 2011). Offsite human activities, such as human alteration to surrounding uplands (Burdick *et al*. 2001, Bertness *et al.* 2002), atmospheric enrichment of nitrogen and carbon dioxide, and altered climate, may also enhance invasions (Minchington 2002, Burdick & Konisky 2003). The changes in land use can be analysed from, e.g.*,* CORINE-remote sensing data, but since this data exists currently only from 2000 and 2006, more data is needed to confirm this relationship. The effects of eutrophication are more complex in macrophyte communities than in plankton or annual macroalgal communities, because macrophytes take up nutrients with roots from the bottom sediments and not directly from the water. The effects of eutrophication are therefore accumulative and should be studied more in relation to a temporal aspect, *e.g.,* the nutrient content of the water column versus the nutrient content in the sediment. When considering grasses, including common reed, the increase in reproductive output resulting from eutrophication may enhance the invaders ability to establish new, genetically distinct populations and enhance the spatial dominance in already invaded areas. Furthermore, increased input of atmospheric nitrogen and carbon dioxide levels can alter the competitive balance of marsh plants in favour of common reed (Jaworski *et al*. 1997). Nutrient enrichment results in taller stems, increase in floret and inflorescence production and overall biomass, but also an increase in asexual reproduction (Minchinton & Bertness 2003, Rickey & Anderson 2004, Saltonsall *et al*. 2004, Saltonsall & Stevenson 2007, Mozdzer & Zieman 2010, Kettenring *et al*. 2011). On one hand, it has been discovered that if the reed colony is under high nitrogen levels, it may invest heavily on rhizome production (Rickey & Anderson 2004). This enables dispersal to areas, where low nitrogen content prevents population establishment by seeds (Bart & Hartman 2002). On the other hand, in high nutrient regime, seedling emergence and establishment benefit from eutrophication

	and increase the probability that population establishment occurs via seeds (Saltonsall & Stevenson 2007). Surprisingly, according to some studies, it has also been discovered that under high nutrient levels the below-ground biomass does not increase, although this is expected in populations where dispersal occurs by fragmented pieces of rhizoids (Haslam 1965, Rickey & Anderson 2004). Instead, the above-ground biomass increases (Minchinton & Bertness 2003, Rickey & Anderson 2004). It has also been discovered that under a high nutrient regime, the species spreads to deeper water than in oligotrophic conditions (Haslam 1965, 1972). The increase in nitrogen levels has been linked to the successful dispersal of common reed in a large number of areas (Haslam 1965, Marks *et al.* 1994). However, it has also been discovered that an increase in nitrogen increases also the growth of native species, so the eradicative effects of nutrients might not be as strong as assumed earlier (Rickey & Anderson 2004). All in all however, present knowledge suggests that eutrophication favours reed belt extent.
Geographical relevance of indicator	4. Baltic Sea wide
How Reference Conditions (target values/thresholds) for the indicator were obtained?	The target is trend-based, expecting no increase of area covered by reed belts, as indicated by the NDVI, in order to achieve Good Environmental Status.
Method for determining GES	The trend-based target for reed belt extent, as indicated by the NDVI, is estimated for the years 2002-2013, using medium resolution images for 2002-2009 and high resolution images for 2009-2013.
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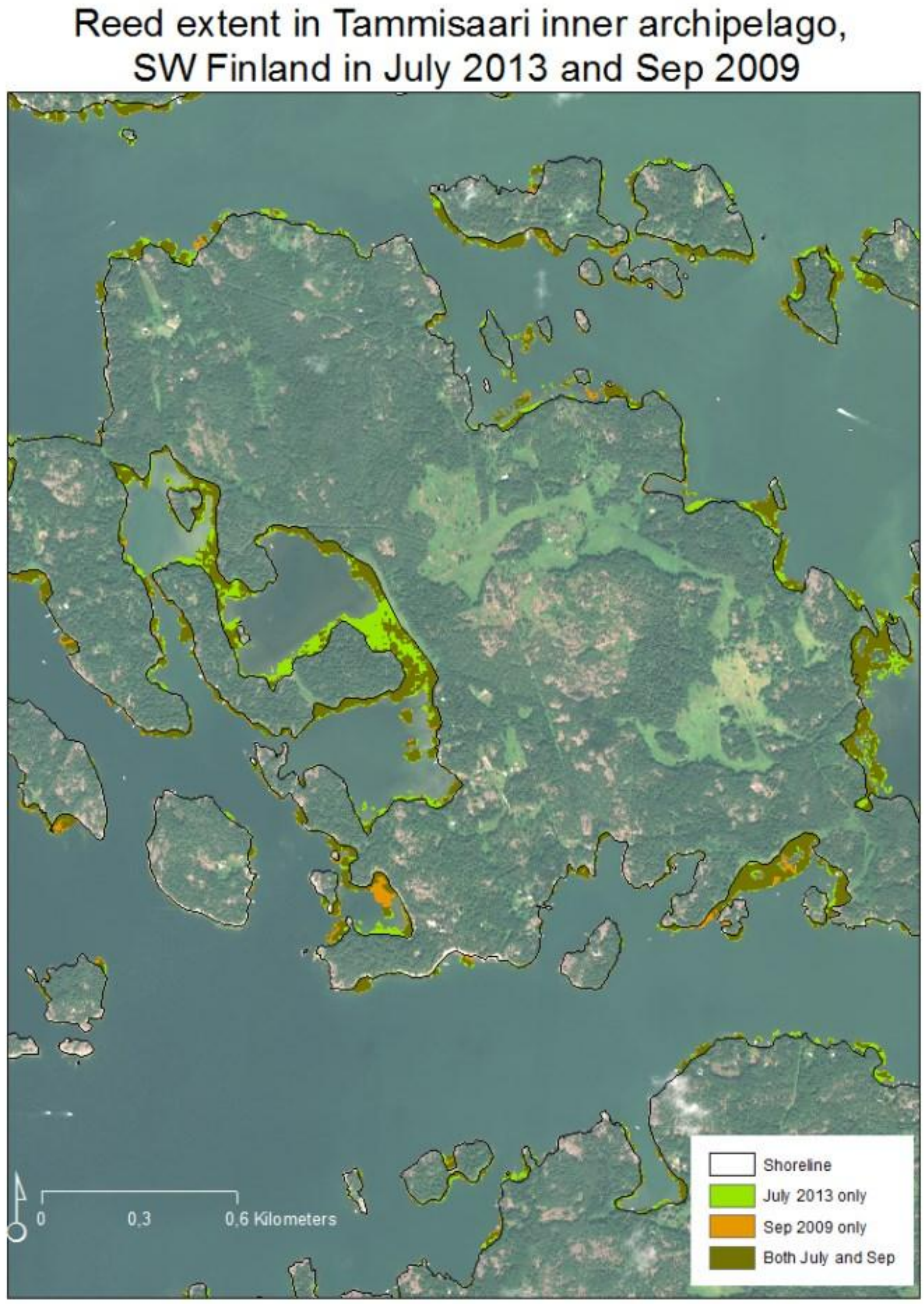
Illustrative material for indicator documentation	

Reed extent in July 2013 with depth-exposition data inTammisaari inner archipelago, SW Finland

Reed extent in September 2009 with depth-exposition data inTammisaari inner archipelago, SW Finland