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The Need for Definitions in Understanding Estuaries

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This paper considers what the definition/classification of estuaries has taught us and why there is a need for classification systems. It further considers why we need to define an estuary and its constituent parts, including the fundamental difficulty and dilemma of trying to define parts of a continuum, as a means to both understanding and managing that estuary. The review considers where an estuary starts and ends and the relative merits of defining estuaries in terms of their biology, physics, chemistry, geographic nature and socio-economic units. It briefly discusses the need for legal and planning definitions and the linkages between science and management. Following this, we present a generic framework for the definition, classification, monitoring, assessment, reporting and management of estuaries. In particular, it is argued that scientists should engage in the debate on the definition of estuaries for legal and socio-economic purposes. It is concluded here that as existing definitions will never be suitable for all needs, a different approach is required. The proposed ' Expert Judgement Checklist Approach ' could provide guidance for those needing to define/delimit an estuary while still acknowledging the inherent variability of such systems. The proposed system mostly relates to the European, temperate estuary, but there are lessons here for estuaries worldwide. © 2002 Elsevier Science Ltd. All rights reserved.

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Introduction

Environmental managers and scientists often divide a problem into manageable pieces before tackling it especially as many subjects are so large that they cannot be studied without being subdivided. In order to communicate the results of these studies, a set of easily understood and well-defined terms is also required. This is particularly so in international scientific fields and the study of estuaries is no exception, hence the perceived and actual need for definitions and classification schemes of estuaries. Estuaries have the predominant characteristic of being sites of spatial and temporal continua, for example in environmental variables such as salinity, and biological variables, such as community structure. Because of this, any superimposed classification scheme is likely to be arbitrary and thus with a subjective element. Widely accepted definitions are required to remove some of that subjectivity and to remove ambiguity in discussing estuarine features.

In addition to the scientific need for classification and definition, there are an increasing number of legislative, administrative and socio-economic statutes, protocols, procedures and concerns that require terms and areas to be defined. In these cases, the desire for precise and unambiguous terms is even more important as there may be substantial legal and/or economic repercussions of poor definition.

This review aims to show that despite the confusion that has been introduced to the definitions of estuaries, for most people working in the field they remain a clear and distinctive physiographic and biological habitat for study. A habitat that, almost uniquely amongst aquatic habitats, experiences a steep gradation in salinity conditions coupled with a high degree of turbidity, which leads to the deposition of muddy inter-tidal areas. These habitats are rich in wildlife, and for many people perhaps the nearest thing to a natural habitat that they ever encounter. It is a habitat that man has exploited and often destroyed, but the estuarine habitat remains as one of the most resilient habitats on earth, maintaining its attractiveness for wildlife, despite industrialization and land-claim. It is a habitat that paradoxically can provide unique ecosystem services to benefit mankind and maintain marine ecosystem health, for example by trapping contaminants in its sediments, whilst also providing nursery grounds for marine fish and feeding grounds for migratory birds.

Definition of an estuary

When considering any estuarine habitat worldwide there are many generalizations that can be applied, for

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TABLE 1. Classification of estuarine divisions (expanded from McLusky, 1993) (salinity is defined according to the Practical Salinity Scale)

Division	Tidal	Salinity	Venice system (1958)	Kinne (1971)
River	Non-tidal	<0·5	Limnetic	
Head	The highest point reached by tides			
Tidal fresh	Tidal	<0·5	Limnetic	
Upper	Tidal	0·5–5	Oligohaline	Oligohalinicum
Inner	Tidal	5–18	Mesohaline	
		5–8		Horohalinicum
Middle	Tidal	8–18		Mesohalinicum
		18–25	Polyhaline	
Lower	Tidal	18–30		Polyhalinicum
		25–30	Polyhaline	
Mouth	Tidal	>30	Euhaline	
Sea	Tidal	30–40		Thalassicum

example, common features such as the gradient of conditions from the open sea into the sheltered estuary, and on to the freshwater river. Along this gradient there are clear changes in salinity ranging from full strength seawater decreasing to fresh water as well as the often-associated sedimentary changes from coarse sediment outside the estuaries to fine sediments within them. Other changes relate to alterations in the turbidity of the water column, or in chemical composition including changes in nutrients, dissolved gases and trace metals. Furthermore all estuaries show a gradual reduction in diversity, but not in abundance or productivity, of species of animals and plants compared to adjacent aquatic habitats.

Perhaps the simplest recognition of an estuary is based on its overall shape, i.e., a physiographical definition. Pethick (1993) has attempted to define the ‘ natural ’ estuarine shape as a given ratio of mouth width to both tidal length and tidal prism. He contends that if this ratio is distorted, through truncation by weirs and barrages, and squeezed through land-claim, then the estuary does not function as it should thus leading to problems of flooding, erosion and storm-surge effects. On a simpler basis, an estuary may be defined geographically as the area between a river and an abrupt coastline break. Unfortunately, many estuaries have a gradual change in shape thus producing a gradual transition between river, estuary, coastal embayment and open coast.

The importance of topography in defining the shape of an estuary, most notably the mouth, is illustrated by Dyer (1996) who uses both the coastline form and the underwater topography, or morphology, together with the associated sediment distribution to indicate the outer limit of the Severn Estuary, UK. A wide estuary will have an outer part dominated by tidal energy, and thus with strong tidal currents, together with an inner part dominated by river currents. As such, the mouth will have an underwater topography characterized by a series of linear banks aligned with the dominant tidal flow.

As a reflection of the definitions based on physical aspects, the English word ‘ estuary ’ is of 16th century origin, derived from the Latin word *aestuarium*, meaning marsh or channel, which is itself derived from *aestus*, meaning tide or billowing movement, related to *aestas* meaning summer (Collins, 1979). By 1958, however, it was realized that estuarine scientists needed to define their terminology more accurately. This led to the Venice symposium in 1958 on the classification of brackish waters, which defined the zones of an estuary and brackish water, in terms of salinity (Table 1) (Venice System, 1958). Following this, Kinne (1971) also gave a biological (ecophysiological)-based salinity classification which in turn led to an increasing appreciation of the existence of the estuary as a habitat, distinct from either the sea or a river, which led to a conference held at Jekyll Island, Georgia, U.S.A. in 1964. The subsequent publication of the proceedings of that symposium, edited by Lauff (1967), marks the clear starting point for the modern study of estuaries worldwide.

The 1964 *Estuaries* symposium (Lauff, 1967) provided a definition of an estuary by Pritchard (1967) as *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 derived from land drainage*. This definition, which moves to a salinity-based distinction, has been widely adopted in subsequent decades. Pritchard (1967), however, explicitly excluded the Baltic Sea and other brackish seas from being designated as estuaries, i.e. the Baltic Sea is a major brackish-water sea area but is not commonly called an estuary. It is not known whether Pritchard (1967) took this view because of the absence of tides in the Baltic although his definition does not explicitly mention tides. Similarly the Mediterranean Sea is an important sea area, which is almost closed except for the Straits of Gibraltar, but cannot be considered estuarine due to its full salinity and it, too, is not tidal. Despite the absence of tides, some Mediterranean river mouths are commonly still called estuaries (McLusky, 1999).

The ECSA symposium held at Gent, Belgium in 1991 (Meire and Vinck, 1993) was probably the first to attempt to bring together information on the tidal freshwater region of estuaries. All the papers presented there showed that this region of estuaries experiences a great deal of natural stress, arising from the chemical and physical processes that characterize the region. A seasonal and spatial oxygen sag is typical of such reaches, in particular associated with a turbidity maximum, compounded in many cases by discharges from human habitation. In reviewing the meeting, McLusky (1993) pointed out that even the authors of papers studying this estuarine environment used terms such as FSI (Freshwater Seawater Interface, replacing Freshwater-Brackish water Interface (FBI) in earlier publications) in several different ways. The biota of the tidal freshwater reaches of an estuary experience the tidal fluctuations of an estuary, without the influence of salinity. All studies show a decline in species richness and diversity throughout the tidal freshwater region, which cannot be explained by salinity stress, but which can be generally attributed to the composition and instability of the sediment compared to adjacent rivers.

Following from the Venice symposium (1958), via Pritchard (1967), Kinne (1971) and Fairbridge (1980), to Meire and Vinck (1993) we can consolidate the definitions of estuarine regions as shown in Table 1. In contrast to a chemical (salinity) based system of definitions, there is now the potential for biologically relevant definitions. For example, Bulger *et al.* (1993) used a multivariate ordination analysis of species distributions according to their salinity preferences to define salinity bands. This indicated that there were five overlapping salinity zones: freshwater to a salinity of 4, 2–14, 11–18, 16–27 and 24-marine. The authors concluded that this type of classification allows a function-based and biological system of defining areas unlike the Venice system. Similarly, Laffoley & Hiscock (1993) proposed a biologically based classification although this relates to only one component, albeit an important one, the benthic communities.

European estuaries, as defined above, are effectively confined to the Atlantic Coast from mid-Norway at 60°N to southern Portugal at 37°N, a latitudinal range of 23°. This region represents all the European estuarine systems possessing predictable and pronounced influence from twice daily tides (the M_2 component). The estuaries of this region mostly possess substantial intertidal habitats with an extensive benthic fauna and flora. Most European estuaries are post-glacial features, being river valleys that became drowned by post-glacial rises in sea level. In the case of many northern European estuaries the land is still rising or sinking as a result of isostatic rebound, as the result of the last ice-age, so that the topography of the estuary has often changed considerably even within recorded historical times. In addition to this, ' coastal squeeze ' (Davidson *et al.*, 1991), in which the inter-tidal habitat is held at its upper limit by sea defences but its lower limit is experiencing Relative Sea Level Rise, is leading to a further loss of area. In addition, there are other dominant features such as the comparatively young and ephemeral nature of European estuaries and other transitional waters such as coastal lagoons which have often been advanced as an explanation for their relative lack of species diversity. Wolff (1971, 1983) emphasizes that estuaries and brackish waters are geologically ephemeral phenomena, and that it is the unstable and unpredictable nature of estuaries which excludes most marine or fresh-water species.

The ECSA symposium held in Aveiro, Portugal in 1994 highlighted differences between ' northern ' and ' southern ' estuaries but again focussed on physical characteristics. Summarizing the meeting, McLusky and McIntyre (1995) commented that in those northern (European and North American) estuaries described at the meeting, the rivers flow all the year round, and although there is more rainfall in winter rather than summer, the rainfall may vary more from week to week than from season to season. All the estuaries also remain open to tidal influence at all times and, as a consequence, the salinity within the estuary may be always fluctuating, although with a few extreme values.

In the more southern estuaries (e.g. South Africa or Australia) there is an extended period of dry weather in the summer, coupled with varying rainfall during the winter (Whitfield, 1998). Not only does the inflowing fresh water cease for many months at a time but also, during these dry seasons, long-shore drift at the seaward end may close the estuary from its tidal connection with the open sea. As a consequence in such southern estuaries, the salinity regime may be stable for months at a time, although extreme salinity reduction can occur spasmodically throughout the winter. As a consequence, the penetration of marine species into the estuary can be enhanced during the summer months but severely curtailed in rainy seasons. But if such an intermittent estuary is sealed from contact with the open sea for prolonged periods, is it an estuary according to Pritchard's definition (*loc. cit.*)?

Despite this distinction, there remains a need to define estuaries that may be only temporarily tidal as in South Africa or Australia. Cooper (1994) has examined the sedimentary processes in the river-dominated Mvoti estuary of South Africa, using it as a case study for many other similar estuaries in that part of the world. He states that the salinity structure, circulation patterns and lack of consistent tidal exchange in these river mouths differ from most definitions of estuaries (*loc. cit.* Pritchard and Fairbridge). After a full discussion of the geomorphology of such estuaries, he concludes that sedimentary processes in such environments conform principally to fluvial processes. In the river-dominated (microtidal) estuaries, the rivers provide sediment, and the relatively constant sediment volume may be temporarily reduced by flood scour, as excess sediment passes into the sea. In the marine (tidal)-dominated (macrotidal) estuaries, by contrast, there is a steady infilling of sediment provided at differing times from the sea and from the river. Thus river-dominated estuaries should be identified as a distinct class of estuaries.

The origin of the word estuary from *aestus,* meaning tide, and the widely used definition of Fairbridge (1980, see below) emphasizes the importance of tides as a distinguishing feature of estuaries whereas that of Pritchard (1967) does not include tides. Whether it is necessary for all estuaries to be tidal or whether it is now accepted that transition waters in all areas are estuaries irrespective of being tidal (as in the Mediterranean and Baltic Seas) is still a matter for debate. Waters with a salinity lower than seawater and higher than fresh water are called brackish waters (a word derived from the Dutch word *brac*, meaning salty). Thus the term *brackish* has a wider meaning than *estuarine* and all waters with salinities between sea and fresh water can be called brackish, whether they are large seas (e.g. Baltic or Caspian), closed lagoons, or tidal estuaries. Thus all estuaries have brackish regions, but not all brackish waters are estuarine.

Given the above anomalies, it may be desirable to quantify and expand as much of the definition as possible to avoid ambiguity in interpretation. As an example of such pitfalls, the definition of an estuary, as modified from Lincoln *et al* (1982), could be *any semi-enclosed coastal water open to the sea having a discharge of freshwater which results in a variable salinity in a significant area (>100 m^2)*. However, firstly this would include many large coastal lagoons such as the Fleet, Dorset, England; secondly, it is likely to provoke a debate regarding the term ' significant area ' and thus the inclusion or exclusion of creeks as individual estuaries, and thirdly, it is questioned whether it should also mention tides.

Where does an estuary start and end?

In addition to determining what is an estuary, it is necessary to consider the inner and outer limits of an estuary. One of the more exceptional consequences of the influence of European Union politics on estuarine ecology and geographical semantics has been the saga of defining when does the estuary become the sea. Under the European Commission's Urban Waste-Water Treatment Directive, large sewage discharges into coastal waters are required to have only ' primary ' treatment, provided that the waste is dispersed efficiently, whereas discharges into waters such as estuaries need more expensive ' secondary ' treatment (Elliott *et al* 1999). This distinction was proposed based on the water-bodies' sensitivity to nutrient enrichment such that estuaries were regarded as sensitive to the adverse effects of organic and nutrient enrichment (and thus required higher treatment) whereas the open coast has a higher dispersing and assimilative capacity and thus requires less treatment. Despite this distinction, the Directive failed to define an estuary.

As with all such directives, the European States had discretion in implementing the Directive and thus the U.K. and others chose a further definition, that of the presence or absence of High Natural Dispersing Areas (i.e. the sea) which reflected the response to organic inputs. As such, the (then) UK Department of the Environment (DoE) redefined the Severn and Humber estuaries as sea even though in the case of the latter that ' sea ' area stopped at the Humber Bridge situated halfway along the estuary, and the Severn stopped at the Severn Bridge, situated almost at the top of the estuary (Dyer 1996)! Given the local pressure to reduce sewage inputs, the two major cities involved, Bristol and Kingston-upon-Hull, successfully brought a judicial review against the UK DoE in January 1996 (Pearce, 1996). In acting for the municipal authorities, the Institute of Estuarine & Coastal Studies at the University of Hull were asked to clarify definitions of estuaries and thus considered biological, chemical, physical and geographic factors.

The scientists and environmental law scholars tended towards an ' expert-view ' definition that ' if it looks like an estuary, smells like an estuary and behaves like an estuary, then there is a good chance that it is an estuary '! In implementing the EU Directive, the UK through its Urban Waste-water Regulations 1994, adopted two alternative definitions of estuaries: *an area receiving freshwater inputs where the waters on a depth-averaged basis have a salinity of less than 95% of the adjacent local offshore seawater for 95% of the time*; or: *an inlet of the sea bounded by a line between such topographical features as define the seaward boundary of the estuary*. The judicial review supported the first of these definitions and took the view that above this threshold it becomes the sea. However, this definition was never tested rigorously as, in the final decision, the court eventually dismissed the case on the grounds that the proposals were not within the spirit of the Directive.

The upper and lower boundary of an estuary continues to provoke debate. Whilst most estuarine scientists have used Pritchard's (1967) definition of an estuary, studies in tidal freshwater regions of estuaries have suggested that the definition of Fairbridge (1980) is more suitable, namely that *an estuary is an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors: (a) a marine or lower estuary, in free connection with the open sea; (b) a middle estuary subject to strong salt and freshwater mixing; and (c) an upper or fluvial estuary, characterized by freshwater but subject to strong tidal action. The limits between these sectors are variable and subject to constant changes in the river discharges*. Although both refer either directly or indirectly to an estuary being an inlet of the sea, the principal difference between the definitions of Pritchard and Fairbridge is in determining the upper limit. For Pritchard it is the upstream limit of salt penetration, and for Fairbridge it is the upstream limit of tidal penetration. In an un-modified estuary, the limit of tidal penetration will always be further inland than the limit of salt penetration. Thus Fairbridge adds the zone of ' tidal freshwater ' to the estuary, compared to Pritchard, and in recent times his definition has become the principal one (see Day *et al.*, 1989). Such an inclusion allows Tidal Freshwater Areas (TFA) to be regarded as important components of estuarine systems (Elliott & Hemingway, 2002). Hitherto these Tidal Freshwater Areas had been ignored by freshwater biologists (due to the inconvenience of the water level regularly rising and falling) and by marine biologists (due to the lack of salt), but are now deemed to play an important role in the functioning of both rivers and estuaries.

In many European estuaries, notably many in Germany and the Netherlands, an artificial weir that limits the penetration of the tidal influence truncates the tidal freshwater region of the estuary. The region that should be the tidal freshwater region then becomes the lower reach of the inflowing river. In this respect, weir construction destroys estuarine habitat in much the same way as land-claim or flood protection works. Michaelis *et al.* (1992), in particular, show that for 12 estuaries which discharge into the German Bight, habitat diversity (and hence the diversity of zoobenthic species) is reduced to a degree far below natural conditions because most of the upper estuarine reaches are cut off by construction works, and the discharge of the rivers occurs by means of sluices or pumping.

It is apparent that the inclusion or exclusion of tides into any definition will create conflict and thus the inclusion or exclusion of areas commonly and locally regarded as estuaries. For example, in a review of Danish estuaries, Conley *et al.* (2000) chose to define an estuary as *a partially enclosed body of water open to saline water from the sea and receiving freshwater from rivers, land run-off or seepage.* It is important, however, to note the lack of tides, and the broader range of freshwater inputs used by Conley *et al.* (2000) compared to other definitions, thus give their definition a Baltic perspective.

The outer limit of an estuary is similarly difficult to determine and agree. As indicated above, there may or may not be convenient geographical discontinuities in the coastline. Following Dyer's (1996) definitions, there may be sub-tidal physical features denoting the marine, tidal conditions, such as linear sandbanks in wide-mouth estuaries but these may not be present elsewhere.

Classification of estuaries

The need for classifying habitats in general and estuaries in particular has developed from merely a scientific debate, such that workers understand the terms used in the field, to the politico-socio-management sphere. The latter is required to delimit management units and, as shown below, to allow legislation to be relevant and selectively implemented. Where management and administrative controls are implemented to protect habitats, selected fisheries, water quality and other uses and users of near shore areas, then the geographical units require to be defined. It is of note that such definitions can be on physical or biological bases.

With respect to a physical basis, the circulation patterns of estuaries have been fully described and

TABLE 2. The proportions of the total British estuarine area within estuaries of different geomorphologic types (from Davidson *et al.* 1991)

Estuary type	% of total area	% of intertidal area
Fjord	2	1
Fjard	5	6
Ria	3	2
Coastal plain	35	31
Bar-built	6	8
Complex	18	17
Barrier beach	2	3
Linear Shore	4	6
Embayment	25	26

defined elsewhere (Dyer, 1979, 1997) and may be classified as Positive, Neutral, or Negative depending on their salinity regime and extent of evaporation. It should be noted that some Negative estuaries could have a salinity greater than that of seawater, due to evaporation. Depending on the tidal amplitude and volume of freshwater flow, four main types of positive estuaries can be recognized: Highly stratified, Fjords, Partially mixed and Homogeneous. Further definition can be whether they are Macrotidal, Mesotidal or Microtidal but, of course, the use of this would emphasize that to be an estuary there must be some tidal influence, thus presenting difficulties in considering ' estuaries ' in the Baltic and Mediterranean Seas (see below).

Geomorphological distinctions can also be useful, with Pritchard's (1967) paper including a classification of estuaries as drowned-river valleys, coastal plain, bar-built, lagoons, fjords or tectonically caused. For the British (=English, Scottish and Welsh) estuaries, Davidson *et al.* (1991) recognized nine geomorphological types and determined the relative proportions of these within Great Britain (Table 2). In a recent review, Roman *et al.* (2000) demonstrate the geomorphological origin of the estuaries of the north-east U.S.A. (New York harbour to Passamaquoddy Bay, Maine), concluding that only by understanding the fundamental characteristics or signatures of estuaries can we begin to understand the unique processes of a particular region or estuary. The estuaries of the North American West Coast (from Skeena River at 54.4°N to the Tijuana River at 32.5°N) are geologically young (like most estuaries world-wide) (Emmett *et al.*, 2000) and most are small and biologically under stress. In many estuaries in the southern part of this region, the freshwater flow is very limited but land-claim has taken away much of the estuarine habitat throughout the entire region. The estuaries of the south-eastern Atlantic coastal plan of North America (North Carolina—Florida) are dominated by shallow meso-tidal bar-built estuaries (Dame *et al.*, 2000).

Recently, Jay *et al.* (2000) considered a hydrographical approach to classifying estuaries but against a background of ecological change. They advocate a process-based approach rather than merely a structural approach (i.e. by considering rate processes rather than features at one time). It is therefore agreed that a definition of estuarine types is required which presents a classification scheme connecting physical processes, such as circulation and sediment dynamics, to biogeochemistry (especially transformation processes) and ecological features. Hence the need to include the physical-forcing variables, such as the hydrodynamics and overall topography/bathymetry, which in turn influence the sediment dynamics and structure. The latter in turn dictates the size and type of the consumer populations whereas the hydrodynamics dictate the size and nature of the primary producer populations as well as larval recruitment, zooplankton dynamics and thus ecological processes within the lower trophic levels.

The limits and use of estuarine definitions

Dyer (1990) showed that the definition of an estuary can vary according to the defining author's perspective, but some examples do make the reader ponder whether liberty for the author has perhaps gone too far, and whether there is a need to re-emphasize the core definition of an estuary. The English language is, perhaps more than most languages, forever changing in that a word becomes adopted or has a meaning purely because of its common usage. As an indication of changing word usage, earlier debates (Herdendorf, 1990) suggested that the Great Lakes of North America should be considered estuaries—a suggestion which has been roundly condemned by others (Schubel & Pritchard, 1990).

Frankignoulle *et al.* (1998) showed in a landmark paper in the journal *Science*, that European (mostly North Sea) estuaries emit 30 to 60 million tonnes of carbon per year to the atmosphere, representing 5 to 10% of the present anthropogenic CO_2 emissions from Western Europe. For their calculations they considered the total surface area of estuaries in Europe to be 111 200 km^2, calculated from marine areas where salinity is lower than 34 and excluding the Baltic Sea. Other authors (e.g. Davidson *et al.*, 1991) have defined the estuaries of the North Sea covering 10 456 km^2, 60% of which is attributable to the

Wadden Sea. There is, however, even a debate as to whether the Wadden Sea is an estuary or not—it may be regarded as a coastal embayment enclosed by barrier islands, especially since the major freshwater source, from the Ijsselmeer (now Lake Ijssel) had been curtailed. Frankignoulle *et al.* (1998) further define estuaries in the sense of Pritchard and Fairbridge as being ‘ inner estuaries ’, and river plumes at sea as being ‘ outer estuaries ’. The problem with this definition is that the North Sea in total is only about 575 000 km^2, so Frankignoulle *et al.* (1998) have effectively designated up to 20% of the North Sea as being a large estuary, and in effect exaggerated the role of the estuaries. By using the same definition, a large part of the Atlantic Ocean would be part of the Amazon Estuary, and the entire Bay of Bengal would be part of the Ganges estuary, and so on. Ketchum (1983) similarly considered estuarine zones to extend out onto continental shelves as the result of river outflows.

In an assessment of the structure of European estuarine fish communities, Elliott & Dewailly (1995) used published and grey literature. Without re-interpreting their source authors' views, they took the pragmatic decision that if an author regarded his/her own area as estuarine or brackish then this was sufficient. However this resulted in the Wadden Sea and the Voordelta of the Rhine/Meuse/Scheldt system being designated as estuarine. Furthermore, Davidson *et al.* (1991) include some coastal embayments as estuaries and took a very broad approach to their definition without needing to consider the repercussions of their definition—a notable change in the past decade in which management initiatives have depended on such definitions. As an indication of their inconsistency, Davidson *et al.* (1991) included the outer parts of the Wash and Morecambe Bay as estuaries but not the Scottish firths. As a further notable complication, the French word *estuaire* is taken to mean both estuary and Firth (Collins-Robert 1990)!

Some scientists working on brackish-water lagoons in the Mediterranean have used the term *paralic*. The French scientists, Guelorget and Perthuisot (1992) coined this term and identified these so-called Paralic aquatic ecosystems as being situated between marine and continental domains, inhabited by biological populations which are strictly bound to that environment, with a zonal organization independent of salinity gradients. They further introduce the concept of ‘ confinement ’ with a range from ‘ thalassic ’ (=marine) conditions to ‘ far paralic ’ conditions near freshwater. This approach has been critically appraised by Barnes (1994), who clearly shows that the term ‘ paralic ’ is in general the environment that in the English-speaking world would be termed ‘ brackish-water ’. He also comments that all of Guelorget & Perthuisot's work related to micro- or non-tidal environments. Although Guelorget & Perthuisot do include estuaries in their paper, Barnes (1994) clearly shows that all species in macro-tidal estuaries originate from and are continuous with marine and freshwater habitats. Although the term ‘ confinement ’ may be useful for describing non-tidal lagoons, he shows that the term ‘ paralic ’—a term neutral with respect to salinity—only has relevance to such lagoons. A computerized literature search by the present authors has shown that the terms paralic and confinement have not been adopted in the English literature. It is considered here that the terms brackish water or estuary provide sufficient definition, again remembering that all estuaries are brackish, but not all brackish waters are estuaries.

Given the above discussions, the present authors are left a little bemused as to why so many scientists are so keen to extend the definition of ‘ estuaries ’ in order to include their own local environment, why there is the need to derive alternative definitions or nomenclature, or whether it is possible to summarize a complex environment in a simple definition.

Legal, socio-economic and administrative definitions

The increasing amount of environmental legislation, protocols and management structures dictate that scientists increasingly have to provide information for lawyers and planners and furthermore they need to be able and willing to defend rigorously their terms. As an example, statutes implemented across the European Union states have to have their terms defined unambiguously for translation into any of 15 languages. Even more than with the science, the lawyers require legally defendable definitions of our habitats and if we as scientists do not provide and agree the definitions then we will have others imposed on us. As shown here, there are already physical, chemical and biological definitions but with increasing environmental awareness, legislation and protocols there is also now the need for conservation, socio-economic and legal definitions. Table 3 summarizes and interprets the available definitions.

As has been seen in Europe and North America and in the northern and southern hemispheres, there is an increasing need within geographical and/or national boundaries to synthesise information from many areas to produce management strategies. Thus a standardized approach of definition and classification is

TABLE 3. The multi-disciplinary approach to defining estuaries

Discipline	Character	Mechanism of definition
Physical	Physiography	Abrupt break between estuary and open coast
	Marine-based hydrographic processes	Penetration of tides (then subdivide by tidal regime)
		Penetration of marine waves
		Presence of density-driven currents
		Sea-derived sediment transport
Chemical	Salinity	Reduced from seawater but greater than freshwater
	Sensitivity	To nutrient enrichment
Biological	Community type	Penetration of marine plankton
		Presence of recognized sea-fishes
		Migration route for diadromous fishes
		Presence of ' estuarine ' community
Environmental quality	Classification	Based on biology, aesthetics, chemistry and with estuarine features
Management	Sea fisheries	Inland penetration of species ' widely recognized as marine '
	Transition waters	Based on differences (by default—neither marine nor freshwaters)
Legal	With a recognized hinterland	Based on a catchment with a recognized coastline and transition area
	Area widely regarded as ' estuarine '	Within a degree of precedence, an area regarded as such both by expert judgement and public perception
	Receiving a catchment	As the area where a river discharges
Conservation	Support of estuarine important biotopes and populations	As an area notable for its functioning (e.g. as for wading birds) or typical biotopes (e.g. saltmarshes, seagrass beds)

required as a precursor to management and communication. For example, the classification scheme: ' The Australian-Environmental Indicators: Estuaries & Sea ' (Ward *et al.* 1998) is comprehensive and includes all major indicators for a statistically-based spatial and temporal monitoring programme. This takes the approach that once the geographic definitions are agreed then the components within estuaries can be discussed on a national scale to provide an early warning of problems in a scientifically credible, easy to understand and use and cost-effective way. The indicators include important features of the physical and biological integrity of estuaries thus including important functional elements such as water flow, substratum types, habitats, biodiversity and species. This example of the need to classify estuaries for management also incorporates existing commercial and managerial indicators that are relevant to policy/management and which provide the targets to be set for the Australian estuaries.

An example of the importance of defining estuaries and coasts for quality classification is the ADRIS/SEPA Estuarine & Coastal Classification Scheme (Scottish Environmental Protection Agency, unpubl.). This describes areas within a four class system (Excellent, Good, Unsatisfactory, Seriously Polluted) based on components of condition (aesthetic, biological, bacteriological, and chemical). The scoring system is partly related to quantitative standards (e.g. Environmental Quality Standards) for bacteriological and chemical determinants. There is a subjective, semi-quantitative element for aesthetic condition and community biology and also an incorporation of biological sub-lethal responses (biomarkers, e.g. imposex, bioaccumulation). The Environment Agency in England & Wales also uses the estuarine part of the scheme.

By taking elements from the above examples in Australia and Europe and assessing the prevailing direction of estuarine management, it is possible firstly to give an overall framework for that management and, secondly, to illustrate the importance of definition and classification systems in that management (Figure 1). It is regarded here as axiomatic that all of the successive management protocols and tools, such as classification systems, comparisons against reference conditions, modelling (conceptual, deterministic and empirical) and reporting and communication of results, require to be underpinned by an agreed, defendable and comprehensive system of definitions and classification.

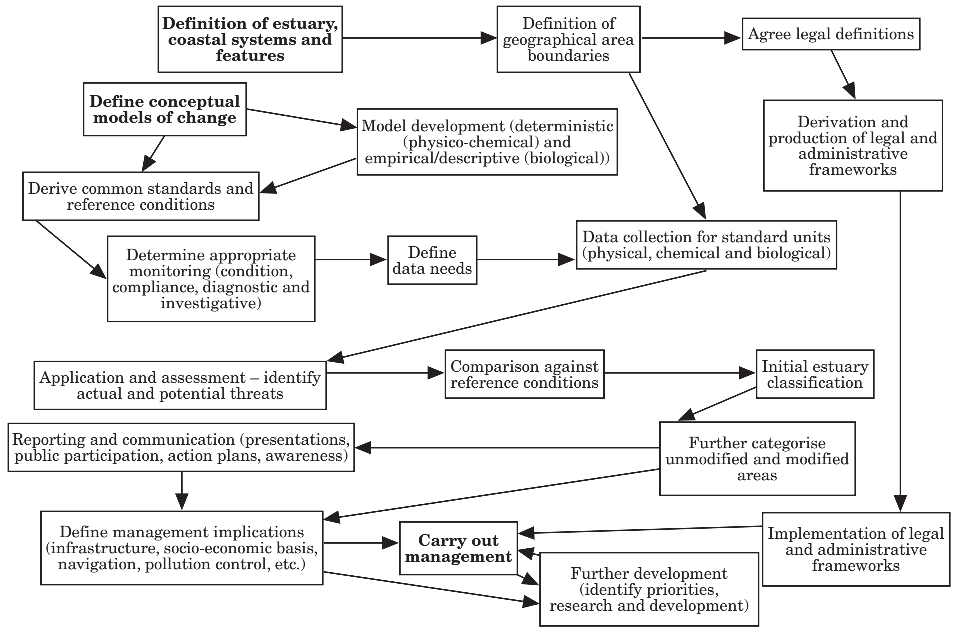

FIGURE 1. Generic framework for estuary definition, classification, monitoring, assessment, reporting and management (upper start and lower end points in bold).

As a continuing and recent example of the above, the recently adopted EU Water Framework Directive (2000/60/EC, European Union 2000) will require all surface waters to be classified, monitored and compared against reference conditions as components of Catchment (River Basin) Management Plans. The Directive considers that estuaries are included in the term ' Transitional Waters ' (which also may include many other habitats) although this gives problems for enclosed, brackish seas such as the Baltic. The Directive proposes to derive catchment management plans which are directed towards River Basin Management Plans and as such groups together as Transitional Waters all environments not regarded as freshwaters and open coasts. Although the typology for this distinction is still being derived, the Transitional Waters category includes estuaries, fjords, rias, lagoons, etc. (European Union 2000). Accordingly, European estuarine scientists will have to discuss and use the term Transitional Waters as a means to understanding and managing estuaries and their related habitats.

As a consequence of this Directive and others, and the importance of the mechanisms for the protection of species and habitats, there will be the increasing need to define habitats in a legally defendable way. For example, the EU Habitats Directive (European Commission,1992) requires member states to designate areas for their habitats as a means to ensuring the protection and sustainable use of those habitats. Once designated (as Special Areas of Conservation, Elliott *et al.*, 1999) then certain activities considered to be harmful may be prevented. Hence the designation of an area will prevent a user, such as a port authority, developing its activities in the area if those are likely to affect the integrity of the site and thus the delimitation of a designated area will have social and economic repercussions and in turn may be challenged legally. This Directive regards ' estuary ' as a habitat in its own right although it is acknowledged to include other habitats such as reedbeds, saltmarsh, and sand and mudflats uncovered at some stages of the tide (e.g. Elliott *et al.*, 1998). As the European habitat definition, Romao (1996) thus regards an estuary as the:

Downstream part of a river valley, subject to the tide and extending from the limit of brackish waters. River estuaries are coastal inlets where, unlike ' large shallow inlets and bays ' there is generally a substantial freshwater influence. The mixing of freshwater and seawater and the reduced current flows in the shelter of the estuary lead to the deposition of fine sediments, often forming extensive intertidal sand and mud flats. Where the tidal currents are faster than the flood tides, most sediments deposit to form a delta at the mouth of the estuary.

The E.U. definition considers that an estuary forms an ecological unit with the surrounding terrestrial coastal habitat types although the term can be dissected further (Table 4). In terms of nature conservation, it considers that these different habitats should

TABLE 4. The definition adopted for nature conservation purposes under the EU Habitats & Species Directive

E.U. Definition	Relevance to the definition for an estuary
' Downstream part of a river valley, subject to the tide and extending from the limit of brackish waters.	Assess the topography and physiography, and determine where the true freshwater stops.
River estuaries are coastal inlets where, unlike ' large shallow inlets and bays' there is generally a substantial freshwater influence.	Assess the salinity contours and determine where noticeable reductions occur.
The mixing of freshwater and seawater and the reduced current flows in the shelter of the estuary lead to the deposition of fine sediments, . . .	Assess where low energy areas occur and . . .
. . . often forming extensive intertidal sand and mud flats.	. . .determine where there are large intertidal flats which have a typical (temperate) functioning.
Where the tidal currents are faster than the flood tides, most sediments deposit to form a delta at the mouth of the estuary .'	Determine whether this occurs although this may not be applicable to many temperate estuaries

not be separated (Romao, 1996) although, as an indication of the inherent difficulties, in providing guidance for implementing the Directive in the U.K., Brown *et al.* (1997) distinguish bar-built, complex and coastal plain estuaries and the estuarine part of rias. The E.U. definition is thus more wordy than others but perhaps is thus realistic and more accurate, and is noticeably closer to the definitions of Pritchard and Fairbridge (*loc. cit*) than many of the subsequent variants which have expanded estuaries into non-tidal brackish seas or river plumes extending into open oceans.

The coastal zone is no more well-defined than estuaries and its definition has posed problems in social, legal and environmental terms. For example, Tromans and Grant (2001) refer to the 1991 UK Water Resources Act which regards coastal waters as including all estuarine waters up to the freshwater limit of rivers and that those limits are to be specified by the Secretary of State on maps. Such waters are within the 3-mile limit and extend landward as far as the limit of the highest tide or, in the case of river waters, the freshwater limit. As such, it is apparent that (a) estuaries do not have a legally-accepted definition, and (b) a Tidal Freshwater Area at the top of an estuary may or may not be included as coastal waters. In essence, and somewhat pragmatically, the coastal zone *extends seaward and landward of the coastline. Its limits are defined by the geographical extent of natural processes and human activities related to the coast* (R. Barnes, the Law School, University of Hull, pers. comm.). While these definitions have to withstand legal scrutiny, it is apparent that they contain several undefinable clauses. This latter definition is used within the U.K. planning guidelines, PPG20 (Section 1.5) which further comments on the division between land and sea but notes (in Section 1.8) that they should not be considered separately, again a tacit admission of the difficulty in classifying a continuum. It is likely that other countries' laws are no clearer than the U.K. in these matters.

In researching this paper, it has been notable that the term ' estuary ' has hitherto been poorly defined in national law if at all. However, as an example of a legal definition of an estuary which takes account of geographical circumstances, the South African National Water Act 36 of 1998 gives the following: *' Estuary ' means a partially or fully enclosed body of water—(a) which is open to the sea permanently or periodically; (b) within which sea water can be diluted to an extent that is measurable, with freshwater drained from land*. This was developed further in Regulations No. 1399 of the National Environmental Management Act 1998: Control of Vehicles in the Coastal Zone (21st December 2001) to replace (b) above with *and in which the water level rises and falls as a result of the action of the tides whenever it is open to the sea*.

Conclusions: estuarine definitions and the Way Ahead

It is concluded here that whereas the physical definitions are apparently more objective, the biological separation of these transitional areas remains more subjective. This is particularly so given both the spatial and temporal variability but also the high mobility (often through seasonal migrations) of many of the components (zooplankton, nekton, hyperbenthos, fishes, wading birds).

Given the inadequacies and difficulties of existing definitions, it is therefore suggested that in order to define an estuarine area, a checklist approach is required and which should be used based on expert judgement synthesized from a variety of definitions. This approach is designed to take, from the published and grey literature as well as informed local sources, comments to indicate estuarine or marine features within a given geographical area. Despite the information often not being precise, or it being available only within common knowledge about an area, by using a tick-box approach to a series of questions it will be possible both to indicate an area as an estuary and to describe it spatially and temporally. Such an approach is developed and proposed here as a set of questions covering many aspects which define the habitat structure and functioning of estuaries (Table 5). The proposed questions thus presents a more subjective but habitat and functionally-based approach, rather than a more detailed and structured physical approach (as for example shown by Jay *et al.*, 2000). It is emphasized here that while the latter may be a more quantitative approach by covering all the physical forcing variables, as shown here most definitions have to relate to the biological components as they are required for biological health/condition assessment and environmental quality purposes. Despite this, for most areas there is often insufficient fully quantitative biological information and so a qualitative/semi-quantitative expert judgement approach is perhaps the best that is achievable.

The above approach, of using an expert judgement approach, is unlikely to be favoured by legislators and lawyers given that it relies heavily on a range of information which may have to be adapted for a particular geographical area. They are likely to argue that legal statutes cannot cope with such a wide-ranging and complex means of defining an area. We take the view, however, that we as scientists have to reinforce to the lawyers and legislators the message that our environments are too complex to be summarized by a few sentences which can encompass the range of estuarine types encountered.

There remains the central problem of trying to superimpose different classifications for areas, habitats, regions, or conditions within one of the most widely-varying ecosystems, an ecosystem that is characterized by continua in both space and time for all its variables. It is important for science to understand the basic and fundamental processes that occur within estuaries and only by understanding the fundamental characteristics or signatures of estuaries can we begin to understand the unique processes of a particular region or estuary. Science cannot progress if every estuary is seen as a unique feature, especially as this would make it impossible to derive baselines or comparisons. Equally if every brackish water habitat is called an estuary it is impossible to distinguish those features that relate to tidal mixing and flushing, and those features that relate solely to salinity. Hence there is the need to agree a common system of classifying estuarine habitats while at the same time allowing for the different habitats.

Within Europe, in the next decade or so, these discussions of habitat definition will become more important given the implementation of the EU Water Framework Directive (European Union 2000). This will require the member states to determine the means of classifying water bodies, to define the different types of Transitional Waters and to implement that classification throughout Europe. Scientists and managers will have to determine whether any particular estuary differs from reference conditions with regard to its biological, physical and chemical characteristics. This involves the major decision of what is a normal estuary, how does it normally vary, and has it changed from that normality due to human activities. It will be impossible to achieve this without defining ‘ normal ’ conditions!

There is a need to continually reflect on our progress so that we can take stock of what we have achieved, and what still needs to be done. To understand estuaries we need to know both their unique *and* their common characteristics, and to know exactly what we are talking about. As shown here, no one definition fulfils all objectives. We should not, however, resort to a simplified definition for a complex subject, hence it may be better to rely on a subjective/semi-quantitative approach based on expert-judgement especially as, for most of our areas, there will not be the availability of fully quantified information. There are no widely acceptable definitions suitable for all purposes but also, as is shown here, it is not sufficient for scientists to rely on legal and socio-economic definitions drawn up by non-scientists. As indicated here, with an increasing amount of environmental legislation, it will be necessary for scientists to engage in the wider debate which may require us to defend such a wide-ranging expert view approach to non-scientists. For example, the EU Water Framework Directive indicates that in order to define a reference condition against which to compare transitional waters such as estuaries then expert-judgement is a last resort but it is argued here that perhaps it should be the first resort. In this way, the skills and expertise of estuarine scientists should be and will be engaged and fully utilized.

TABLE 5. A proposed ' Expert Judgement Checklist Approach ' to defining an estuarine area (in which comments would be taken from the literature to indicate estuarine or marine features)

Physical	Is there the presence of erosion-deposition cycles in the channels and on the flats? Is there an asymmetrical flood and ebb tidal flow due to constricting effects and bottom profile of the estuary? Is there a turbidity maximum zone as found in the upper reaches of most macro-tidal estuaries? Is there a tidal-freshwater area—where does the salinity penetrate on high, medium and low river flows? Can the TFA, FSI, TMZ be delimited under differing conditions of tide and river flow? Would a hydroclimagraph (of temperature against salinity of the water column) indicate the presence of a Freshwater-Seawater Interface? Do the sub-tidal areas have coarse substratum and are they well scoured (although these could be marine conditions they will require strong tidal streams)? Is there a well-mixed or stratified salinity profile influenced by Coriolis force?
Primary producers	Are the nutrients not limiting (the area is hypernutrified as with many estuaries) and is there less evidence of a spring maximum as observed in the sea? Is the phytoplankton dominated by diatoms but poorer than marine areas due to turbidity? Does the macro-algal community show a transition from domination by red and brown algae at the outer regions, through a brown and green dominance in the middle regions to green algal domination in the upper regions? Does the area have a macroflora such as saltmarsh and reedbeds in the inner reaches and eelgrass in the outer reaches as indicative of a typical estuarine flora? Where do the *Phragmites* (reed) beds start and do these indicate the upper limit of the estuary and start of the river?
Primary consumers	Is it possible to differentiate the intertidal fauna into marine, transitional and estuarine zones? Can an area be delimited with typical estuarine community, i.e. those species widely regarded by estuarine biologists as ' estuarine'—*Nereis diversicolor*, *Macoma balthica*, *Tubificoides* spp., *Manayunkia aestuarina*, *Corophium volutator*, *Hydrobia ulvae*? Where does the boundary come between these typical euryhaline species and typical freshwater species (chironomids, *Tubifex* sp.)? Is there a limited penetration by ' typically ' marine species, e.g. what is the limit of incursion of Sabellariid polychaetes, echinoderms, *Balanus crenatus*? Is the upper estuarine area zooplankton fauna dominated by the typical estuarine zooplankton/hyperbenthos, for example, by *Eurytemora* spp., and mysids such as *Neomysis integer*?
Vertebrate predators	Does the fish community taken in the estuary contain estuarine elements (see Elliott & Dewailly, 1995), even if it is not possible to indicate the spatial extent of that estuarine fish community? Are there fisheries for marine fishes (e.g. sprat) and diadromous (migratory) fishes (e.g. salmonids)? Is it a migration route for diadromous species that pass through estuaries from freshwater to seawater (or vice versa) for breeding—salmonids, smelt, shads, eels, and lampreys? Is there the presence of unconsolidated sediment banks and extensive inter-tidal flats used by over-wintering wading birds? Does it have large intertidal flats which provide a rich feeding area for juvenile fishes and overwintering birds, as in most estuaries?
General	Is there no doubt that the area supports an estuarine fauna (see below) even though the upstream and downstream delimitation of this community is likely to be unclear? Does the estuarine fauna occur and vary from the typically marine community at the outer reaches to an area upstream where no marine forms are found? Does the species richness *vs.* salinity curve occur as a sigmoid curve and do the upper and lower plateaux represent marine and freshwater areas; does the steepest part of the sigmoid curve occur in the estuarine area?

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