Estuarine, Coastal and Shelf Science 140 (2014) 95–122

Contents lists available at SciVerse ScienceDirect

Estuarine, Coastal and Shelf Science

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

An overview of ecological status, vulnerability and future perspectives of European large shallow, semi-enclosed coastal systems, lagoons and transitional waters

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ARTICLE INFO

Article history:
Received 22 October 2012
Accepted 23 May 2013
Available online 14 June 2013

This paper is dedicated to the memory of 2 great lagoon scientists and dear colleagues: Thang Do Chi and Josema Zaldivar.

Keywords:
transitional water
coastal lagoon

ABSTRACT

The paper gives an overview of some of the large, shallow, semi-enclosed coastal systems (SECS) in Europe, These SECS are important both from the ecological and the economic perspective (socio-ecological systems) and provide many valuable ecosystem goods and services.

Although some of the systems are transitional waters under the Water Framework Directive, this is not the case for all of the systems. The paper adopts a Driver-Pressure-State-Impact-Response approach to analyse the ecological status, vulnerability and future perspectives of these systems in the context of global change.

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0272-7714/$ – see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.ecss.2013.05.023

DPSIR
vulnerability
global change
ecological status
WFD

1. Introduction and scope, definitions and characteristics of shallow, semi-enclosed coastal systems (SECS)

1.1. Scope

This overview addresses some of the largest European shallow, semi-enclosed coastal systems (SECS), including lagoons and transitional waters (TW). These SECS are not only important ecological systems, but also have considerable historical and socio-economic value (Lassere, 1979). In recent years, there has been increasing recognition of the economic importance of SECS through their provision of ecosystem services, although these services are increasingly threatened as SECS are among the most vulnerable coastal systems to both natural and human pressure (Eisenreich, 2005). The overview of SECS is presented from the perspective of the Driver-Pressure-State-Impact-Response adaptive management framework that links human drivers and pressures through to ecological state and the impact on human welfare, and then on to societal responses. The results are interpreted in the context of European environmental legislation, such as the Water Framework Directive (WFD) (EU, 2000) and from the perspective of global change and coastal vulnerability.

Transitional waters include a wide range of typologies including some lagoons (Basset et al., 2006). The WFD does not include a definition of lagoons, but the definition of TW specifies a salinity gradient and significant freshwater inputs. This means that some SECS, such as the Ria Formosa and the Mar Menor, are considered to be sheltered coastal waters (CW) rather than TW, with respect to the WFD. The "legal" classification of these systems as TW or as CW has important implications in the assessment of ecological status, because the type-specific reference conditions for TW are naturally very different from those for CW.

Although many of the SECS are European coastal lagoons, they are not fully representative of the heterogeneity of lagoons, because small eu-haline and hyper-haline lagoons and a myriad of small systems are not included. Most of the systems described can also be considered as coastal wetlands (Perillo et al., 2009). In addition, similar but deeper systems, such as the Gulf of Riga and Puck's Bay, are also considered for purposes of comparison; as well as systems that are not strictly lagoons, such as the Wadden Sea.

The geomorphology of SECS makes them particularly vulnerable to global changes, such as sea-level rise, increased temperatures, storminess, droughts, floods and changes in sediment dynamics. They are "hotspots" of global change and vulnerability to environmental, economic and social pressures, especially when they are associated with river-mouths systems (Newton et al., 2012). Human activities cause changes in demographics, urbanisation, agriculture and land-use, as well as industrial development and shipping that affect the structure and function of these vulnerable and valuable coastal ecosystems.

The overview includes a range of coastal systems, so this section explores the definitions that have been applied to these systems. There is a gradient between the open sea, semi-enclosed bays, coastal lagoons and transitional waters. The United Nations glossary of environment statistics (UNSD, 2006) defines coastal lagoons as "*Sea-water bodies situated at the coast, but separated from the sea by land spits or similar land features. Coastal lagoons are open to the sea in restricted spaces*". Most of the systems included in this overview fit this definition. Coastal lagoons are therefore regions of restricted exchange. However, this is also the case for some enclosed bays and some fjords that may be much deeper (Tett et al., 2003; Newton and Icely, 2006). Geomorphology, in particular the length of the width of marine entrances at high tide relative to the total length of the enclosing barriers, has been used to distinguish enclosed bays from lagoons (Lassere, 1979). This allows for some quantitative interpretation, rather than qualitative, especially with respect to the size of the connection to the adjacent sea. Nevertheless, the degree of connectivity with the sea depends not only on geomorphology and openness, but also on tidal amplitude and the general hydrological regime.

Coastal lagoons are often sub-divided into "choked", "restricted", "leaky" (Kjerfve, 1994) and even "open" (Lassere, 1979; Bird, 1994) with respect to the characteristics of their hydrodynamic exchange properties with the adjacent open sea. The Wadden Sea (southern part of the North Sea) and its extensive intertidal areas behind the Frisian barrier islands has been classified as an "**open lagoon**" (Lassere, 1979; Bird, 1994). **Leaky lagoons** are connected by many entrances to the adjacent sea and are therefore characterised by almost unimpaired water exchange (Kjerfve, 1986). However, **choked lagoons** are connected to the sea by a single or few narrow and shallow entrances, resulting in delayed and dampened tidal oscillation or low water exchange with the open sea. The repletion coefficient of a system (Wolanski, 2007) gives a more quantitative definition based on residence time and tidal prism, but these data are not always available and hence a more arbitrary and qualitative classification is more frequently used.

Table 1 lists some examples of SECS, and similar systems for comparison, and classifies them qualitatively as open, leaky, restricted or choked. It also specifies how they are classified according to the WFD, either as TW or CW.

1.2. Formation and development of SECS

Sediment transport processes are the main mechanism of SECS formation. Barriers of sediment are deposited parallel to the coastline and maybe fragmented into islands and peninsulas. Six main factors influencing the distribution and dynamics of coastal lagoons are: antecedent geomorphology; material characteristics; sediment supply; tectonics; tide range; and climate (Bird, 1994).

The development of SECS is favoured by a low-lying coastline with a fractured geomorphology. Material for barrier formation is sediment drifting along the shoreline. SECS formation also requires sediments of a medium grain size originating either from cliff erosion, riverine input of terrestrial origin, or input from the adjacent seafloor. The evolution of SECS depends mainly on the balance between sediment import and export. The fate of the system is also influenced by: (1) the strength of tidal currents; (2) the force of the wind; as well as (3) the rate of sediment supply. The climate, especially the precipitation, storminess and storm surges, also affects the sediment fluxes, overtopping events and erosion. With respect to tectonics, subsidence potentially leads to an increase in size and depth of the SECS and may even result in reopening of the coastal inlets whereas the opposite will occur in uplift areas (for a detailed review see: Bird, 1994 and references therein).