



Short communication

The concept of an estuary: A definition that incorporates systems which can become closed to the ocean and hypersaline

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ABSTRACT

The majority of the definitions of estuaries have been based on the characteristics of estuaries in temperate regions of the northern hemisphere. As previously pointed out (Day, 1980), such definitions do not take into account such features as periodic closure of their mouths and hypersaline conditions during dry periods, which characterise many estuaries in southern Africa and south-western Australia. There is also ambiguity as to whether an estuary *sensu stricto* must be fed by a river. The following definition was developed to encompass the main characteristics of all estuaries: *An estuary is a partially enclosed coastal body of water that is either permanently or periodically open to the sea and which receives at least periodic discharge from a river(s), and thus, while its salinity is typically less than that of natural sea water and varies temporally and along its length, it can become hypersaline in regions when evaporative water loss is high and freshwater and tidal inputs are negligible.* Estuaries are thus regarded as unique ecosystems, which, in the case of fishes, for example, are occupied by species that collectively represent a particular suite of guilds.

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1. Transitional waters and estuaries

During recent years, several attempts have been made to revisit definitions of estuaries with a view to accommodating the different physiographic types of these systems (e.g. Elliott and McLusky, 2002; Tagliapietra et al., 2009). In Europe, there has been an increasing acceptance of the use of transitional waters as an overarching term to include all water bodies between freshwater and the marine environment (McLusky and Elliott, 2007). Transitional waters thus include, for example, coastal plain estuaries, rias, fjords, lagoons and intermittently closed and open lakes and lagoons (ICOLLs), which are characterised by a suite of features that relate mostly to ecotones and gradients. Although Wolanski (2007) recognised that the above different types of water body did not constitute “classical” estuaries, he included them, for convenience, under the heading of estuary in his book entitled *Estuarine Ecology*. It should be recognised, however, that transitional waters is essentially a bureaucratic term designed to ensure that all water bodies in Europe are subject to water quality control in accordance with the Water Framework Directive (European Communities, 2000; McLusky and Elliott, 2007).

There has been increasing concern that, while all estuaries are transitional waters, not all transitional waters are estuaries. Furthermore, the majority of previous definitions of an estuary have been derived largely from a northern hemisphere perspective in which these systems typically have freshwater merging along a salinity gradient into full-strength natural seawater. A detailed historical description of the development of concepts regarding the features that define an estuary, and particularly those in temperate regions of the northern hemisphere, are given in Fairbridge (1980), Elliott and McLusky (2002), McLusky and Elliott (2007), Tagliapietra et al. (2009), and consequently will not be considered in detail in this paper. The stimulus to produce the present paper was provided by the fact that estuarine biologists in south-western Australia and southern Africa are working in systems that they regard as estuaries and have characteristic faunas, but which do not conform to the criteria typically used to define estuaries.

2. Definitions of estuaries

Prior to 1964, there had been little agreement on a suitable definition for an estuary. A special committee of the American Society for the Advancement of Science was thus convened to address this problem, which resulted in the production of the following definition (Pritchard, 1967). “An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water

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derived from land drainage". This definition was largely based, however, on the features of estuaries in temperate regions of the northern hemisphere and failed to take into account certain characteristics of many systems in southern Australia (e.g. Hodgkin and Lenanton, 1981; Roy et al., 2001) and southern Africa (e.g. Day, 1980, 1981). Some estuaries in these latter two regions, for example, become separated from the sea for periods by the formation of sand bars across their mouths and some of these can become hypersaline when rates of evaporation become high during dry periods. In contrast, typical macrotidal estuaries in temperate regions of the northern hemisphere are usually hyposaline, i.e. their salinities are less than that of full-strength natural seawater. On the basis of his studies of estuaries in southern Africa, Day (1980, 1981) modified Pritchard's (1967) definition to the following, "An estuary is a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of sea water with fresh water derived from land drainage". While this definition recognised that estuaries do not always have a permanent free connection with the sea, it neither explicitly recognised that the salinity in estuaries can exceed that of full-strength natural seawater nor identified whether freshwater input has to be derived mainly from fluvial discharge or can solely come from direct rainfall and localised runoff. Despite the fact that, when considering the characteristics of estuaries in southern Africa and south-western Australia, Day (1980, 1981) drew attention to the limitations of Pritchard's (1967) definition in a global context, that definition, as pointed out by Elliott and McLusky (2002), continues to be widely used.

3. Salinity gradients and the role of rivers

Previous definitions of estuaries have emphasised that such systems contain "sea water measurably diluted by freshwater derived from land drainage" (Pritchard, 1967). This implies that the salinity gradient is unidirectional and represents a gradual progression from freshwater to seawater (Fig. 1a, b), whereas the waters in estuaries that become hypersaline change from being fresh to hypersaline and then to full-strength natural seawater (Fig. 1c). In contrast to the gradual changes that occur in environmental conditions throughout the length of typical northern hemisphere temperate coastal plain estuaries, e.g. the Severn and Humber in the United Kingdom (see e.g. Warwick and Gee, 1984), the closure of the mouth of many estuaries in southern Africa and Australia results in a truncating of the salinity gradient (Fig. 1d, e). However, during periods of heavy riverine discharge into those southern Australian estuaries, which, at other times, are hypersaline and closed to the ocean, the gradients can show the same progressive increase in salinity from the river to the sea into which the estuary then opens.

Many workers regard riverine input as an essential component of an estuary (e.g. Dionne, 1963; Fairbridge, 1980; Day, 1981; Day et al., 1989; Dalrymple et al., 1992; Perillo, 1995; Hodgkin and Hesp, 1998; Elliott and McLusky, 2002; Whitfield, 2005; Hume et al., 2007). Indeed, an estuary has been defined as "a wide tidal mouth of a river" in the Oxford English Reference Dictionary (Pearsall and Trumble, 2002) and as "the mouth of a river where tidal effects are evident and where fresh water and sea water mix" in the Dictionary of Geography (Moore, 1988).

The connectivity between the catchment and the sea via a river provides estuaries with one of their most important and unique characteristics. The presence of a river is essential for providing a route through which anadromous fish species, such as certain salmonids and lampreys, can migrate from their main feeding areas in the sea to their spawning areas in freshwater in the rivers and by which catadromous species, such as certain anguillids, can migrate

from their feeding areas in rivers to their spawning grounds in oceanic waters (McDowall, 1988; Elliott et al., 2007). Furthermore, in southern Australia for example, the absence of a riverine component would mean that the main habitats of several of the abundant species of fishes found in those estuaries would not be present (e.g. Loneragan et al., 1987; Potter et al., 1997; Chuwen et al., 2009a). For example, the riverine component of an estuary, sometimes referred to as the upper estuary, constitutes the main environment of the marine-estuarine opportunist species *Mugil cephalus* during its juvenile life (Thomson, 1957; Chubb et al., 1981), and contains the areas in which the semi-anadromous species *Nematalosa vlaminghi* and the estuarine *Acanthopagrus butcheri* spawn (Chubb and Potter, 1984; Sarre and Potter, 1999).

In contrast to Pritchard (1967), who considered the boundary between estuary and river to be represented by the upper limit of saltwater intrusion, some workers regard the tidal limit as that boundary (Dionne, 1963; Day et al., 1989; Perillo, 1995; Elliott and McLusky, 2002), which, in the case of systems that become closed to the sea, would correspond to the tidal limit when the estuary is open. More recently, McLusky and Elliott (2004) considered that the upper limit of an estuary should be defined as the maximum extent of any marine influence, due either to the presence of tidal action or traces of salinity derived from marine intrusion.

The eastern seaboard of temperate Australia contains numerous coastal bodies of water that become periodically closed to the ocean through the formation of sand bars at their mouths (Roy et al., 2001). These systems are referred to as intermittently closed and open lakes and lagoons (ICOLLs) by Gale et al. (2007) when they lack river inflow and are driven by rainfall and runoff alone, which distinguishes them from those systems that are widely regarded as estuaries. Some workers, however, term systems on the east coast of Australia as estuaries, irrespective of whether or not they contain a riverine input (e.g. Roy et al., 2001; Jones and West, 2005).

4. Hypersalinity

We agree with Day (1980, 1981) that those systems in southern Australia and southern Africa that possess many estuarine characteristics but become hypersaline at times and do not then contain seawater that is measurably diluted with freshwater (Whitfield, 1999; Hoeksema et al., 2006; Chuwen et al., 2009b), should continue to be regarded as estuaries. Such systems are considered to form part of a continuum. Whether or not some regions in the permanently-open estuaries of south-western Australia become hypersaline through evaporation during the long dry summer and autumn months is determined by a combination of factors, such as the size and depth of their mouths and thus the amount of intrusion by marine waters, the area and depth of the various estuarine regions and the volume of riverine discharge (Chuwen et al., 2009b).

Although most estuaries that become hypersaline on the south-western Australian coast do so when they are closed to the ocean during dry periods (Chuwen et al., 2009b), the Peel-Harvey Estuary provides an example of a system in which regions can become hypersaline even though that system remains permanently open to the ocean (e.g. Loneragan et al., 1987). Thus, in contrast to other permanently-open estuaries on the lower west coast of Australia, such as the Swan River, Leschenault and Blackwood River estuaries, in which the salinities remain below 40 (Loneragan et al., 1989; Potter et al., 1997; Valesini et al., 1997), those in certain large and shallow regions of the Peel-Harvey Estuary, reach ca 50. Despite becoming hypersaline at times, those localised areas still support a diverse and abundant fauna, which includes the fish and crustacean species that are typically abundant throughout the rest of that system (e.g. Loneragan et al., 1987). Furthermore, the compositions

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