CSIRO PUBLISHING

www.publish.csiro.au/journals/mfr *Marine and Freshwater Research*, 2009, **60**, 497–509

A review of terms and definitions to categorise estuaries, lagoons and associated environments

Davide Tagliapietra[A,C], *Marco Sigovini*[A,B] *and Annamaria Volpi Ghirardini*[B]

[A]Consiglio Nazionale delle Ricerche – Istituto di Scienze Marine (CNR-ISMAR), Riva 7 Martiri, 1364/a, I-30122 Venice, Italy.

[B]Dipartimento di Scienze Ambientali, Università Ca' Foscari di Venezia, Campo Celestia, 2734/b, I-30122 Venice, Italy.

[C]Corresponding author. Email: d.tagliapietra@ismar.cnr.it

Abstract. Estuaries, rias, fjords, coastal lagoons, bahiras, river mouths, tidal creeks, deltas and similar coastal environments are often regarded as a single broad conceptual class. 'Brackish', 'estuarine', 'paralic' and 'transitional' are terms used in different contexts to designate collectively this class of environments. Nevertheless every term, generated from different historical perspectives and scientific points of view, excludes some of the above-mentioned environments. These terms and definitions were examined with regard to their meaning and history. The main attributes have been extracted from definitions and arranged in a conceptual scheme giving an overall direct perception of their relationships. This analysis provided evidence for the occurrence of two major groups of attributes: hydrological and geomorphic. Although the significance of hydrological attributes is instantly recognisable, geomorphic attributes imply subjacent concepts of geographical scale and hydrological features not expressly formulated in definitions, such as a limited supply of seawater to the system.

Additional keywords: coastal transitional ecosystems, seascapes, transitional waters, Water Framework Directive.

Introduction

There is general agreement to include estuaries, rias, fjords, fjards, coastal lagoons, bahiras, intermittently closing and open lakes and lagoons (ICOLLs), river mouths, tidal creeks and deltas into a single, if broad, conceptual class (e.g. Guelorget and Perthuisot 1983; Kjerfve 1994; McLusky and Elliott 2007). Most of these nearshore, protected environments are related to the main estuarine and lagoonal types. Kjerfve (1994) divided these 'inland coastal ocean-connected waters' into six categories: estuaries, coastal lagoons, fjords, bays, tidal rivers and straits. These water bodies are located within the coastline (e.g. lagoons, fjords) or cross through it protruding into the sea (e.g. deltas). Open-shore environments, such as strandplains, are seldom included in this list, except for tidal mudflats that lie at the outer edge of estuarine systems. In an ecological approach, the class includes both deepwater and coastal wetland habitats, such as mangroves and saltmarshes, as pointed out by Cowardin *et al*. (1979) for estuarine systems.

One of the most general and common traits of this class of coastal environments is a significant departure of physicochemical variables (salinity, ionic composition, temperature, turbidity, dissolved oxygen, pH, redox potential, nutrients, dissolved and particulate organic matter) from the normal range of variability measured in the offshore waters. Estuaries, lagoons and embayments have many physical and ecological processes in common (Ketchum 1983; Thrush and Warwick 1997; Constable and Fairweather 1999; McLusky and Elliott 2004). All these coastal aquatic systems are generated by the merging of sea, land and rivers and mark the passage between marine and non-marine realms. This merging gives rise to new, emergent properties shared by all these environments, such as the presence of strong gradients, variability in mesological parameters, prevalent sedimentary bottoms, high biological production and susceptibility to anoxia. The functional traits of these environments were illustrated by Levin *et al*. (2001), who highlighted their importance as links between land, freshwater and the sea.

Places of passage: a common feature

These peculiar coastal ecosystems are characterised by progressive changes in several environmental variables, often mutually dependent or correlated. These variations generate composite gradients that involve salinity, marine water renewal (e.g. residence time), nutrients, turbidity and sediment structure. It is important to recognise gradients if we are to understand these environments, as pointed out by McLusky (1993). The direction of the gradient depends mainly on river or tide energy; therefore, it is generally oriented perpendicularly to the coastline or along the river mouth axis. The shape of the gradient can change in different basins and sub-basins, depending on the relative importance of the environmental variables within the gradient. In very low-energy environments, the gradient can be differently oriented, for instance, owing to the presence of wind-driven water circulation. In these situations, gradients with different

 10.1071/MF08088 1323-1650/09/060497

directions can generate complex fields. The contribution of different variables in distinct systems (e.g. salinity in estuaries, seawater renewal in microtidal lagoons) depends on the main hydrodynamic energy source of the system. In environments with high fluvial energy (Boyd *et al*. 1992; Dalrymple *et al*. 1992; Heap *et al*. 2001), the gradient is structured mainly by the freshwater flows, which dilute the seawater and rearrange the sediments. In this case, salinity can be profitably used as a proxy for the composite gradient. Conversely, in coastal lagoons with weak river input (Boyd *et al*. 1992; Dalrymple *et al*. 1992; Heap *et al*. 2001) the component that mainly influences the gradient is seawater renewal, which can be considered as a proxy for the whole gradient.

In these coastal systems, both landforms (see Pethick 1984; Harris and Heap 2003) and biological processes are physically controlled (Sanders 1968). Environmental gradients directly influence another important feature: the progressive reduction in the number of species when entering a water body, either from the sea or from the river. This recurring pattern is a relevant feature because diversity is one of the 'biological quality elements' required by the recent European Water Framework Directive (WFD) (European Community 2000, Annex V 1.2.3). Furthermore, a considerable number of Indices of Biotic Integrity include some measure of species richness in their metrics (Diaz *et al*. 2004). The decline in species number and diversity along the gradient has been the subject of various conceptualisations, each one emphasising a different aspect of the gradient depending on the environment investigated: salinity (e.g. Remane 1934; Attrill 2002), seawater renewal (e.g. D'Ancona *et al*. 1954; Guelorget and Perthuisot 1983) or sediment type (e.g. Boesch 1973; Thrush *et al*. 2003). Sediment organic content plays a key role in oxygen availability as a component of the gradient related to sedimentary processes (e.g. Pearson and Rosenberg 1978; Diaz and Rosenberg 1995; Gray *et al*. 2002).

Colonisation rates and dispersal processes have also been used to explain the structure and horizontal zonation of benthic lagoonal assemblages in addition to water renewal, salinity and ionic composition (Pérez-Ruzafa and Marcos 1992). Connectivity with the sea strongly influences the recruitment of species requiring a marine dispersal phase, with effects on diversity patterns (Platell and Potter 1996; Dye and Barros 2005). Wagner (1999) considered the effects of the length of the salinity gradient on diversity. A general framework for richness patterns in relation to estuary type was proposed by Roy *et al*. (2001) for Australian estuaries, taking into account tidal exchange, salinity, recruitment and migration. Most species dwelling in these environments are of marine origin (Barnes 1989; Cognetti and Maltagliati 2000). Consequently, moving landward, it can be expected that an increasing divergence from marine conditions is tolerated by progressively fewer species (McLusky and Elliott 2004). In a river, this pattern is mirrored moving downstream towards the fluvial delta (Roy *et al*. 2001) by species of freshwater origin (Remane 1934, 1971; Guelorget *et al*. 1987); thus, the double environmental gradient is reflected by a double ecocline (Attrill and Rundle 2002).

Bulger *et al*. (1993) proposed a classification of the salinity gradient in estuaries and presented a zoning scheme based on fish and invertebrate distributions in line with these principles. In the inner part of the basins or near the heads of estuaries, variability in the physical environment (freshwater discharge, anoxia) can cause periodic mortality of several species, which is followed by recolonisation and restructuring of the communities (Barnes 1999). Times of emergence/submergence related to tidal regime are also an important factor in structuring benthic assemblages in this type of environment (Swinbanks and Murray 1981). Where the freshwater inflow is negligible or absent, Guelorget and Perthuisot's 'biological zoning' can be regarded as an operational simplification of a single ecocline lying along a gradient of seawater renewal. In Mediterranean lagoons where the hydroclimate sustains eu/hyperhaline conditions, the decline of species along the sea–land axis is attributed mainly to hydrology and sediment properties and, to a lesser extent, to salinity (e.g. Guelorget *et al*. 1987; Reizopoulou and Nicolaidou 2004; Rossi *et al*. 2006).

Terms and definitions

The present paper focuses on the terms and definitions used to collectively describe estuaries, lagoons and associated environments. Coastal water bodies not strictly marine in nature are regarded as estuarine, brackish, paralic and, more recently, transitional waters. Despite common agreement on the affinity of these environments, it is difficult to find a comprehensive term to identify this category of coastal systems as a single group.

Estuaries, rias, fjords, fjards, coastal lagoons, bahiras, river mouths, tidal creeks and deltas are different basic physiographical types of coastal environments. These basic types are often identified quite clearly by simple terms often taken from local names in a region where a specific physiographical type frequently occurs. These lexical definitions are almost universally accepted and it is often enough to consult a reliable dictionary to obtain a suitable definition. A lexical definition explains how a term is actually used. It is generally assumed that a definition will be stated in a simple and concise way. Concise definitions give us the main traits of the *definiendum* in just one or two sentences and are sufficient to circumscribe the subject, but these characteristics make some definitions vague. As terms become more inclusive of different types of environments, definitions become less precise. Therefore, 'open definitions' would be more appropriate, but 'closed definitions' are often required for operational and legal purposes. To reduce the vagueness of a lexical definition, specific or explicit definitions are needed that expand the dictionary definition by including additional criteria. Hence, in the specialist literature, after a first-level lexical definition, a term is accompanied by a more detailed definition to reduce any possible vagueness, for instance, describing the physical limits of an estuary. Some concise observations on the history and meaning of some common terms could help to better address the questions. In this overview, we will start with the terms 'lagoon' and 'estuary' as the first level of aggregation of the basic physiographical types, and then we will move on to terms used to group 'lagoons' and 'estuaries' together and their definitions. The nested relationships among the main terms discussed in the text are represented in Fig. 1. As well as grouping lagoons and estuaries, these terms can also include other natural coastal environments, such as embayments, and artificial environments, such as saltworks, harbours, fish farms and coastal sewage outlets.

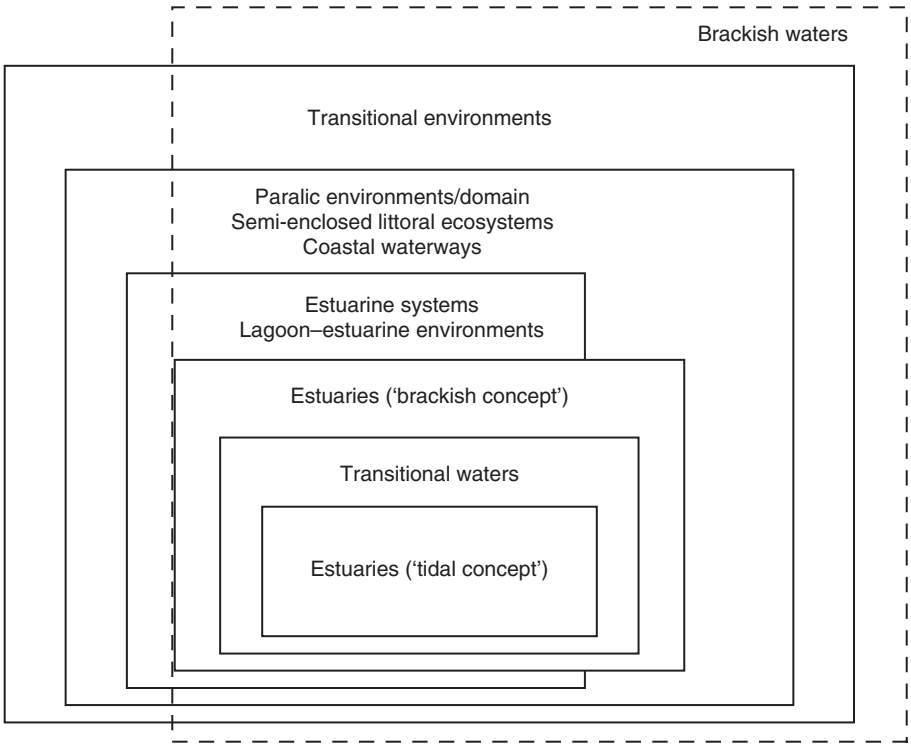

Fig. 1. Conceptual scheme of the relationships among the terms. The eccentricity of 'estuarine system' set results from doubt about its applicability to rocky shores.

'Lagoons' and 'estuaries' refer not only to single physiographical types, but are currently used as collective nouns. For example, the term 'lagoons' includes coastal lagoons, coastal lakes, bahiras, ICOLLs and limans; the term 'estuaries' includes fjords, fjards, rias, karstic estuaries, arid estuaries, coastal plain estuaries and bar-built estuaries. These two collective terms are acknowledged in the scientific literature, although their domains do overlap in 'estuarine lagoons' from the lagoonal perspective or in 'bar-built estuaries' from the estuarine perspective. Therefore, we have seen good reasons to unite lagoons and estuaries under a single term. Collective terms at a higher hierarchical level than 'lagoons' or 'estuaries' are less accepted; new terms and definitions are formulated from time to time, but they are often of limited use.

Estuaries and lagoons

'Estuaries' is the most commonly used term throughout the English-speaking world to describe most of these environments, but this term should be more correctly applied to a precise subclass, the proper estuaries, than to the whole group. There are many definitions of an estuary emphasising the role of rivers and tides. Estuaries are identified mainly by three groups of definitions based on three main attributes: (*i*) the presence of tides; (*ii*) the dilution of seawater by land run-off; and (*iii*) the degree of enclosure. These groups of definitions were formulated by the progressive exclusion of one basic attribute. The more restrictive category (called 'tidal concept' in the present paper) involves all attributes. The second ('brackish concept') and perhaps the most diffused meaning of the term does not require the presence of tides. The third category ('estuarine system') is the broadest and requires only the semi-enclosure of a body of water. Lagoons are included in this group as end members of a geomorphic series.

Estuaries 'tidal concept'

Elliott and McLusky (2002) denounced a semantic misuse of the term 'estuary' when applied to non-tidal environments because the term comes from the Latin '*aestuarium*' (from '*aestus*' meaning tide or billowing movement). In these authors' view, the terms 'estuary' and 'estuarine' should properly be used to indicate situations characterised by tides (the 'tidal concept' of the term). In their stimulating paper, they provided a series of definitions for an estuary, going back to the appearance of the term in the English lexicon during the 16th Century. Actually, early definitions of an estuary are based on tides. The first text that explicitly defines an estuary is the 'Etymologies' by Saint Isidore of Seville written ~621 AD (that, translated, says 'Tide pertains to the ocean, strait to all seas. For the tide is the flow or the ebb of the sea, that is restlessness; therefore estuaries are those places where the sea in turn goes in and out.' Isidorus Hispalensis 621, 13.18). A similar definition is given by Rabanus Maurus in his '*De rerum naturis*' (Rabanus Maurus 846, 11.7). The two compilers most likely refer the term to intertidal areas affected by ample ocean tides, as on north-western European shores. Another historically relevant definition of an estuary mentioning tides was given by Charles Lyell (1833) in his 'Principles of Geology' 'inlets of the lands which are entered

both by rivers and tides of the sea' (p. 323). Tides are also central to the definitions of Odum (1959) 'river mouth where tidal action brings about a mixing of salt and fresh water' (p. 364) and Fairbridge (1980) 'an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise. . .' (p. 7). The latter, in its complete form, was considered to be a suitable definition of an estuary by Elliott and McLusky (2002). This concept of the term refers more to a single physiographical type than to a collective class.

Estuaries 'brackish concept'

The early meaning of 'estuary' in English was related to a coast open to tidal expansion; 'river mouth' and 'estuary' were, therefore, distinct. The idea was that the river enters the estuary (see Simpson and Weiner 1989); the two terms became inextricably linked probably because British rivers typically face tidal areas. Despite its etymology, not all definitions of estuary refer to tides; other common definitions focus only on the dilution of seawater by freshwater derived from rivers or, generally, from land drainage ('brackish concept'). Ketchum (1951) defined an estuary as a 'region where river water mixes with, and measurably dilutes, sea water' (p. 19). Tides are not included in the perhaps most widely used definition of an estuary: 'a semi enclosed coastal body of water which has a free connection with the open sea and within which seawater is measurably diluted with fresh water derived from land drainage' (Cameron and Pritchard 1963, p. 306; Pritchard 1967, p. 3). It should be pointed out that substitution of the word 'river' by 'fresh water derived from land drainage' takes into account groundwater flow that can be an important source of fresh water (Nixon *et al*. 2004).

Day (1981), considering the applicability of Pritchard's definition to estuaries of the southern hemisphere, produced a similar definition basically changing 'free connection with the open sea' to 'either permanently or periodically open to the sea', thus including all coastal water bodies that are connected to the sea only occasionally. Tides are also not taken into account in the broader definition of Cowardin *et al*. (1979): 'The Estuarine System [. . .] consists of deepwater subtidal habitats and adjacent tidal wetlands that are usually semienclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land. . .' (p. 18). A definition based on the 'brackish concept' was proposed by the United Nations: 'generally broad portion of a river or stream near its outlet that is influenced by the marine water body into which it flows. . . .' (United Nations Statistics Division 1997).

Hopkinson and Hoffman (1984) underlined the need to extend Cameron and Pritchard's definition to the whole interface system coupling continent to ocean, including the nearshore region. On the other hand, the need to expand the definition to include high-salinity systems typical of dry climates (e.g. negative or inverse estuaries) steered some authors towards a definition less dependent on seawater dilution. Tomczak (1996) proposed the following definition: 'An estuary is a narrow, semienclosed coastal body of water which has a free connection with the open sea at least intermittently and within which the salinity of the water is measurably different from the salinity in the open ocean'. This definition is broad enough to include inverse estuaries. The appearance of the term 'semi-enclosed' (or similar) limits the inclusion of brackish offshore waters in the definition and is central in the next group of definitions.

Lagoons

The term 'lagoon' originated from the Latin '*lacūna*', meaning gap, pond or pool (see also '*lacus*', lake). The Venetian word '*laguna*' derived from the Latin term and spread in Italian literary texts from the 16th Century, with the meaning of shallow coastal basin connected to the sea (Pisani 1960). This term has been present in the English lexicon since 1612; the word came from the Italian '*laguna*' because it was first used with reference to the lagoon of Venice (Serjeantson 1936).

Postma (1969) gave the following definition: 'a body of shallow coastal water with a restricted connection but free exchange with the adjacent open sea' (p. 422) that is similar to the definition given in the same Symposium on Coastal Lagoons by Phleger (1969), who added that the major axis is oriented parallel to the coast. Kjerfve (1994) synthesised the definitions of the Symposium: 'a shallow coastal water body separated from the ocean by a barrier, connected at least intermittently to the ocean by one or more restricted inlets, and usually oriented shore-parallel' (p. 3). Barnes (1980) adopted a plain definition from the Oxford English Dictionary (Simpson and Weiner 1989) 'an area of salt or brackish water separated from the sea by low sand-banks or a similar barrier, esp. one of those in the neighbourhood of Venice'. In the same textbook, he reported the distinction made by many geographers between 'estuarine lagoons' into which rivers flow and 'marine lagoons' without a major freshwater input. 'Marine lagoons' are often called 'coastal lakes', especially when the connection with the sea is reduced or temporarily obliterated. The term 'estuarine lagoon' is not unequivocally defined; the Glossary of Hydrology issued by the American Geological Institute (Wilson and Moore 2003) defined 'estuarine lagoons' as lagoons 'produced by the temporary sealing of a river estuary by a storm barrier' (p. 74) and put them in synonymy with 'blind estuaries'. Some authors (e.g. Heap *et al*. 2001) refer to 'estuarine lagoons' as 'wave-dominated estuaries' and leave the term '(coastal) lagoons' to small, shallow basins that have very low freshwater input, that is, 'marine lagoons'. Kjerfve (1994) suggested a classification of lagoons according to water exchange with the sea: at one extreme there are the 'leaky lagoons' characterised by abundant seawater exchange, at the opposite extreme there are 'chocked lagoons' with little connection with the sea. This classification can be further refined at a local scale; for instance, in New Zealand, Kirk and Lauder (2000) described two subtypes of chocked lagoons typical of that geographical region.

The acronym ICOLLs for 'Intermittently Closed and Open Lakes and Lagoons' has been developed by Australian authors, and includes small coastal lagoons and small coastal creeks, with entrances that are mostly closed as well as occasionally closed barrier estuaries with untrained entrances (Roy *et al*. 2001). ICOLLs are conceptually related to 'Temporarily Open/Closed Estuaries' (TOCEs; Whitfield 1992), a term originating in the South African literature where 70% of estuaries belong to this class (Whitfield 1995). 'Intermittently Closed Estuaries' (ICEs) and 'Intermittently Open Estuaries' (IOEs) were proposed to classify TOCEs more precisely on the basis of the average time

they are linked with the sea (Whitfield and Bate 2007). In defining ICOLLs and TOCEs, stress was put on the intermittent character of the connection with the sea. Periodic or unpredictable floods and marine overwashing are the leading factors in determining the mouth phase (Hadwen and Arthington 2006; Rustomji 2007). When closed, these environments have no interaction with the sea with water levels and salinity responding to hydrological balance. They can vary from oligohaline to hyperhaline. Variation in the connection with the sea affects the energy and biogeochemical budgets and nutrient regime, along with related biological processes, such as primary production (Snow and Adams 2007). Hadwen and Arthington (2006) reported a series of terms such as 'seasonally open estuaries', 'closed estuaries', 'temporary lakes' and 'semi-permanently closed estuaries' that has been used locally for similar environments. Some authors explicitly include artificially managed systems (e.g. Dye 2006).

Eu/hyperhaline coastal systems typical of Mediterranean climates not covered by the term are 'bahiras'. 'Bahiras' ('small sea' in Arabic, definition in Guelorget and Perthuisot 1989) are landlocked continental depressions of various origins invaded by the sea during post-glacial transgression, communicating with the sea by permanent passages and usually deeper than lagoons (Guelorget and Perthuisot 1983). Another type of lagoon, or estuarine lagoon, is the 'liman'. This term refers to basins formed by sediment accumulation at the mouth of a river either by fluvial transport (fluvial limans) or coastal transport (marine limans) (Vespremeanu 1987). This term typically identifies brackish basins, but is often applied to lake-like water bodies in an estuarine area (Konstantinov 1979) that became fresh after modification of the connection with the sea. The attribution of the term to fresh or brackish environments is not always unequivocal, perhaps because it developed along the north-western shores of the Black Sea, a region where large rivers flow into a brackish nanotidal sea and oligohaline conditions are common in coastal basins. The term (лиман, '*liman*') originated from the Greek '*limenas*' (λιμένας) meaning 'harbour' and spread throughout the Black Sea area during the Turkish domination (Fasmer 1967; Ozhegov and Shvedova 1992). The term is used by European Black Sea countries and sporadically along Russian coasts. Examples are the Dniester Liman in Ukraine and the Beysugsky Liman in Russia. It is evident that there is a very wide spectrum of coastal lagoons with, on the one hand, 'marine lagoons' and, on the other, 'estuarine lagoons'.

'Estuarine system'

Considered separately, lagoons and estuaries show marked differences in physiographical, hydrological and ecological features (Barnes 1994*a*, 1994*b*); nevertheless on sedimentary coasts 'marine lagoons' and estuaries are the endpoints of a *continuum*. Lagoons into which rivers flow, that is, 'estuarine lagoons' (Barnes 1980; Kjerfve 1989) are in the midpoint of this continuum.

Yáñez-Arancibia *et al*. (1994) focussed attention on the fact that coastal lagoons are defined mostly on geomorphological terms, whereas estuaries are defined mainly in terms of hydrological conditions and gradients of salinity and density (Yáñez-Arancibia *et al*. 1994 and references therein). The etymological roots of the two terms reflect this situation. The term 'lagoon' (Latin '*lacūna*') has a strong geomorphic denotation, whereas 'estuary' is a term related to tides (latin '*aestus*') of hydrological denotation. Kjerfve (1989) proposed a very open definition neutral for both tides and salinity: 'An estuarine system is a coastal indentation that has a restricted connection to the ocean and remains open at least intermittently' (p. 50). This definition is focussed on the spectrum of environments, with coastal lagoons generated by wave action at one end and deltas at the other, where the river flow is dominant and retains only the degree of enclosure from the marine environment as the main estuarine feature. Day and Yáñez-Arancibia (1982), recognising important ecological analogies between estuaries and lagoons, proposed the comprehensive term 'lagoon–estuarine environments', defined as 'shallow, semi-enclosed water bodies of variable volume, connected to the sea in a permanent or ephemeral manner, with variable temperature and salinities, permanent muddy bottoms, high turbidity, irregular topographic characteristics, and biotic elements' (in Yáñez-Arancibia *et al*. 1994, p. 363). This definition underlines the high turbidity of these water bodies, not always present in semi-enclosed coastal systems, which can have high sediment-trapping efficiency and consequent naturally low turbidity. This term is currently used mostly in literature from Central and South America.

Brackish waters

From a linguistic point of view, 'brackish water' means 'partly fresh, partly salty' (etymologically a 'broken' water; Simpson and Weiner 1989). Although the term is sometimes used to indicate hyperhaline waters (i.e. brines), it is normally used to designate waters that are saltier than freshwater, but less salty than seawater. The lexical definition of 'brackish' therefore includes inland brackish lakes, where salts are supplied mainly by rocks and soil weathering (i.e. athalassic; Bayly 1972), such as Qinghai Lake (on the Tibetan Plateau), and brackish seas, such as the Baltic and Black Seas. Barnes (1994*a*) offered a definition specifying that in our context, the term 'brackish waters' is properly applied where the salts are of thalassic origin (i.e. supplied by seawater). This author (Barnes 1980) also pointed out the difference between the terms 'saline', applicable to inland salty waters, and 'haline', appropriate for coastal waters. This designation excludes inland brackish water bodies from the definition. The composite term 'coastal brackish waters' (or 'brackish coastal waters') used in many papers (e.g. Barnes 1999) can be used to restrict the term to coastal environments and exclude brackish seas.

Half a century ago, marine biologists decided to avoid the use of 'brackish' as a classificatory term 'because of its ambiguous meaning', proposing the term 'mixohaline' to indicate diluted seawater (Anonymous 1959, p. 243). Nonetheless, the term is used colloquially to indicate water or an environment that is neither marine nor fresh. Appropriate definitions based on one of the existing classification systems (e.g. Anonymous 1959; Por 1972; Bulger *et al*. 1993) would be more correct in scientific papers when precise identifications of salinity ranges are needed. This inclusive term is also suitable for basins characterised by large spatial or temporal excursions in salinity not definable by a single Venice System class. Den Hartog (1974) preferred the more ecological term 'brackish habitat' to 'brackish waters' in view

of the fact that other factors in addition to average salinity have to be considered in a 'brackish' environment classification. For a historical review on the brackish water classification previous to the Venice System, see Segerstråle (1959).

Paralic

A broad term meant to identify the coastal systems that are the subject of the present paper is 'paralic'. 'Paralic basin', 'paralic environment', 'paralic ecosystem' 'paralic habitat' and 'paralic domain' are the main related composite terms. The adjective 'paralic' (from the ancient Greek, παραλιοσ, '*parálios*', 'by the sea') can be found in the English lexicon since the early 20th Century. The presence of the term in the English language can be dated to 1911, both in the form 'paralic basin' and in the German form '*paralisch*', with reference to the Naumann theory of coal deposits formation (Naumann 1852; in Stevenson 1911). The term '*paralisch*' has therefore been used in German since at least 1852, whereas in French the term '*paralique*' has been in use since 1877 (Simpson and Weiner 1989). The first mention of 'paralic' in a technical manual probably occurred in 'Stratigraphy and Sedimentation' (Krumbein and Sloss 1963). Until then the term had been used in geological contexts, yet in 1964 it was used to define mangrove forests (Scholl 1964). The term was used by Perthuisot (1975) to qualify evaporitic basins whose salts were essentially of marine origin.

Paralic environments

This term can be used to indicate a large number of coastal settings without necessarily bringing tides or freshwater inputs into play. The cataloguing includes a wide range of sedimentary environments, such as deltas, estuaries, bays, mangrove swamps and coastal lagoons. 'Paralic environments' can range in salinity from hypohaline to euhaline to hyperhaline (Emery and Myers 1996; Neuendorf *et al*. 2005), according to fluvial, tidal and climatic regimes. 'Paralic' is commonly used in the geological sciences and is widely used by foraminifera researchers (e.g. Serandrei-Barbero *et al*. 1999; Debenay and Guillou 2002).

Paralic domain

The term 'paralic domain' has been used by a small group of marine ecologists (e.g. Lefebvre *et al*. 1997; Debenay *et al*. 2003; Frenod and Goubert 2007) since the work of Guelorget and Perthuisot (Guelorget and Perthuisot 1983; Guelorget *et al*. 1987). These French authors identified the environments between the maritime and continental domains as a distinct domain: the 'paralic domain'. The term 'paralic domain' was not limited to coastal environments, since it includes large bodies of water, such as the Baltic Sea (Guelorget and Perthuisot 1983). The term was coupled with their 'confinement theory' because they identify 'confinement' as the fundamental parameter of the paralic domain. The 'degree of confinement' is a characteristic of being contained, possibly creating an adverse environmental gradient. In this theory, the biological zonation of a given body of water should reflect the 'confinement field', 'confinement' being a variable defined as the mean time taken by the dissolved elements of the marine reservoir to reach any given point of the basin (Perthuisot and Guelorget 1995). Therefore, in the view of Guelorget and Perthuisot 'confinement' is not an attribute comparable to 'semi-enclosed' for estuaries, but rather a quantifiable variable. As they specified (Guelorget and Perthuisot 1989, p. 1; Guelorget and Perthuisot 1992, p. 216) 'The adjective "paralic" applied to an area, a basin or an ecosystem, simply means that it possesses a certain relationship with the sea'; therefore, the use of the term itself would not imply any acceptance or refusal of the confinement theory.

Transitional

The term 'transitional' comes from the Latin '*transitiònem*', which means passage from one place or state to another. 'Transitional environments' and 'transitional waters' are the main related composite terms.

Transitional environments

The transition is, in this case, between terrestrial and maritime domains. As far as we know, the first scientific definition of 'transitional environments' was given by Twenhofel, one of the founders of sedimentology, in his book 'Principles of Sedimentation': 'Transitional environments – the place of meeting of land and sea produces environments that are ruled jointly by the two great environmental realms, or each alternatively maintains an often repeated rule for short time' (Twenhofel 1939, p. 91). A more synthetic definition was given by Füchtbauer (1974, p. 109) 'Transitional environments are intermediate in time or space between marine and nonmarine environments'. 'Transitional environments' are ruled by hydrodynamic forces and fashioned by the joint and/or alternating action of marine and continental processes. 'Transitional environments' are represented mainly by estuaries, deltas and lagoons, but they also include other coastal environments such as beaches and prodeltas.

Transitional waters

The term 'transitional waters' usually expresses the transition between water masses with different physical properties; the 'transition' this time is between freshwater and seawater. 'Transitional waters' is a legal term introduced by the WFD (European Community 2000) that is rapidly consolidating as a scientific term. The recent WFD aims to protect and improve the physical and biological conditions of European aquatic ecosystems. To achieve these challenging goals, the WFD identifies the following surface-water categories: rivers, lakes, transitional waters and coastal waters. The term is central to the WFD and subsequent guidance documents (European Commission 2003) and is increasingly used in technical papers and regulations. The given definition, '. . .bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows' (WFD, Article 2.6), is very close to the definition of estuary given by Pritchard (1967) and Day (1981). 'Partly saline in character' and 'substantially influenced by freshwater' is equivalent to 'brackish'. The main difference between the 'brackish concept' of estuary and 'transitional waters' seems to be the change of the expression 'semi-enclosed' to 'in the vicinity of river mouths', resulting in the inclusion of river plumes into 'transitional waters', as clearly indicated by a subsequent technical guidance: 'If riverine dynamics occur in a plume outside the coastline because of high and strong freshwater discharge, the transitional water

may extend into the sea area' (Common Implementation Strategy 2002; Section 2.3.4, p. 27). This specification restricts the 'brackish concept' to the surroundings of river mouths, resulting in a limited extension of the 'tidal concept'. These definitions exclude other 'brackish coastal waters', such as some of the coastal waters of the Baltic Sea and the Black Sea.

Discussion

Almost all the terms presented in the previous section contain some vagueness that can limit their use. The term 'estuary' is used both for a single physiographical type and for a group of types, including fjords and deltas. In the various definitions of an estuary, the conditions used are mainly the presence of tides, seawater dilution from fresh watercourses and partial isolation of the water body. In some definitions, there is an explicit reference to fluvial landforms, such as 'river mouth' (Odum 1959), 'river valley' (Fairbridge 1980) or 'narrow' (Tomczak 1996). The term 'estuary' is applied *sensu stricto* to the 'tidal concept' of an estuary because it retains the original tidal root. Lyell's (1833) early definition expresses this concept and precedes the analogous definitions given by Odum (1959) and Fairbridge (1980) by more than a century. Therefore, according to the more rigorous definitions there are not estuaries without tides, so these definitions of the term exclude non-tidal water bodies from the estuarine family. Among these are some important systems, such as the deltas of the two largest European rivers, the Volga (draining into the Caspian Sea) and the Danube (Black Sea), the delta of the longest African (and world's) river, the Nile (Mediterranean Sea), and the delta of the largest North-American river, the Mississippi–Missouri (Gulf of Mexico).

Here the reasoning becomes delicate; what is the minimum tidal range for a water body to be considered tidal? Microtides range from zero to 1 m (Hayes 1979) or 2 m (Davies 1964); by definition, a water body should be considered tidal even with a mean tidal range of a few centimetres, and as a consequence very few coastal waters remain non-tidal. To avoid the tidal/non-tidal dichotomy, Tagliapietra and Volpi Ghirardini (2006) suggested the use of a lower tidal category, the nanotidal. Nanotides are usually masked by meteorological conditions and waves; as a result, the common perception is that 'real' tides begin with microtides and nanotidal water bodies can therefore be considered non-tidal. In the presence of nanotides, for example, in the Mediterranean, submergence is dependent more on wave motion or barometric pressure than tides; in this case the intertidal is referred to as mediolittoral (*Ètage mediolittoral*; Pérès and Picard 1964). When the term 'tides'; 'tidal' or 'non-tidal' are present in definitions, the tidal range or tidal classes they are referring to should be specified.

The 'brackish concept' extends the term 'estuaries' to non-tidal areas, but it loses some etymological strength because the presence of tides is no longer a necessary requisite. Nonetheless, it is to the image of a river mixing with the sea that we owe the classical idea of 'estuary' and the diffusion of this definition in the scientific and legal literature, as in everyday language, makes the 'brackish concept' of an estuary the most accepted connotation. Definitions by Pritchard (1967) and Day (1981) are the most consolidated, but it is the definition of Ketchum (1951) that gives the idea in a few words. The clause 'measurably diluted' contained in these definitions excludes negative estuaries and prompted Tomczak (1996) to another definition tailored to arid climate estuaries.

Categorisation of ICOLLs and TOCEs, along with other terms defining intermittently opening systems, reflects the debate about the different concepts of 'estuary'. ICOLLs are sometimes considered a subset of estuaries (Roy *et al*. 2001) and sometimes not because they do not always experience tides and water dilution (Hadwen and Arthington 2006). Some problems arise from the attribution of shallow basins receiving a considerable freshwater input to lagoons or estuaries, but they can be overcome by accepting the idea of the lagoon–estuary typological continuum. To cover the whole continuum, Kjerfve (1989) gave a definition of the 'estuarine system' founded on the geomorphic idea of water bodies developing behind or across the coastline, with no reference to tides or salinity. It is not clear if this continuum refers only to sedimentary shores; in any case the definition also fits rocky shore environments.

Brackish, paralic and transitional are the adjectives used in the more inclusive terms. These requisites also reveal the environmental models where they originated: 'brackish' stresses the importance of freshwater inflow and seawater dilution, 'paralic' underlines the proximity of the sea and the role of the marine component, 'transitional' points out the presence of gradients and ecotonal traits. The term 'brackish waters' (or 'brackish habitats') excludes 'marine lagoons' and generally eu/hyperaline environments from the definition. This definition, based on seawater dilution, can also be applied to open shores or to very large water bodies like the Baltic Sea. The discussion about the term 'paralic' drew attention to the fact that much of what is called 'brackish water fauna' (Barnes 1989) occurs not only in diluted seawater, but also in euhaline and hyperaline conditions. Barnes (1994*b*) stated that 'paralic environments' would be generally termed 'brackish waters' in English. The correspondence of the terms 'paralic' and 'brackish' was also reported by Elliott and McLusky (2002). This correspondence is not entirely correct because the term 'paralic' also includes environments that are not 'brackish', for example, marine lagoons. The disagreement between Barnes and Guelorget and Perthuisot was more a difference of opinion on the 'confinement' theory rather than on terminology. Barnes (1994*b*) expressed some criticisms about the application of the confinement theory to European macrotidal environments on the basis of the occurrence of characteristic groups of species (i.e. marine/estuarine, lagoonal and freshwater species) in north-western European waters. The French authors replied sustaining their positions on the basis of species distributions in Mediterranean lagoons, concluding that neither the term 'lagoonal' nor the terms 'marine/estuarine' used by Barnes were appropriate (Perthuisot and Guelorget 1995). The debate following these articles was very limited; as a consequence of the association with the confinement theory this term did not spread among marine ecologists, but in other scientific disciplines, such as geology, palaeobiology and biogeography, 'paralic' is currently used to identify this class of environments. The adjective 'paralic' was historically coupled with the terms 'domain' and 'realm' (Guelorget and Perthuisot 1983, 1989) to underline the originality of this category of environments, which should be considered not just a mere blending of marine and continental realms, but a self-standing entity with new emergent

properties. The use of 'paralic' itself would not imply any acceptance or refusal of the theory and it could be accepted (if not welcomed; Barnes 1994*b*) as neutral with respect to salinity and advantageously used as a term comprehensive of estuaries and lagoons. The adjective 'transitional' highlights the presence of gradients, a crucial feature of these environments. 'Transitional environments' was applied to the coast, including open beaches; therefore, it is less connotative of the protected environments that are the subject of this discussion.

After their stimulating article on the need for definitions in understanding estuaries (Elliott and McLusky 2002), McLusky and Elliott (2007) promoted a both formal and substantial discussion on the use of the composite term 'transitional waters'. According to these authors, 'transitional waters' can be considered a linguistic evolution in this subject area because the expression includes classical estuaries and non-tidal brackish lagoons, bringing together tidal and non-tidal brackish coastal water bodies. These authors suggested that the term was a way for legislators to avoid the problem of the use of tides in defining estuaries (McLusky and Elliott 2004). Dauvin *et al*. (2008) criticised the term, judging it to be ambiguous with no scientific basis and underlined the uncertainty about the inclusion of environments other than estuaries (e.g. lagoons), owing to the stress placed by the WFD definition on salinity gradients/variations. The legal term introduced in the WFD influenced its adoption as a scientific term; this is evident from the increasing frequency of the term in scientific papers. A quick online search on the 'Web of Science' on the term 'transitional water(s)' resulted in 82 documents in the past 30 years (1978–2007). No record was found before 1991. The first paper referring to 'transitional waters' in the sense of 'estuarine' waters was published in 2002, previous papers used the term with reference to temperature transitions. After the issuing of the WFD, the number of scientific papers that used the term increased (Fig. 2). The term 'transitional ecosystems' was used in the scientific literature in addition to 'transitional waters' to indicate estuaries, lagoons and wetlands (e.g. Basset *et al*. 2006; Danovaro and Pusceddu 2007; Simboura and Reizopoulou 2008). In our opinion, the recent diffusion and success of the term 'transitional' results from, in addition to its inclusion in the WFD, a need to condense within a single definition the trait that mainly characterises these environments, that is, the presence of strong environmental gradients. In 2007, two new journals dedicated to the subject, *Transitional Water Bulletin* and *Transitional Water Monographs*, were launched on the web. A growing number of scientific papers now include euhaline or hyperhaline coastal environments, such as 'marine lagoons' and saltworks, under the term 'transitional waters' (e.g. Barbone *et al*. 2007; Evagelopoulos *et al*. 2007; Orfanidis *et al*. 2008). Despite the increasingly open use of the term, 'transitional waters' cannot be extended to include eu/hyperhaline lagoons because it will be in contrast with the legal and managerial definition given in the WFD.

Terms and definitions presented above reflect their scientific, historical and geographic context. Definitions generated in a given context are often revised when terms are taken by another discipline, sometimes drifting from their etymological roots. Definitions are not free of regional influences. For instance, the most quoted definitions of estuaries reflect the historical development of the term along the temperate North Atlantic coasts and modifications of the original definitions are needed to be extended to arid climates. In the discussion about 'brackish' and 'paralic', British authors supported the term that points out the importance of the saline gradient as if their viewpoint were classical estuaries, whereas French authors supported a term that underlines the importance of the marine gradient as if their viewpoint were marine lagoons. The need for aggregation of 'marine lagoons' and 'estuaries' in a single term also seems to be influenced by the importance of lagoons in regional coastal seascapes.

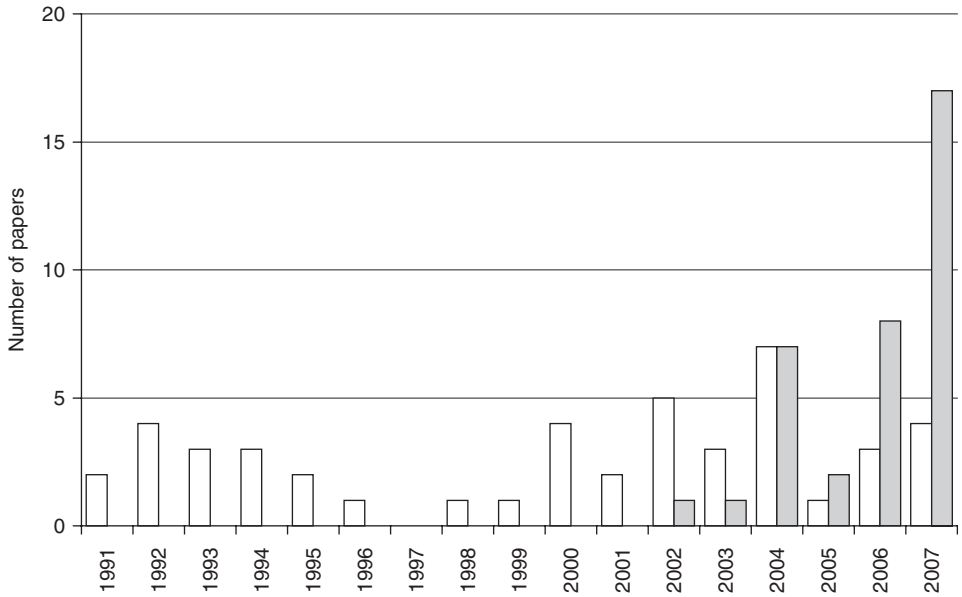

Fig. 2. The number of papers reporting the term 'transitional water(s)' from the scientific literature from 1991 to 2007. Terms in grey are used in the sense of the Water Framework Directive; terms in white are used in other senses.

Scientists working in Mediterranean climates, where lagoons are frequent, felt the need to join marine lagoons and estuaries, this is the case of the 'lagoon–estuarine environments' proposed by Day and Yáñez-Arancibia (1982) and the 'paralic domain' proposed by Guelorget and Perthuisot (1983), but also a reason for the extension of the term 'transitional waters' to euhaline and hyperhaline water bodies operated *de facto* by Mediterranean scientists.

From the definitions, the main attributes have been distilled and arranged in a conceptual scheme to have a direct and overall perception of their relationships. These attributes are either hydrological or geomorphic. Hydrological attributes include the presence of distinct tides ('tidal') and seawater dilution ('brackish'). The main geomorphic attributes reported in the definition are 'river mouth' and 'river valley', 'semi-enclosed' and 'indentation', 'coastal' and 'littoral' and these attributes can be ordered according to inclusiveness.

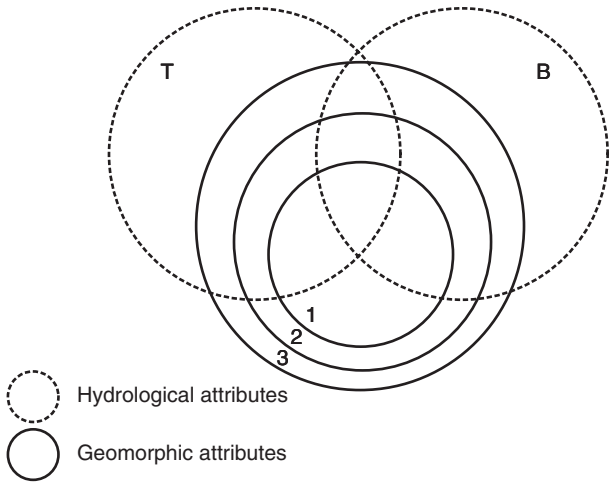

Fig. 3. Euler diagram showing the relationships among attributes used in the definitions specified in Table 1. Hydrological attributes comprise 'brackish' (B) and 'tidal' (T); geomorphic attributes ordered in terms of increasing inclusiveness are 'river mouth'/'river valley' (1), 'semi-enclosed'/'indentation' (2) and 'coastal'/'littoral' (3).

Fig. 3 is a Euler diagram representing the main attributes; the intersection between the attributes defines the relationships between coastal environments according to the definitions. These relationships can be formalised by the means of set theory (Table 1). Basic physiographical types can also be located in the Euler diagram. For instance, an estuarine lagoon is located on the intersection between 'tidal', 'brackish' and 'semi-enclosed' sets.

Existing definitions put emphasis on geomorphic and hydrological features, but geomorphic attributes also imply hydrological processes; the attribute 'semi-enclosed' (or similar terms such as 'indentation') involves a feature of paramount importance not expressly formulated in definitions, that is, a limited supply of seawater to the system. Therefore, in current definitions we can find the two main components of the composite gradient: the salinity, explicitly recognised, and the seawater renewal, implicit in the 'semi-enclosed' condition.

The present paper has shown that there are some difficulties in producing a single term and a suitable definition for the whole class of environments. To the best of our knowledge, it seems that there are no obstacles to expanding the definition of Kjerfve (1989) to the whole class. This definition can be applied to proper estuaries, rias, fjords, fjards, river mouths, deltas, bar-built estuaries, coastal lagoons, bahiras, ICOLLs and embayments. It can also be applied to artificial or heavily modified water bodies, such as saltworks, urban canals, aquaculture ponds and harbours. The associated term 'estuarine system' cannot be used without generating confusion with the previous use and with other uses of the adjective 'estuarine' because it refers not only to 'estuaries'.

The Australian online coastal information portal 'OzCoasts' (OzCoasts 2000) gave a definition of a 'coastal waterway' as 'A body of water situated on or near the ocean coast, with some association with the ocean. Includes embayments, wave- and tide-dominated estuaries, wave- and tide-dominated deltas, coastal lagoons, and tidal creeks'. This definition embraces a large assortment of coastal water bodies (see also Heap *et al*. 2001).

Table 1. Relationships between the terms denoting groups of coastal environments and hydrological and geomorphic attributes according to the Euler diagram in Fig. 3

Hydrological attributes comprise 'brackish' (B) and 'tidal' (T); geomorphic attributes ordered in terms of increasing inclusiveness are 'river mouth'/'river valley' (1), 'semi-enclosed'/'indentation' (2) and 'coastal'/'littoral' (3). Intersections are denoted by the symbol '∩', according to the syntax of set theory

Terms	Attributes	Main references
Transitional environments	3	Twenhofel 1939; Füchtbauer 1974
Paralic environments/domain	2	Guelorget and Perthuisot 1983
Semi-enclosed littoral ecosystems (SELE)	2	Guarini and Blanchard 2001
Coastal waterways	2	OzCoasts 2000; Madden and Grossman 2004
Estuarine systems[A]	2	Kjerfve 1989
Lagoon–estuarine environments[A]	2	Day and Yáñez-Arancibia 1982
Brackish waters (coastal)	B∩3	Segerstråle 1959; Den Hartog 1974; Barnes 1994*a*
Estuaries ('brackish concept')	B∩2	Ketchum 1951; Pritchard 1967; Day 1981
Transitional waters	B∩1	European Community 2000
Estuaries ('tidal concept')	B∩1∩T	Lyell 1833; Odum 1959; Fairbridge 1980

[A]Rocky shores possibly not included.

The same definition was picked up by the Coastal/Marine Ecological Classification Standard (CMECS 2006) developed through a collaboration between the USA National Oceanic and Atmospheric Administration (NOAA) and the NatureServe organisation (Madden and Grossman 2004). The first sentence of this definition is less precise than Kjerfve's definition and had to be followed by a specification of some included environments. The term 'coastal waterways' is usually understood as a generally navigable body of water, and is little used by scientists in the CMECS sense.

Among the existing terms, 'paralic environments' was expressly coined for this purpose; it is etymologically correct because it refers to the relationships of a coastal environment with the sea. The transdisciplinarity of the term could be particularly useful in environmental sciences, which are intrinsically multidisciplinary, and in environmental management. Nevertheless, in the minds of ecologists, the adjective 'paralic' has remained inexorably linked to the related confinement theory and the term 'paralic environments' could not obtain the necessary consensus. A quick online search (1978–2007) on the 'Web of Science' provided 258 results for 'paralic', of which 23 were in ecology/biology. An alternative existing term is 'semi-enclosed littoral ecosystems' (SELE), introduced by Guarini and Blanchard (2001), but, as far as we know, this term was only used in a few papers by the authors who had proposed it.

'Transitional waters', as defined in the WFD, excludes all environments not substantially influenced by river flow. Its meaning is therefore very close to the 'brackish concept' of estuary, with the exception that it is not restricted to 'semi-enclosed' settings. The use of this term in a wider context is strongly hindered by the existing legal definition in the WFD. However, the inclusive use of the term is growing. The reason could lie, in addition to its inclusion in the WFD, in the appeal of the adjective 'transitional', which efficiently draws attention to the main features of these environments that mark the passage between marine and non-marine realms: the variability of the milieu and the structuring action of environmental gradients.

Conclusions

From our analysis, it emerges that there is currently neither a commonly accepted term nor a common definition for the whole range of sheltered, semi-enclosed coastal environments.

Only two published terms, 'paralic environments' and 'semi-enclosed littoral ecosystems', were expressly created to identify these environments. The use of either poses some problems: the first term encountered resistance from ecologists because of its association with the 'confinement theory', the second was almost ignored. Considering the growing use of the term 'transitional', we suggest that new terms should retain this adjective because it denotes a major feature of this kind of environment. In a landscape ecology context, this class could be termed 'transitional seascapes'. The term 'seascapes' is more comprehensive than just 'waters' or 'habitats' (Bartlett and Carter 1991; Costello and Emblow 2005), giving a holistic perspective to the environment, very close to the idea of the 'estuarine system' expressed by Cowardin *et al.* (1979) as comprehensive of 'wetlands' and 'deepwaters'. The adjective 'transitional' can also be applied to the composite gradient that characterises this type of environment as 'transitional gradient'. The definition given by Kjerfve (1989) could conceptually be applied to the entire class of considered environments. This definition emphasises the geomorphic features linked to key processes: as a consequence of a restricted connection to the sea the supply of seawater to the whole system is also restricted. Therefore, 'coastal transitional ecosystems' could also be defined as coastal water bodies with limited seawater supply.

Acknowledgements

Thanks are due to Professor M. Elliott, Hull University, UK, for his constructive suggestions and to Professor D. S. McLusky, University of Stirling, UK, for his kind, but firm criticism about the term 'paralic'. Professor M. Holland, University of Georgia, USA, Professor P. Styles and Dr N. Mountney, University of Keele, UK, kindly provided information on the early use of the term 'paralic'. Thanks to Professor N. Berlinski, Odessa State Environmental University, Odessa, Ukraine, and Dr A. Stanica, National Institute of Marine Geology and Geo-ecology (GeoEcoMar), Bucharest, Romania, for information about 'limans'. A special thank you to Dr L. Colussi for helping with translations from Latin and to Dr O. Faraponova, ISPRA, Italy, for the translation from Russian. Thanks to Dr T. Minuzzo, Philosophy of Language, CNR-ISMAR, Italy, for fruitful discussions on definitions. The authors gratefully acknowledge the helpful comments and suggestions provided by three anonymous referees and the editor Professor A. Boulton.

References

Anonymous (1959). Final resolution. The Venice System for the classification of marine waters according to salinity. In 'Symposium on the Classification of Brackish Waters, Venice, 8–14 April 1958'. (Ed. U. D'Ancona.) *Archivio di Oceanografia e Limnologia* **11**, 243–248.

Attrill, M. J. (2002). A testable linear model for diversity trends in estuaries. *Journal of Animal Ecology* **71**, 262–269. doi:10.1046/J.1365-2656.2002.00593.X

Attrill, M. J., and Rundle, S. D. (2002). Ecotone or ecocline: ecological boundaries in estuaries. *Estuarine, Coastal and Shelf Science* **55**, 929–936. doi:10.1006/ECSS.2002.1036

Barbone, E., Rosati, I., Pinna, M., and Basset, A. (2007). Taxonomic and dimensional structure of benthic macroinvertebrate guilds in the Margherita di Savoia Salt Pans (Italy). *Transitional Waters Bulletin* **4**, 21–31.

Barnes, R. S. K. (1980). 'Coastal Lagoons. The Natural History of a Neglected Habitat.' (Cambridge University Press: Cambridge.)

Barnes, R. S. K. (1989). What, if anything, is a brackish-water fauna? *Transactions of the Royal Society of Edinburgh. Earth Sciences* **80**, 235–240.

Barnes, R. S. K. (1994*a*). 'The Brackish-Water Fauna of Northwestern Europe.' (Cambridge University Press: Cambridge.)

Barnes, R. S. K. (1994*b*). A critical appraisal of the application of Guélorget and Perthuisot's concepts of the paralic ecosystem and confinement to macrotidal Europe. *Estuarine, Coastal and Shelf Science* **38**, 41–48. doi:10.1006/ECSS.1994.1003

Barnes, R. S. K. (1999). The conservation of brackish-water systems: priorities for the 21st century. *Aquatic Conservation: Marine & Freshwater Ecosystems* **9**, 523–527. doi:10.1002/(SICI)1099-0755(199911/12)9:6<523::AID-AQC368>3.0.CO;2-A

Bartlett, D., and Carter, R. W. G. (1991). Seascape ecology: the landscape ecology of the coastal zone. *Ekologia (Bratislava)* **10**, 43–53.

Basset, A., Sabetta, L., Fonnesu, A., Mouillot, D., Do Chi, T., *et al.* (2006). Typology in Mediterranean transitional waters: new challenges and perspectives. *Aquatic Conservation: Marine & Freshwater Ecosystems* **16**, 441–455. doi:10.1002/AQC.767

Bayly, I. A. E. (1972). Salinity tolerance and osmotic behaviour of animals in athalassic saline and marine hypersaline waters. *Annual Review of Ecology and Systematics* **3**, 233–268. doi:10.1146/ANNUREV.ES.03.110172.001313

Boesch, D. F. (1973). Classification and community structure of macrobenthos in the Hampton Roads area, Virginia. *Marine Biology* **21**, 226–244. doi:10.1007/BF00355253

Boyd, R., Dalrymple, R. W., and Zaitlin, B. A. (1992). Classification of clastic coastal depositional environments. *Sedimentary Geology* **80**, 139–150. doi:10.1016/0037-0738(92)90037-R

Bulger, A. J., Hayden, B. P., Monaco, M. E., Nelson, D. M., and McCormickray, M. G. (1993). Biologically based estuarine salinity zones derived from a multivariate analysis. *Estuaries* **16**, 311–322. doi:10.2307/1352504

Cameron, W. M., and Pritchard, D. W. (1963). Estuaries. In 'The Sea, vol. 2'. (Ed. M. N. Hill.) pp. 306–324. (John Wiley & Sons: New York.)

Coastal and Marine Ecological Classification Standard (CMECS) (2006). A working draft classification of North American coastal and marine habitats. Available at http://www.natureserve.org/getData/CMECS/glossary.htm#C [accessed 19 September 2008]

Cognetti, G., and Maltagliati, F. (2000). Biodiversity and adaptive mechanisms in brackish water fauna. *Marine Pollution Bulletin* **40**, 7–14. doi:10.1016/S0025-326X(99)00173-3

Common Implementation Strategy (2002). Guidance on typology, reference conditions and classification systems for transitional and coastal waters. CIS Working group 2.4 (COAST), Copenhagen.

Constable, A. J., and Fairweather, P. G. (1999). Ecology of estuaries and soft-sediment habitats: symposium introduction. *Australian Journal of Ecology* **24**, 289–290. doi:10.1046/J.1442-9993.1999.00982.X

Costello, M. J., and Emblow, C. (2005). A classification of inshore marine biotopes. In 'The Intertidal Ecosystem: The Value of Ireland's Shores'. (Ed. J. G. Wilson.) pp. 25–37. (Royal Irish Academy: Dublin.)

Cowardin, L. M., Carter, V., Golet, F. C., and LaRoe, E. T. (1979). Classification of wetlands and deepwater habitats of the United States (Version 04DEC98). Available at www.wbdg.org/ccb/ENVREG/habitat.pdf [accessed 19 May 2009]

D'Ancona, U., Faganelli, A., Ranzoli, F., and Marchesoni, V. (1954). Il trofismo della Laguna Veneta e la vivificazione marina. *Archivio di Oceanografia e Limnologia* **9**, 9–285.

Dalrymple, R. W., Zaitlin, B. A., and Boyd, R. (1992). Estuarine facies models: conceptual models and stratigraphic implications. *Journal of Sedimentary Petrology* **62**, 1130–1146.

Danovaro, R., and Pusceddu, A. (2007). Biodiversity and ecosystem functioning in coastal lagoons: does microbial diversity play any role? *Estuarine, Coastal and Shelf Science* **75**, 4–12. doi:10.1016/J.ECSS.2007.02.030

Dauvin, J. C., Bellan, G., and Bellan-Santini, D. (2008). The need for clear and comparable terminology in benthic ecology. Part II. Application of the European Directives. *Aquatic Conservation: Marine & Freshwater Ecosystems* **18**, 446–456. doi:10.1002/AQC.864

Davies, J. H. L. (1964). A morphogenic approach to world shorelines. *Zeitschrift fur Geomorphologie* **8**, 127–142.

Day, J. H. (1981). The nature, origin and classification of estuaries. In 'Estuarine Ecology with Particular Reference to Southern Africa'. (Ed. J. H. Day.) pp. 1–6. (Balkema: Rotterdam.)

Day, J. W., and Yáñez-Arancibia, A. (1982). Coastal lagoons and estuaries: ecosystem approach. *Ciencia Interamericana* **22**, 11–26.

Debenay, J. P., and Guillou, J. J. (2002). Ecological transitions indicated by foraminiferal assemblages in paralic environments. *Estuaries* **25**, 1107–1120. doi:10.1007/BF02692208

Debenay, J. P., Carbonel, P., Morzadec-Kerfourn, M. T., Cazaubon, A., Denefle, M., and Lezine, A. M. (2003). Multi-bioindicator study of a small estuary in Vendee (France). *Estuarine, Coastal and Shelf Science* **58**, 843–860. doi:10.1016/S0272-7714(03)00189-6

Den Hartog, C. (1974). Brackish-water classification, its development and problems. *Aquatic Ecology* **8**, 15–28.

Diaz, R. J., and Rosenberg, R. (1995). Marine benthic hypoxia: a review of its ecological effects and the behaviour responses of benthic macrofauna. *Oceanography and Marine Biology Annual Review* **33**, 245–303.

Diaz, R. J., Solan, M., and Valente, R. M. (2004). A review of approaches for classifying benthic habitats and evaluating habitat quality. *Journal of Environmental Management* **73**, 165–181. doi:10.1016/J.JENVMAN.2004.06.004

Dye, A. H. (2006). Is geomorphic zonation a useful predictor of patterns of benthic infauna in intermittent estuaries in New South Wales, Australia? *Estuaries and Coasts* **29**, 455–464.

Dye, A. H., and Barros, F. (2005). Spatial patterns of macrofaunal assemblages in intermittently closed/open coastal lakes in New South Wales, Australia. *Estuarine, Coastal and Shelf Science* **64**, 357–371. doi:10.1016/J.ECSS.2005.02.029

Elliott, M., and McLusky, D. S. (2002). The need for definitions in understanding estuaries. *Estuarine, Coastal and Shelf Science* **55**, 815–827. doi:10.1006/ECSS.2002.1031

Emery, D., and Myers, K. J. (1996). 'Sequence Stratigraphy.' (Blackwell Publishing: Oxford.)

European Commission (2003). Common implementation strategy for the Water Framework Directive (2000/60/EC). Guidance document number 5. Transitional and coastal waters. Typology, reference conditions and classification systems. Office for Official Publications of the European Communities, Bruxelles.

European Community (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Communities 43 (L327), Bruxelles.

Evagelopoulos, A., Spyrakos, V., and Koutsoubas, D. (2007). The biological system of the lower salinity ponds in Kalloni Saltworks (NE Aegean Sea, Greece): phytoplankton and macrobenthic invertebrates. *Transitional Waters Bulletin* **3**, 23–25.

Fairbridge, R. W. (1980). The estuary: its definition and geodynamic cycle. In 'Chemistry and Biogeochemistry of Estuaries'. (Eds E. Olausson and I. Cato.) pp. 1–35. (John Wiley & Sons: New York.)

Fasmer, M. (von Vasmer, M.) (1967). 'Ètimologicheskij Slovar' Russkogo Jazyka (Etymological Dictionary of Russian Language).' Vol. 2. (Progress: Moskow.) Available as 'Vasmer's Russian Etymological Dictionary' at http://starling.rinet.ru/cgi-bin/response.cgi?root=/usr/local/share/starling/morpho&morpho=1&basename=\usr\local\share\starling\morpho\vasmer\vasmer&first=1 [accessed 19 September 2008]

Frenod, E., and Goubert, E. (2007). A first step towards modelling confinement of paralic ecosystems. *Ecological Modelling* **200**, 139–148. doi:10.1016/J.ECOLMODEL.2006.07.009

Füchtbauer, H. (1974). 'Sediments and Sedimentary Rocks 1.' (Schweizerbart'sche Verlag: Stuttgart.)

Gray, J. S., Wu, R. S., and Or, Y. Y. (2002). Effects of hypoxia and organic enrichment on the coastal marine environment. *Marine Ecology Progress Series* **238**, 249–279. doi:10.3354/MEPS238249

Guarini, J. M., and Blanchard, G. E. (2001). An integrated approach to quantify the dynamics of the microalgal biomass in semi-enclosed, European-type littoral ecosystems. Available at http://www.erf.org/cgi-bin/conference_abstract.pl?conference=erf2001&id=347 [accessed 19 September 2008]

Guelorget, O., and Perthuisot, J. P. (1983). Le domaine paralique: expressions géologiques, biologiques et économiques du confinement. *Travaux du Laboratoire de Géologie* **16**, 1–136. [In French]

Guelorget, O., and Perthuisot, J. P. (1989). The paralic realm, geological, biological and economic expression of confinement. FAO Report No: FAO-FI–RAB/83/016. Food and Agriculture Organization, Rome.

Guelorget, O., and Perthuisot, J. P. (1992). Paralic ecosystems. Biological organization and functioning. *Vie et Milieu* **42**, 215–251.

Guelorget, O., Perthuisot, J. P., Frisoni, G. F., and Monti, D. (1987). Le rôle du confinement dans l'organisation biogéologique de la lagune de Nador (Maroc). *Oceanologica Acta* **17**, 105–114. [In French]

Hadwen, W. L., and Arthington, A. H. (2006). 'Ecology, Threats and Management Options for Small Estuaries and ICOLLs.' (Sustainable Tourism Cooperative Research Centre, CRCST Press: Gold Coast.)

Harris, P. T., and Heap, A. D. (2003). Environmental management of clastic coastal depositional environments: inferences from an Australian geomorphic database. *Ocean and Coastal Management* **46**, 457–478. doi:10.1016/S0964-5691(03)00018-8

Hayes, M. O. (1979). Barrier island morphology as a function of wave and tide regime. In 'Barrier Islands from the Gulf of St. Lawrence to the Gulf of Mexico'. (Ed. S. P. Leatherman.) pp. 1–29. (Academic Press: New York.)

Heap, A., Bryce, S., Ryan, D., Radke, L., Smith, C., *et al.* (2001). 'Australian Estuaries and Coastal Waterways: a Geoscience Perspective for Improved and Integrated Resource Management. Record 2001/07.' (Australian Geological Survey Organisation: Canberra.)

Hopkinson, C. S., Jr, and Hoffman, F. A. (1984). The estuary extended – a recipient-system study of estuarine outwelling in Georgia. In 'The Estuary as a Filter'. (Ed. V. S. Kennedy.) pp. 313–330. (Academic Press: New York.)

Isidorus Hispalensis (621). Etymologiarum sive Originum. Liber XIII. De mundo et partibus. Caput XVIII. De aestibus et fretis [1]. Available at http://www.fh-augsburg.de/~harsch/Chronologia/Lspost07/Isidorus/isi_et13.html#c14 [accessed 19 September 2008]

Ketchum, B. H. (1951). The exchange of fresh and salt water in estuaries. *Journal of Marine Research* **10**, 18–38.

Ketchum, B. H. (Ed.) (1983). 'Ecosystems of the World. Vol. 26. Estuaries and Enclosed Seas.' (Elsevier: Amsterdam.)

Kirk, R. M., and Lauder, G. A. (2000). 'Significant Coastal Lagoon Systems in South Island, New Zealand.' (Department of Conservation: Wellington.)

Kjerfve, B. (1989). Estuarine geomorphology and physical oceanography. In 'Estuarine Ecology'. (Eds J. W. Day, C. A. S. Hasll, M. W. Kemp and A.Yáñez-Arancibia.) pp. 47–78. (John Wiley & Sons: New York.)

Kjerfve, B. (Ed.) (1994). 'Coastal Lagoon Processes.' (Elsevier: Amsterdam.)

Konstantinov, A. S. (1979). 'Obshchaya Gidrobiologiya (General Hydrobiology).' (Vysshaya Shkola: Moscow.) [In Russian]

Krumbein, W. C., and Sloss, L. L. (1963). 'Stratigraphy and Sedimentation.' (W. H. Freeman: San Francisco.)

Lefebvre, A., Guelorget, O., Perthuisot, J. P., Courties, C., and Millet, B. (1997). Hydrobiological organization of a bahira type paralic basin: Kalloni Bay (Lesbos, Greece). *Oceanologica Acta* **20**, 757–768.

Levin, L. A., Boesch, D. F., Covich, A., Dahm, C., Erseus, C., *et al.* (2001). The function of marine critical transition zones and the importance of sediment biodiversity. *Ecosystems* **4**, 430–451. doi:10.1007/S10021-001-0021-4

Lyell, C. (1833). 'Principles of Geology.' 3rd edn. Vol. 3. (John Murray: London.)

Madden, C. J., and Grossman, D. H. (2004). 'A Framework for a Coastal/Marine Ecological Classification Standard.' (NatureServe: Arlington.)

McLusky, D. S. (1993). Marine and estuarine gradients – an overview. *Netherlands Journal of Aquatic Ecology* **27**, 489–493. doi:10.1007/BF02334809

McLusky, D. S., and Elliott, M. (2004). 'The Estuarine Ecosystem. Ecology, Threats and Management.' (Oxford University Press: New York.)

McLusky, D. S., and Elliott, M. (2007). Transitional waters: a new approach, semantics or just muddying the waters? *Estuarine, Coastal and Shelf Science* **71**, 359–363. doi:10.1016/J.ECSS.2006.08.025

Naumann, C. F. (1852). 'Lehrbuch der Geognosie.' (Engelmann: Leipzig.) [In German]

Neuendorf, K. K. E., Mehl, J. P. J., and Jackson, J. A. (Eds) (2005). 'Glossary of Geology.' (Springer-Verlag: New York.)

Nixon, S., Olsen, S., Buckley, E., and Fulweiler, R. (2004). 'Lost to tide' – the importance of fresh water flow to estuaries. University of Rhode Island, Graduate School of Oceanography, Final report submitted to the Coastal Resources Center. Narragansett, RI.

Odum, E. P. (1959). 'Fundamentals of Ecology.' 2nd edn. (Sanders: Philadelphia.)

Orfanidis, S., Reizopoulou, S., and Basset, A. (2008). Transitional states in transitional waters – editorial. *Aquatic Conservation: Marine & Freshwater Ecosystems* **18**, S1–S3. doi:10.1002/AQC.958

OzCoasts (2000). Australian online coastal information, glossary. Available at http://www.ozcoasts.org.au/glossary/def_c-d.jsp [accessed 19 September 2008]

Ozhegov, S. I., and Shvedova, N. Yu. (1992). 'Tolkovyj Slovar Russkogo Jazyka (Explanatory Dictionary of Russian Language).' (AZ: Moscow.) [In Russian]

Pearson, T. H., and Rosenberg, R. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Annual Review* **16**, 229–311.

Pérès, J. M., and Picard, J. (1964). Nouveau manuel de bionomie benthique de la Mer Méditerranée. *Recueil des Traveaux de la Station Marine d'Endoume* **31**, 1–137. [In French]

Perthuisot, J. P. (1975). La Sebkha el Melah de Zarzis. Genèse et évolution d'un bassin salin paralique. *Travaux du Laboratoire de Géologie* **9**, 1–252. [In French]

Pérez-Ruzafa, A., and Marcos, C. (1992). Colonization rates and dispersal as essential parameters in the confinement theory to explain the structure and horizontal zonation of lagoon benthic assemblages. *Rapports de la Commission Internationale pour l'Exploration Scientique de la Mer Meditterranée* **33**, 100.

Perthuisot, J. P., and Guelorget, O. (1995). A reply to R. S. K. Barnes: a critical appraisal of the application of Guélorget and Perthuisot's concepts of the paralic ecosystem and confinement to macrotidal Europe. *Estuarine, Coastal and Shelf Science* **40**, 721–722. doi:10.1006/ECSS.1995.0049

Pethick, J. (1984). 'An Introduction to Coastal Geomorphology.' (Arnold: London.)

Phleger, F. B. (1969). Some general features of coastal lagoons. In 'Coastal Lagoons, a Symposium. Memoirs of the International Symposium on Coastal Lagoons (Origin, Dynamics and Productivity), UNAM-UNESCO, Mexico, D.F., 28–30 November 1967'. (Eds A. Ayala-Castañeras and F. B. Phleger.) pp. 5–26. (Ciudad Universitaria: México.)

Pisani, V. (1960). Note sulla storia della parola laguna. *Paideia* **15**, 9–15. [In Italian]

Platell, M. E., and Potter, I. C. (1996). Influence of water depth, season, habitat and estuary location on the macrobenthic fauna of a seasonally closed estuary. *Journal of the Marine Biological Association of the United Kingdom* **76**, 1–21.

Por, F. D. (1972). Hydrobiological notes on the high-salinity waters of the Sinai Peninsula. *Marine Biology* **14**, 111–119. doi:10.1007/BF00373210

Postma, H. (1969). Chemistry of coastal lagoons. In 'Coastal Lagoons, a Symposium. Memoirs of the International Symposium on Coastal Lagoons (origin, dynamics and productivity), UNAM-UNESCO, Mexico, D.F., 28–30 November 1967'. (Eds A. Ayala-Castañeras and F. B. Phleger.) pp. 421–430. (Ciudad Universitaria: México.)

Pritchard, D. W. (1967). What is an estuary: a physical viewpoint. In 'Estuaries'. (Ed. G. H. Lauff.) pp. 3–5. (American Association for the Advancement of Science: Washington.)

Rabanus Maurus (846). De Rerum Naturis. Liber XI. Caput VII. De estibus uel fretis. Available at http://www.mun.ca/rabanus/drn/11.html#11.7 [accessed 19 September 2008]

Reizopoulou, S., and Nicolaidou, A. (2004). Benthic diversity of coastal brackish-water lagoons in western Greece. *Aquatic Conservation: Marine & Freshwater Ecosystems* **14**, S93–S102. doi:10.1002/AQC.653

Remane, A. (1934). Die Brackwasserfauna. *Verhandlungen der Deutschen Zoologischen Gesellschaft* **36**, 34–74. [In German]

Remane, A. (1971). Ecology of brackish water. In 'Biology of Brackish Water, 2nd edn'. (Eds A. Remane and C. Schlieper.) pp. 1–180. (Schweizerbart'sche: Stuttgart.)

Rossi, F., Castelli, A., and Lardicci, C. (2006). Distribution of macrobenthic assemblages along a marine gradient in Mediterranean eutrophic coastal lagoons. *Marine Ecology* **27**, 66–75. doi:10.1111/J.1439-0485.2006.00078.X

Roy, P. S., Williams, R. J., Jones, A. R., Yassini, I., Gibbs, P. J., *et al.* (2001). Structure and function of south-east Australian estuaries. *Estuarine, Coastal and Shelf Science* **53**, 351–384. doi:10.1006/ECSS.2001.0796

Rustomji, P. (2007). Flood and drought impacts on the opening regime of a wave-dominated estuary. *Marine and Freshwater Research* **58**, 1108–1119. doi:10.1071/MF07079

Sanders, H. L. (1968). Marine benthic diversity: a comparative study. *American Naturalist* **102**, 243–282. doi:10.1086/282541

Scholl, D. W. (1964). Recent sedimentary record in mangrove swamps and rise in sea level over the southwestern coast of Florida: part 1. *Marine Geology* **1**, 344–366. doi:10.1016/0025-3227(64)90020-9

Segerstråle, S. G. (1959). Brackish water classification, a historical survey. *Archivio di Oceanografia e Limnologia* **11**, 7–33.

Serandrei-Barbero, R., Carbognin, L., Taroni, G., and Cova, E. (1999). Distribution of recent benthic foraminifera in the southern basin of the Venice Lagoon (Italy): statistical evaluation of taxa significance. *Micropaleontology* **45**, 99–111. doi:10.2307/1486205

Serjeantson, M. S. (1936). 'A History of Foreign Words in English.' (E. P. Dutton and Company: New York.)

Simboura, N., and Reizopoulou, S. (2008). An intercalibration of classification metrics of benthic macroinvertebrates in coastal and transitional ecosystems of the Eastern Mediterranean ecoregion (Greece). *Marine Pollution Bulletin* **56**, 116–126. doi:10.1016/J.MARPOLBUL.2007.09.042

Simpson, J. A., and Weiner, E. S. C. (Eds) (1989). The Oxford English Dictionary, 2nd edn. (Oxford University Press: Oxford.) Online version (2005). Available at http://www.oed.com [accessed 19 September 2008].

Snow, G. C., and Adams, J. B. (2007). Relating microalgal spatial patterns to flow, mouth and nutrient status in the temporarily open/closed Mngazi estuary, South Africa. *Marine and Freshwater Research* **58**, 1032–1043. doi:10.1071/MF07016

Stevenson, J. J. (1911). The formation of coal beds. I. An historical summary of opinion from 1700 to the present time. *Proceedings of the American Philosophical Society* **50**, 1–116.

Swinbanks, D. D., and Murray, J. W. (1981). Biosedimentology zonation of Boundary Bay tidalflats, Fraser River Delta, British Columbia. *Sedimentology* **28**, 201–237. doi:10.1111/J.1365-3091.1981.TB01677.X

Tomczak, M. (1996). The Shelf and Coastal Zone. Lecture notes. Available at http://www.cmima.csic.es/mirror/mattom/ShelfCoast/chapter11.html [accessed 19 May 2009]

Tagliapietra, D., and Volpi Ghirardini, A. (2006). Notes on coastal lagoon typology in the light of the EU Water Framework Directive: Italy as a case study. *Aquatic Conservation: Marine & Freshwater Ecosystems* **16**, 457–467. doi:10.1002/AQC.768

Thrush, S. F., and Warwick, R. M. (Eds) (1997). The ecology of soft-bottom habitats: matching spatial patterns with dynamic processes. *Journal of Experimental Marine Biology Ecology* **216** (Special Issue), ix.

Thrush, S. F., Hewitt, J. E., Norkko, A., Nicholls, P. E., Funnell, G. A., and Ellis, J. I. (2003). Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. *Marine Ecology Progress Series* **263**, 101–112. doi:10.3354/MEPS263101

Twenhofel, W. H. (1939). 'Principles of Sedimentation.' (McGraw-Hill Book Co.: New York.)

United Nations Statistics Division (1997). Environment Glossary (last update in UNdata: 25 May 2007). Available at http://unstats.un.org/unsd/environmentgl/ [accessed 19 September 2008]

Vespremeanu, E. (1987). 'Probleme de Geomorfologie Marină.' (Universitatii din Bucuresti: Bucarest.) [In Romanian]

Wagner, M. (1999). Expression of the estuarine species minimum in littoral fish assemblages of the lower Chesapeake Bay tributaries. *Estuaries* **22**, 304–312. doi:10.2307/1352986

Whitfield, A. K. (1992). The characterization of southern African estuarine systems. *Southern African Journal of Aquatic Sciences* **26**, 31–38.

Whitfield, A. K. (1995). Available scientific information on individual South African estuarine systems. Water Research Commission, Report 577/1/95, Pretoria.

Whitfield, A. K., and Bate, G. (Eds) (2007). A review of information on temporarily open/closed estuaries in the warm and cool temperate biogeographic regions of South Africa, with particular emphasis on the influence of river flow on these systems. Water Research Commission, Report 581/1/07, Pretoria.

Wilson, W. E., and Moore, J. E. (Eds) (2003). 'Glossary of Hydrology.' (Springer-Verlag: Berlin.)

Yáñez-Arancibia, A., Lara-Domínguez, A. L., and Pauly, D. (1994). Coastal lagoons as fish habitats. In 'Coastal Lagoon Processes'. (Ed. B. Kjerfve.) pp. 363–376. (Elsevier Oceanography Series: Amsterdam.)

Manuscript received 20 March 2008, accepted 28 November 2008