ADAPTATIONS TO LIFE IN ESTUARIES

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Summary

Organisms living in estuaries are subject to a harsh and often variable physico-chemical environment. The major stressor is salinity, but others, notably hypoxia, increase the difficulties for survival. As a consequence, biodiversity is low in comparison to other aquatic habitats. While the stresses do adversely impact on many facets of the life strategies of estuarine organisms, those which can cope with the pressures can flourish by exploiting the abundant resources available.

Anthropogenic pressures in the form of pollution, habitat loss/modification, introduction of exotic species and human contributions to climate change add to the difficulties of life in estuaries. The stocks of fish, including shellfish, have also largely been over-exploited, many are now endangered and action is needed at all levels to deal with these threats.

1. Salinity and sampling

The most commonly-used definition of an estuary is that of Cameron and Pritchard, in which it is defined in terms of its topography and its chemical constituents thus:

“An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage”

The word ‘estuary’ comes from the latin *aestuarium*, a tidal arm of the sea, and like the word itself, the bulk of the organisms which live in the estuary, with varying degrees of success, are of marine origin. As such they have come into the estuary from full-strength (or near full-strength) seawater and the "measurable dilution" of the sea water by the fresh water is the major factor to which they must adapt. The impact of this problem on the organisms has been recognized in the EC Water Framework Directive (WFD: 2000/60/EEC), in which estuaries were termed 'Transitional Waters', that is where the freshwater domain was being gradually replaced by the marine, and for which distinct biological (and also physical and chemical) reference values needed to be established.

Not only is there a chemical transition from river to sea, but there is also unpredictability within this transition imposed by the variability in the two end-members in addition to wider changes to which river and sea organisms as well are subject (e.g. global temperature rise, storms). Thus the salinity in the estuary at any one location is not simply a constant ratio of river:sea, but changes with river flow (flood/drought), with tide (high/low, neap/spring) and with the degree of mixing of the two at the interface (wind, depth, size).

These changes impose both spatial and temporal variability on the estuarine system, and this must be recognized, not only for the problems engendered for estuarine living but also from the pragmatic standpoint of sampling. Sampling programmes must therefore recognize the spatial and temporal variability of the system and that of the target compartment. The examples in Table 1 (originating out of the EC-MAST JEEP92 project) illustrate the effects of size, in that smaller organisms demand a higher intensity of sampling, and also compartment, in that the higher variability of the water column as compared to the benthos demands a higher sampling frequency and density.

a) Month

Benthic compartment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**N°.**
Microphytobenthos	X		X	X	X	X	X		X		X		3
Macrophytes				X						X			4
Meiofauna				X						X			4
Macrofauna				X						X			4
Water compartment													
Nutrients	X		X	X	X	X	X		X		X		1
Phytoplankton	X		X	X	X	X	X		X		X		3

b) Salinity

Benthic compartment	**0**	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**N°.**
Microphytobenthos	X	X			X				X			X	3
Macrophytes		X			X				X				4
Meiofauna		X			X				X				4
Macrofauna		X			X				X				4
Water compartment													
Nutrients	X	X	X	X	X	X	X	X	X	X	X	X	1
Phytoplankton	X	X			X				X			X	3

Table 1. Minimal sampling intensities for estuarine sampling programmes

a) temporal frequency with month and number of replicates b) spatial frequency and number of replicates

Although salinity can rightly be considered the main stressor, there are others. In addition to the factors such as temperature and desiccation to which estuarine intertidal organisms, as with all intertidal organisms, are subject, there are often problems with contaminants of anthropogenic origin. These contaminants can include nutrients, which can result in eutrophication, which in turn exacerbates the heterotrophic nature of estuaries and their tendency towards hypoxia (lowered oxygen concentrations) or even, in extreme cases, complete anoxia.

2. Opportunism, tolerance and competition

Thus organisms in estuaries must adapt to a mixture of sub-optimal conditions, and conditions moreover which may be rapidly changing in time and in space. Models have been proposed for evolutionary adaptive strategies, which have been successively later developed for pollution and then for estuaries, and in which species could be aligned along gradients of disturbance, stress and competition respectively. The suggestion is that estuarine species in general should score low along the competitive gradient, but highly in terms of response to disturbance and stress. This is shown graphically in Figure 1.

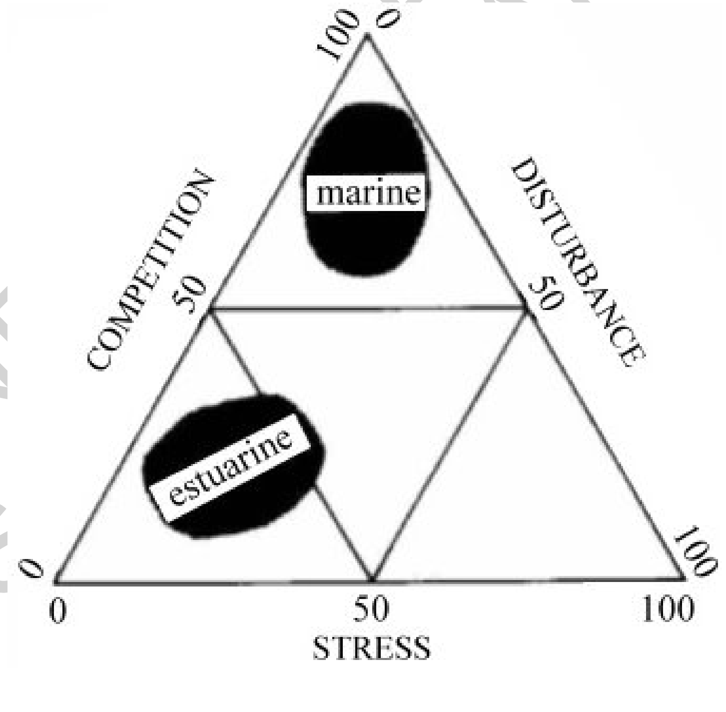

Figure 1. A model for the alignment of estuarine species compared to marine species on competitive/disturbance/stress axes.

Disturbance, which is high intensity but of short duration, favours r- (reproductive) strategists, while stress, which is low intensity but of long duration, favours tolerance strategists. In the absence of either disturbance or stress, competitive (K-) strategists win out, while under conditions of both disturbance and stress there is no successful strategy.

It has even been suggested that the latter combination may be encountered even in unpolluted estuaries and that in some situations the limit of adaptation may be surpassed such that some parts of estuaries can be naturally abiotic.

Much of our initial understanding of the impacts of lowered salinity came from the work of scientists in the Baltic, where the salinities change from near full-strength seawater (~34) at its junction with the North Sea, to almost freshwater (>5) in its innermost reaches along the coast of Finland. The biological transition from sea through brackish-water to freshwater was elegantly expressed diagrammatically (Figure 2) by Remane, and these curves underpin the general understanding of species' distribution in estuaries.

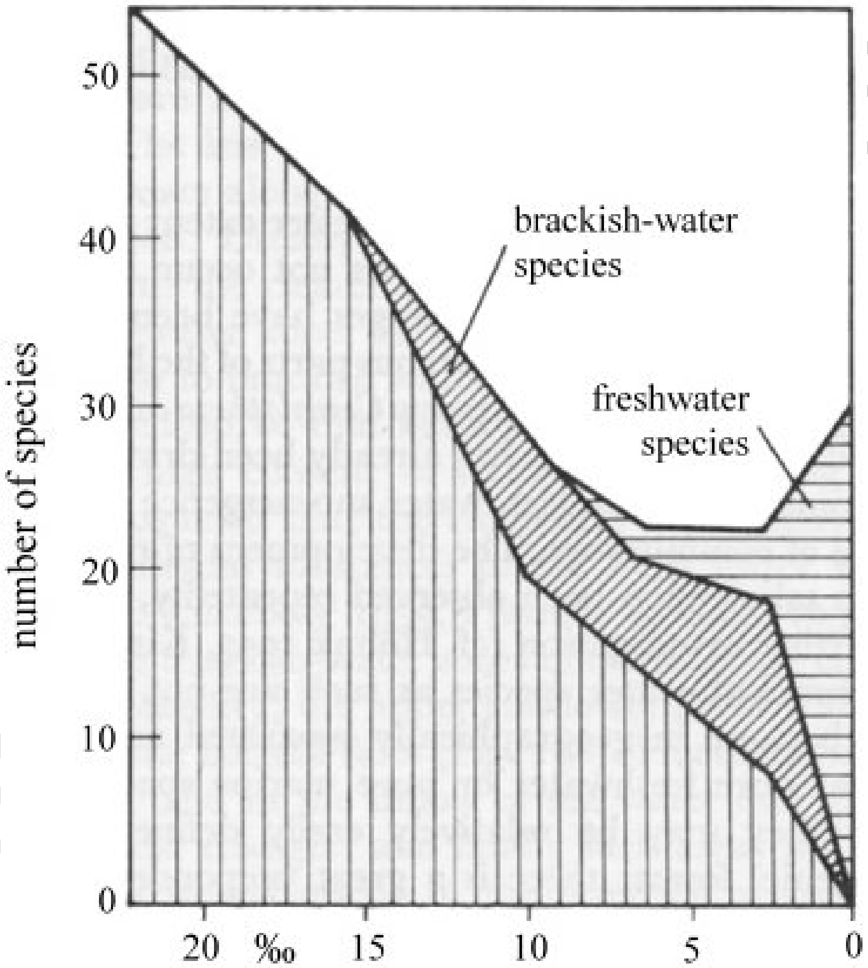

Figure 2. Remane curves showing the relative abundances of marine, brackish and freshwater species through the Baltic salinity (as ‰) gradient.

Under Remane's model (Figure 2), the numbers of both marine and of freshwater species decline sharply along the transitional salinity gradient, with relatively few species (the 'brackish-water species') able to tolerate or survive in the most stressful conditions – here between salinities of between 3 and 10.

Remane's conceptual model continues to underlie current thinking on species' distribution in estuaries. However, there have been modifications, and these were codified in 1959 into the ‘Venice system’ (Table 2) for the classification of brackish waters, so-called after the host city where the meeting was held. Under the Venice system, it was recognized that while Remane’s principles could still hold, some adjustment was necessary, especially in view of the different problems imposed by a largely static (in terms of salinity changes) Baltic, on which Remane had based his model, and the variability outlined above prevalent in most estuaries. For instance, under the Venice system, the biodiversity minimum is indicated between salinity 5 – 18, which is slightly higher than originally proposed by Remane (Figure 2 above).

Zone	**Reach**	**Salinity**	**Substratum**	**Life strategy**	**Example**	**Number of species**
Limnetic	River	<0.5	Gravels	True freshwater	*Dreissena polymorpha*	>50
Oligohaline	Head	0.5 - 5	Mixed	Oligohaline, FW migrants	*Potamopyrgus jenkinsi Corbicula fluminensis*	20
Mesohaline	Upper reaches	5 - 18	Mud	True estuarine Limit of migrants	*Nereis diversicolor Callinectes sapidus*	12
Polyhaline I	Middle reaches	18 – 25	Sandy mud	Estuarine Euryhaline	*Mytilus edulis Crassostrea virginica*	20
Polyhaline II	Lower reaches	25 – 30	Muddy sand	Èstuarine, Euryhaline SW migrants	*Arenicola marina Cerastoderma edule*	40
Euhaline	Mouth	>30	Clean Sand & rock	Stenohaline marine	Echinoderms	>100

Table 2. Venice system of estuarine zonation with hydrophysical, sedimentary and biological characteristics.

However, the basic principles of both the Remane and the Venice systems are the same. Table 2 details the life strategies necessary in each salinity zone along with an example for each. Stenohaline organisms, that is organisms which essentially cannot cope with changes in salinity (in either direction) are confined to the fresh- and salt-waters at each end of the estuary, and these constitute the majority of freshwater and marine species.

It is worth noting at this stage that adaptation to estuarine conditions is not evenly spread among animal groups. For instance, although there are marine sponges and freshwater sponges, they are rarely found in estuaries. Likewise for the coelenterates, for which the freshwater *Hydra* and the marine jellyfish are probably the best-known examples, and which are rarely found in estuaries. Other groups, such as the Echinoderms (starfish, sea urchins and their allies) are marine only, although it should be acknowledged at this stage that the numbers of all aquatic animal species (marine and freshwater) are probably less than one quarter of those of the insects alone which are overwhelmingly terrestrial.

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Biographical Sketch

Prof. James G. Wilson, BSc, PhD, MA, MIEEM, CEnv, FTCD.

Prof. James G. Wilson is an Associate Professor in Zoology and Environmental Science at Trinity College, University of Dublin (TCD).

Prof. Wilson graduated from the University of Glasgow in 1976 with a PhD in Zoology (Marine Biology) before moving to TCD. There, he devised two synoptic indices of estuarine quality, the BQI and the PLI, which have now been applied in Ireland, France and the US as well as Black Sea.

Prof. Wilson main research interests centre on the fitness (in the Darwinian sense) of organisms and this is a key concept to understanding natural systems and anthropogenic impacts. From this arises his work in bioenergetics, bioindicators and indices and in the network analysis of ecosystems.

Prof. Wilson has written or edited 6 books and over 100 peer-reviewed papers covering the whole range of his research interests. These have been supported by national and international funding and have included collaborations with colleagues throughout the EC as well as Russia, Ukraine, Georgia, USA and Australia.

Prof. Wilson has been an active member of many outside organizations, including the Irish Marine Sciences Association (Chairman 1992-5), the Marine Conservation Society, the Institute of Ecology and Environmental Management, and the Environmental Sciences Association of Ireland (Chairman 1998-2002). Currently he is the Secretary to the Life Sciences Committee of the Royal Irish Academy and the Secretary to the Estuarine and Coastal Sciences Association.