



The Wadden Sea Region: Towards a science for sustainable development

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ABSTRACT

The Wadden Sea is one of the largest intertidal areas in the world and has been designated as a UNESCO World Heritage Site in recognition of its unique natural features. Major changes in the morphology and ecology of the Wadden Sea over the past millennium resulted from increasing anthropogenic influences such as coastal protection, land claim from the sea and drainage of wetland for agriculture, exploitation of natural resources from hunting and fishing to the extraction of groundwater, gas and oil, industrialisation at port locations and tourism at the islands. A sustainable future can only be achieved if policy and management are backed by solid science. Many of the anticipated changes result from the upscaling of pressures on the Wadden Sea system. Economic globalization leads to upscaling of fisheries, tourism and industrial activities, and thus to changed pressures on space and nature. Climate change will lead to changes in hydrographic patterns, species distribution and possibly tourism; through sea-level rise it will put pressure on coastal protection and the extent of intertidal areas. Invasions of exotic species will transform the ecosystem. There are three major related challenges to management: 1. Nature conservation in a changing system requires a focus on preservation of the *values* and not the *state* of the system; 2. The adaptation of the management structure to the scale increase of the pressures, so that local and regional management becomes better nested in transregional and transnational governance structures; 3. Finally, the management approach needs to deal with increasing uncertainty in external forcing of the system, as well as with nonlinearities in system dynamics when it is pushed outside its normal range of operation. Based on these pressures and management challenges, we advocate an integrated social-ecological systems approach for the scientific study and the science-based management of the Wadden Sea Region. The essential characteristics of this approach are strong interdisciplinarity and a focus on aspects of scale and cumulative processes.

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1. Introduction

The Wadden Sea is one of the world's most valuable stretches of coastline. Since 2009 the Dutch and German parts have been designated a World Heritage Site (CWSS, 2008). The area presents the world's largest coherent intertidal flats: 4700 km² emerge during low tide. Its ecosystem is characterized by a rich benthic fauna supporting millions of coastal birds visiting in the course of a year (Reise et al., 2010 and references therein). The Wadden Sea extends roughly 500 km along the southeast coast of the North Sea

from Den Helder in The Netherlands to Blåvands Huk in Denmark (Fig. 1). A large part of the intertidal area is sheltered by barrier islands and sand bars against the surf of the North Sea. The area counts 25 inhabited islands and several smaller vegetated islands and barren high sands. The total area of the islands is about 2000 km² and the Wadden Sea itself covers about 8000 km². Part of the mainland is included in what is defined as the Wadden Sea Region (see Fig. 1) which has one of the oldest and most complex cultural landscapes in Europe and has been inhabited for more than 5000 years (Knottnerus, 2005; Vollmer et al., 2001).

Traditionally, the Wadden Sea Region has been an important agricultural area. Tourism has achieved an important source of employment especially on the islands and some mainland port

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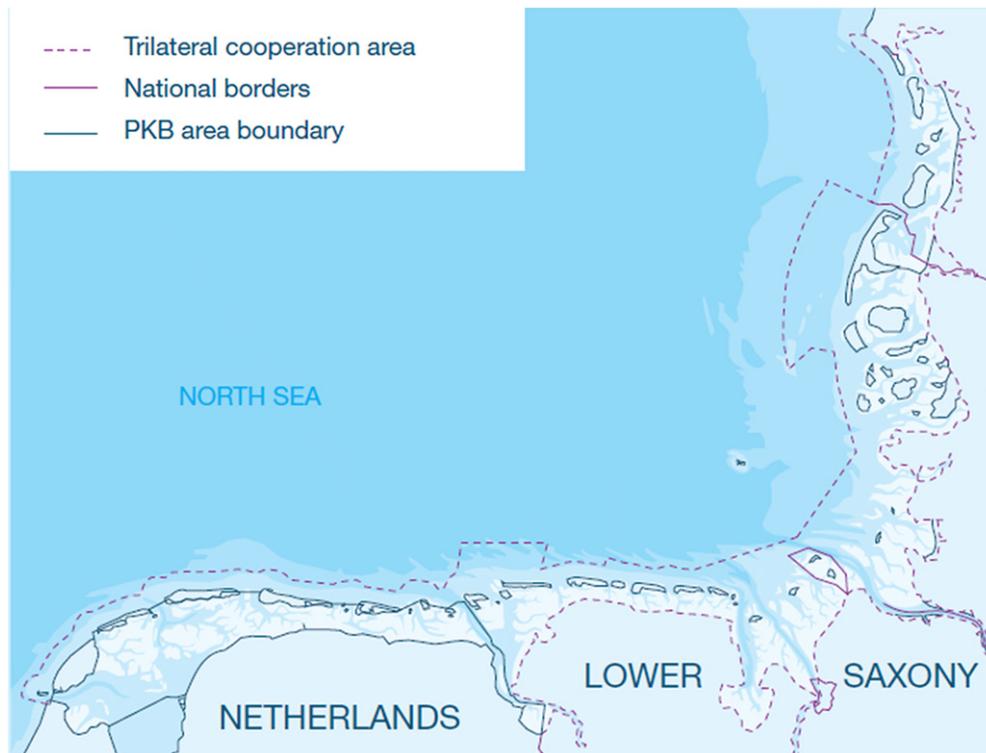


Fig. 1. The trilateral Wadden Sea Region.

localities (Sijtsma et al., in this volume). The major German ports of Hamburg, Bremen/Bremerhaven and Wilhelmshaven, the Dutch Eemshaven/Delfzijl and the Danish Esbjerg harbour important industries. At present, an estimated 3.5 million inhabitants live in the 17,500 km² of land at less than 5 m above or even below mean sea-level in this region (CPSL, 2010). Knowledge about the past, present and future development and management of the nature, cultural heritage and the regional socio-economy of the Wadden Sea Region is of great interest for the future use of other coastal lowlands and extensive tidal zones all over the world.

The natural processes and socio-economic activities in the Wadden Sea Region form a complex interplay which we need to understand in order to achieve a solid, science-based management for a sustainable future of the region. In this paper, we advocate that an integrated approach is required to understand the Wadden Sea Region as a system in the short, medium and long term. In order to provide a background to the complexity of the combined natural, socio-economic and socio-cultural system, below we first analyse the development of the Wadden Sea Region from an exclusively naturally formed system towards a system that is the result of a combination of natural change and progressive anthropogenic influences. We then describe the major future challenges for this system. From these descriptions, we derive the essential components of an integrated system approach, and address the question how scientific research can best be organised in order to adequately inform the public and to support management.

2. Natural and human history of the Wadden Sea Region

Although the Wadden Sea Region is certainly not homogeneous in terms of nature and culture, the sub-regions do have an almost identical geological history and a shared history of human habitation. We present a chronological overview that shows the main patterns in the increasing human influence on the region. Interactions between the natural and the socio-economic system since

the Wadden Sea came into existence are illustrated. We refer to Bazelmans et al. (in this volume) for a more elaborate review of the increasing human influence on the landscape of the Wadden Sea Region during the Holocene from a cultural-historical perspective. The geological evolution of the Wadden Sea during the Holocene period has been described in detail by Aagaard et al. (1995) (the Danish Wadden Sea); Bartholdy and Pejrup (1994); Chang et al. (2006) (the German Wadden Sea); Oost (1995); Streif (2004); Van der Spek and Beets (1992) and Vos and Van Kesteren (2000) (the Dutch Wadden Sea).

2.1. The early development of the Wadden Sea Region after the last Ice Age

Some 18,000 years ago, at the last glacial maximum, the sea-level in the region was about 125 m lower than it is today (Streif, 2004). In contrast with the previous Saale glaciation, the region was not covered with ice during this Weichselian glaciation. The Pleistocene landscape of the Wadden Sea Region has been formed both by glacial processes e.g. in the form of terminal moraines and by glaciofluvial processes e.g. in the form of outwash plains formed by the melting water from the Weichselian ice sheet. Some of the 16 present barrier islands have developed attached to local heights in the Pleistocene landscape. The islands Texel (The Netherlands), Amrum, Föhr and Sylt (Germany) have outcrops of Pleistocene sediments.

After the last Ice Age, melting of the Fennoscandian and Canadian ice shields caused the sea-level to rise rapidly. Initially, the rate of sea-level rise was too high to allow the formation of a barrier island system. Although there are some indications that the first barrier islands formed approximately 8000 years BP it was primarily when the rate of sea-level rise decreased to well below 10 mm/y that the present-day landscape started to form (Streif, 2004). From 5000 BP the sea-level rise slowed to 1–2 mm per annum, and crustal adjustments in response to the unloading of the

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