Natural England Commissioned Report NECR039

Coastal saline lagoons and the Water Framework Directive

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

The Water Framework Directive (WFD) came into force in December 2000. This introduced a new system of monitoring and assessing the aquatic environment. Member states are now required to report on the ecological status (or potential) for each "water body" (defined as a significant and discrete unit of water).

A number of coastal saline lagoons have been identified as WFD water bodies in the UK. This means that there is a requirement to develop type-based classification tools to help assess their ecological status.

Developing suitable generic tools to classify coastal saline lagoons poses a considerable challenge, as they are unlike other "types" of transitional and coastal waters.

This study was commissioned by Natural England to inform future work of the UK Technical Advisory Group and Marine Task Team in developing a national consistent approach to the assessment of lagoons under the WFD.

Natural England held a workshop in October 2008 entitled *Coastal Lagoons and the WFD*. The aim of this was to bring together scientists from across Government agencies and research institutes with expertise in either the conservation of lagoons or WFD implementation, to discuss the draft report and how recommendations from this work could be taken forward. A short summary of this workshop can be seen at Annex 1.

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Further information
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Summary

Coastal saline lagoons are areas of shallow, coastal saline water, wholly or partially separated from the sea by sandbanks, shingle or, less frequently rocks (Brown *et al*., 1997). They are of significant value to nature conservation due to the rarity in habitat and specialist species which they support, and are protected through a number of national and international wildlife designations. Under the Water Framework Directive, where coastal saline lagoons are of sufficient size, they are identified as "water bodies" and require assessment and reporting of ecological status. In England there are 28 lagoon water bodies.

However, the Water Framework Directive was formulated without consideration for the particular conditions of coastal saline lagoons, viz. their inherent variability over ranges of scale and duration, both in space and in time, which are not experienced in other aquatic habitats. This variability imparts comparatively severe environmental stresses, which themselves are responsible for the development of a specialist community in lagoons. These specialist species are mainly restricted to certain stretches of the UK coastline, probably owing to zoogeographic considerations rather than availability of habitat. In addition, the process of recruitment to lagoons is unknown, and the suite of species present in any given lagoon is unpredictable.

The establishment of "type-specific reference conditions" (under Annex II 1.3 of the Water Framework Directive) is therefore challenging for lagoons. These will need to be either wide-ranging for a broad typing of lagoonal habitats, or alternatively appropriate to specific lagoons if they are treated on an individual basis. This process is a major stumbling block for coastal saline lagoons, which will have to be treated in isolation from other transitional or coastal waters. The inevitable conclusion is that, as a starting position, "good condition" must be defined on a site-specific basis for each lagoon, and this condition must include the range of variation experienced naturally.

It is possible to reformulate the standards laid down in the Water Framework Directive to be appropriate to coastal saline lagoons, while remaining within the spirit of that Directive. Equally, a wider understanding of variability in both habitat conditions and community structure may be a necessary referent for addressing the degree of change which is acceptable before the status of the habitat drops from one status category to another.

It should be possible to formulate a preliminary site-assessment protocol based on the considerations, from which to determine the necessity of more intensive monitoring.

Differences between the Water Framework Directive assessment criteria and those under the "Habitats Directive" relate purely to the presence and condition of scheduled species in the lagoons. However, ideal habitat conditions for those species do not differ significantly from those required by other lagoonal taxa. While the presence or absence of specialist species might be considered outside the terms of the Water Framework Directive, in fact this is a non-sequitur, as the species present in any habitat are specialists to that habitat, and, to risk a circular argument, the plant and animal species present in lagoons are almost inevitably largely specialists to that habitat.

Finally, it must be appreciated that lagoons by their very nature are naturally temporary habitats, and some decline in their status is inevitable with time, and on a shorter timescale than may be the case for freshwater lakes or estuaries. The implications of this natural decline in condition over time are beyond the scope of this assessment.

Contents

1. Chapter One

Introduction

Coastal saline lagoons are areas of shallow, coastal saline water, wholly or partially separated from the sea by sandbanks, shingle or, less frequently rocks (Brown *et al*., 1997).

They are essentially aquatic habitats of low hydrodynamics. They act as sinks for organic, detrital, fine-sedimentary and other materials entering the system. There is nothing unique about the habitats surrounding coastal saline lagoons; the lagoonal habitat itself is sublittoral, as are the specialist species associated with this habitat.

As the distinction of habitat preferences/associations of species associated with lagoons of extremely low salinity and those from freshwater habitats (the latter commonly defined as waters of 0 to 2‰) are not understood or clear, the following will be limited to consideration of saline waters, from the brackish to the hyperhaline.

The term “lagoon” when used in isolation below refers only to coastal saline lagoons.

The nature conservation importance of saline lagoons is reflected by the fact that:

- lagoons are apriority Annex 1 habitat under the EC “Habitats Directive” (Anon., 1992), and thus some such lagoons are designated as Special Areas of Conservation (SACs);
- lagoons are examples of habitats which support internationally important bird features designated in Special Protection Areas (SPAs) under the EC Bird Directive;
- lagoons are qualifying features and designated as Sites of Special Scientific Interest;
- lagoons are included as a priority feature under the UK Biodiversity Action Plan (UKBAP).

In addition, within the UK, lagoons are habitats which support a number of species of plant and animal which are either mainly or entirely restricted in their distribution to lagoonal habitats.

These species include plants and animals scheduled under the Wildlife Countryside Act 1981 (Table 1)

The currently accepted hypothesis for the restricted distribution of these “lagoonal specialist species” is that the habitat in which they live shows uniquely high levels of environmental stress owing to the short-term and spatial variations in conditions prevalent in such lagoons. The specialist species are apparently tolerant of these stress conditions and, while out-competed in adjacent saline habitats (estuaries, tidal rock- or marsh-pools, or the sea), are able to survive better in lagoonal habitats than are those more common taxa which out-compete them elsewhere.

At present in England there are fifty-two lagoons defined in SACs or SPAs, and a further twenty-eight lagoonal water bodies falling under the auspices of the Water Framework Directive. Most of these lagoons are man-made, or their current condition is a result of human activity. The former will be included under the register of protected areas required under Article 6 of the Water Framework Directive. All fall under the Water Framework Directive objectives requiring prevention of deterioration, with the aim to achieve “good ecological status” by the year 2015. The Water Framework Directive imposes a requirement to monitor, assess and report the ecological quality of these habitats. In addition, appropriate management needs to be in place in order to protect and enhance their ecological quality where necessary to achieve relevant objectives.

Plants	
Lamprothamnium papulosum	Foxtail stonewort
Chara canescens	Bearded stonewort
Cnidaria	
Clavopsella navis	a hydroid
Edwardsia ivelli	Ivell's sea-anemone
Nematostella vectensis	Starlet sea-anemone
Bryozoa	
Victorella pavida	Trembling sea-mat
Polychaeta	
Armandia cirrhosa	Lagoon sand-worm
Alkmaria romijni	Tentacled lagoon-worm
Crustacea	
Gammarus insensibilis	Lagoon sand-shrimp
Mollusca	
Tenellia adspersa	Lagoon sea-slug

Table 1. Species of lagoonal-specialist plants and animals currently protected under schedules 8 and 5 (respectively) of then Wildlife & Countryside Act, 1981

In order to determine the qualifying parameters of coastal saline lagoons in the context of the Water Framework Directive, and to attempt to define such criteria as “good [high, moderate, poor, bad] ecological status”, it is necessary to understand the range and variation in environmental parameters and thus the habitat conditions of these sites, as well as the species characterizing the lagoonal community.

2. The natural habitat conditions of coastal saline lagoons

2.1 Salinity

Coastal saline lagoons are habitats fed by saline water from the adjacent sea or estuary, either by restricted inlets (narrowed, sluiced or silled) or by percolation (including groundwater supply). Because of the diurnal macrotidal regime of the seas around the United Kingdom, this supply of saline water is normally tied in with the tidal cycle, occurring twice a day, or during spring-tide periods only. Some percolation lagoons may be sufficiently removed from the saline-water source that this tidal effect is damped, and often not even apparent (e.g. Holkham Salts Hole, Norfolk). Lagoons fed only by overtopping (i.e. waters pushed over a barrier during storms or extreme high-tide conditions) may also be entirely independent of the tidal cycle. However, lagoons fed by groundwater supply through a saline water-table will also follow a tidal pattern of saline input.

All coastal saline lagoons receive a freshwater input from rainfall. Some, but certainly not all, also receive a freshwater input from rivers or streams or groundwater supply. When this latter category of freshwater input is significant, the lagoons are typically of reduced salinity in comparison with full-strength sea-water (hypohaline, or brackish). However, it would be wrong to assume that a freshwater supply is essential to coastal saline lagoons, or that they are invariably brackish water habitats. Lagoons whose only freshwater supply is from rainfall (as well as many others) commonly become hyperhaline (also known as supersaline). And the majority of the specialist species listed in Table 1 are tolerant of salinities both above and below 35‰ (normal sea-water concentration) (see Section 3).

There are patterns in the timing of freshwater input as much as with saline input. Rainwater input tends to be greater in winter and spring, and least in summer, early autumn. River or stream flows, or groundwater supplies of freshwater, follow a similar pattern (with a lag which is irrelevant in this context), driven by the intensity of rainfall.

Furthermore, there is often an antagonism between freshwater and saline-water input in the influence of water supply to the lagoon, particularly where tidally-driven groundwater supply competes with freshwater sources to the water table.

Where lagoons have a flowing freshwater input, this will often lead to vertical or horizontal stratification of water in the lagoon, generating a spatial variation in salinity. While the extent or degree of this variation will vary seasonally (as explained above), and can to a degree be broken down by wind-driven turbulence, permanent vertical stratification can exist in some lagoons, e.g. Swanpool Lagoon in Cornwall (Fig. 1).

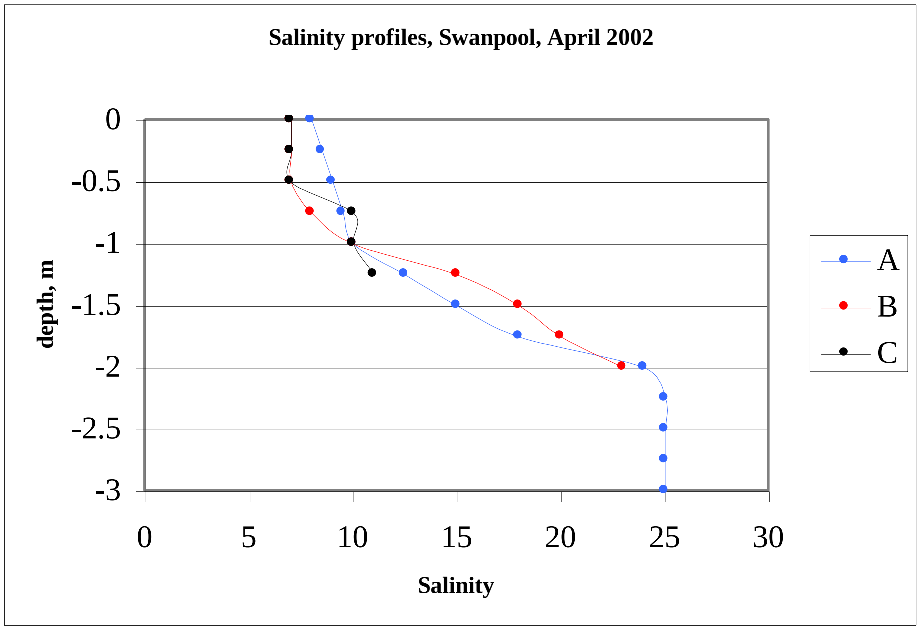

Figure 1. Salinities at 0.25 m depth intervals in Swanpool, showing halocline.

An additional confounding factor for salinity conditions is water loss. All lagoons are prone to evaporative loss. Where there is minimal replenishment of water, evaporation leads to hyperhaline conditions (as was recorded the lagoons of Kings Marsh and Orford Ness in where levels rose to over 80‰). Note that an input of full-strength sea-water will reduce salinity in these conditions.

Where the outflow of water from a lagoon is restricted, then seasonal (or other) pulses of freshwater input may result in extended periods of low-salinity. Note that, in any lagoon, the “head” of water from the sea is inevitably greater than that from within the lagoon, and thus water inflow per unit time, be it across a percolation barrier or through a restricted inlet, will be faster than water outflow.

The result of this rate of ingress-egress will be defined by the duration of the inflow, i.e. the length of time when the tide is sufficiently high to result in an inflow at all. Figure 2 shows the tidal curve of a small lagoon at Calshot, Hampshire in comparison with the tidal curve of the Solent (the saline water supply): the inlet sluice is sufficiently high in relation to the tidal-level that the inflow is restricted, while the ensuing outflow allows the whole input volume (some 60% of the water volume of the lagoon) to be expelled before the next high-tide.

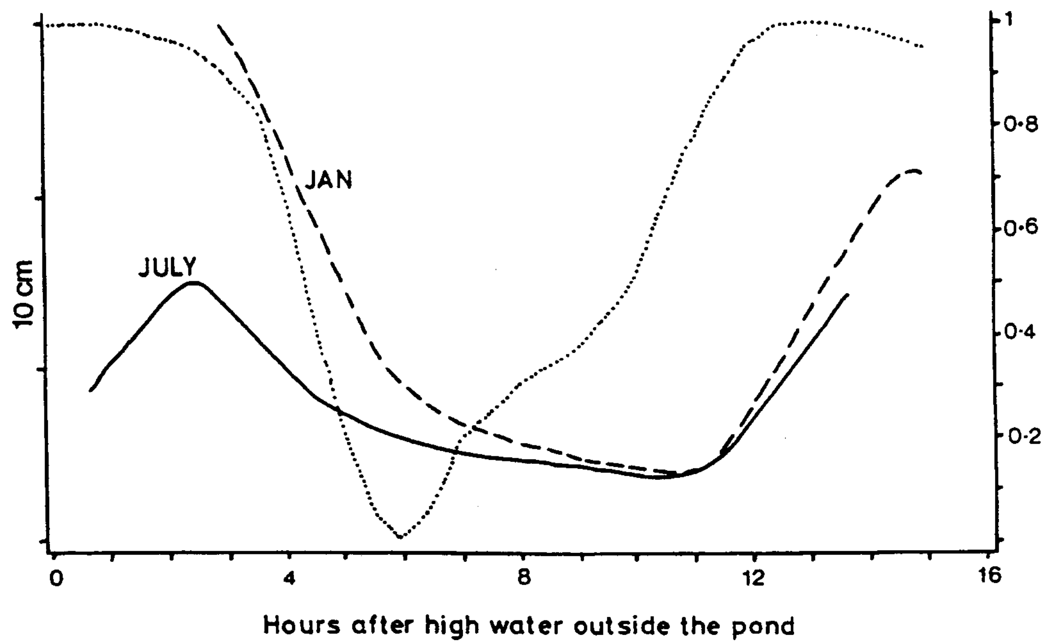

Fig. 2. Neap tidal curves in Calshot Pond, Hampshire plotted against the ambient tidal curve (dotted line, right axis, proportionate)

To summarize the above, the salinity within a lagoonal basin will depend on the degree and timing of inputs *and outputs* of both saline and fresh waters, influenced by the restriction of flow across the barrier or inlet, seasonality, tidal range and cycle, and lagoon shape and depth. The salinity conditions that result may be complex to predict readily, but can range typically between 0 and 40‰ with time and space, in the short- (within hours in relation to a tidal cycle), medium- (weeks in relation to spring- and neap-tides) or long- (seasonally in relation to rainfall and evaporation; over years in relation to extreme weather or tidal events) term, as well as over short distances within the lagoon with stratification (and thus simultaneous variation).

This salinity variation is one of the environmental stresses of the saline lagoonal habitat alluded to in Section 1. As should be evident, significant variation in salinity will be the norm in coastal saline lagoons over distances of centimetres and within time-spans of minutes, as well as over wider space and in the longer term. Such variation does not occur in other aquatic habitats.

2.2 Temperature

From the foregoing, it should be apparent that the temperature of lagoonal waters will also show extreme variation in the short to long term in time as well as in space. The differential inputs of saline and fresh-water will involve sources at different temperatures. The development of haloclines will also involve thermoclines; extremes of this are found when superficial low-salinity water layers can freeze during winter conditions. The shallow nature of most lagoons will lead to a rapid influence of both insolation and evaporative cooling.

As a result, similarly to, but not entirely coincident with, the variations in salinity, there will be rapid to long-term variations in temperature of the lagoon water (tidal, diel, seasonal, year-to-year) as well as spatial variation horizontally and vertically, and to a degree more extreme than occurs in most other saline habitats.

2.3 pH

Perhaps surprisingly for a saline habitat, coastal saline lagoons also show temporal and spatial variations in pH.

At a low-level, the variability in salinity allows an influence of the freshwater-source pH less modified by the carbonate-bicarbonate buffering system of sea-water.

Phytoplankton blooms are a common occurrence within lagoons, owing to their propensity for a comparatively high organic content in the water; such blooms can occupy the majority of the water body of a small lagoon, and the photosynthetic activity of the organisms concerned results in a reduction of the carbon-dioxide content of the water, and a concomitant increase in pH, often above 9 (normal full-strength sea-water pH being in the range 7.8 to 8.4). Fig. 3 shows the simultaneous pH levels of an adjacent series of the Keyhaven-Lymington lagoons (part of the Solent and Isle-of-Wight Lagoons SAC) during 2001, with phytoplankton blooms present in Keyhaven, Fishtail and Butts Lagoons.

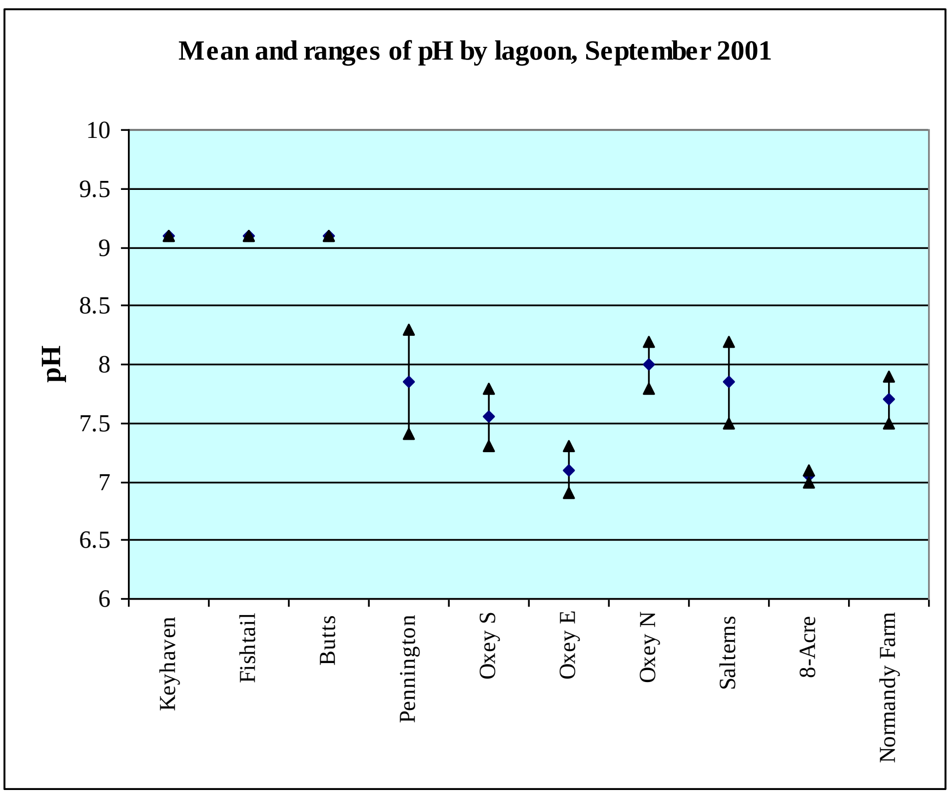

Fig. 3. pH levels in the Keyhaven-Lymington lagoons, September 2001.

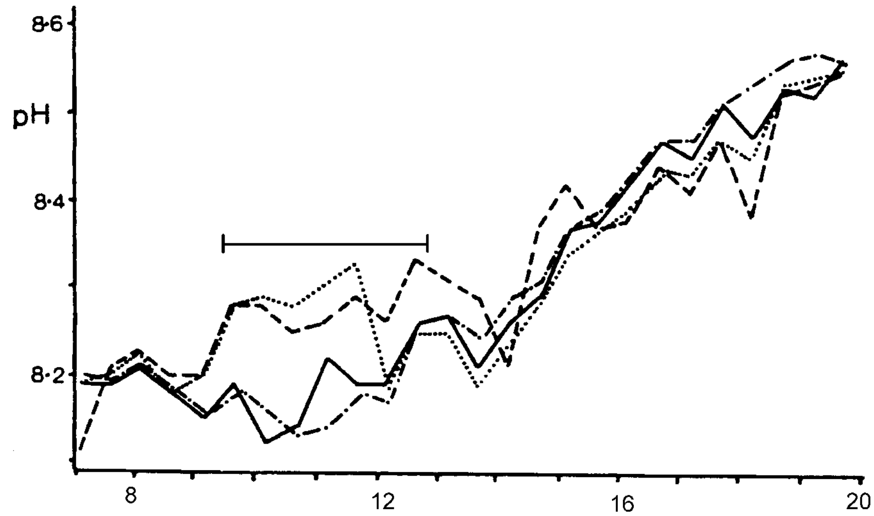

Fig. 4. Stratification of pH around a July tidal cycle in Calshot Pond, Hampshire. Readings are every 30 minutes from 5 cm (dashed line), 15 cm (dotted line), 25 cm (solid line) and 35 cm (dashed-and-dotted line) above the lagoon bed. Horizontal bar shows period of stratification (oxitetacline).

Owing to the shallow nature of most lagoons, diatom mats on the sediment surface are a common feature. During sunny days, these diatoms begin to photosynthesize in the morning, again using up the carbon-dioxide in the vicinity of the substratum and causing the pH to rise. Since lagoons are of low hydrodynamics, this process results in a cline of pH – an "oxitetacline" – within a few centimetres of the lagoon bed (note that, unlike the halocline and thermocline, this is not a pycnocline). Such a cline is unique to coastal saline lagoons. As photosynthesis continues, the diatom mats generate sufficient bubbles of oxygen that they become buoyant, and rise from the bed to the lagoon surface, disrupting the cline of pH as they do so. Such a process is shown in Fig 4 on a sunny day in Calshot Lagoon, Hampshire.

2.4 Oxygen

Less surprisingly, in an aquatic basin habitat where the organic content can be comparatively high, water-movement is low, and the water body is prone to stratification, there is also a propensity for high rates of respiration to lead to significant oxygen reduction towards the bed of the lagoon. A common result of this seen in lagoons is the presence of temporary mats of *Beggiatoa,* which do not have an associated fauna (thus not analogous to the *Beggiatoa* biotope of Connor *et al.*, 1997).

Significant long-term anoxia is not recorded for any UK lagoon.

2.5 Substratum

Saline lagoons are temporary habitats. The sedimentary bed of the lagoon is normally a combination of the original sediment present prior to lagoon closure and the input of fine silts and clays brought into the lagoon subsequently. Where the original sediment is significantly coarser than silt-clay, and it is commonly sand or gravel, the final substratum tends to show a distinct bimodality (e.g. Fig.5). Such a substratum will become progressively, but slowly, finer with time. The commonest sedimentary substratum within UK lagoons is of muddy-sand (contrary to appearances) which supports the ENLag. IMS.Ann biotope (and its variants) of Bamber (1997).

Aquatic plants also act as a substratum for other plants (epiphytic algae) and animals; indeed, a significant lagoonal biotope is associated with the submerged plant life of the lagoon, almost independently of the lagoon-bed-sediment (the ENLag.Veg biotope of Bamber, 1997). The species of plant present are not entirely predictable, as they depend on the random process of colonization, particularly with regard to perennial plants. Most lagoons will show a seasonal variation in the presence of annual algae such as *Enteromorpha* and *Ulva*.

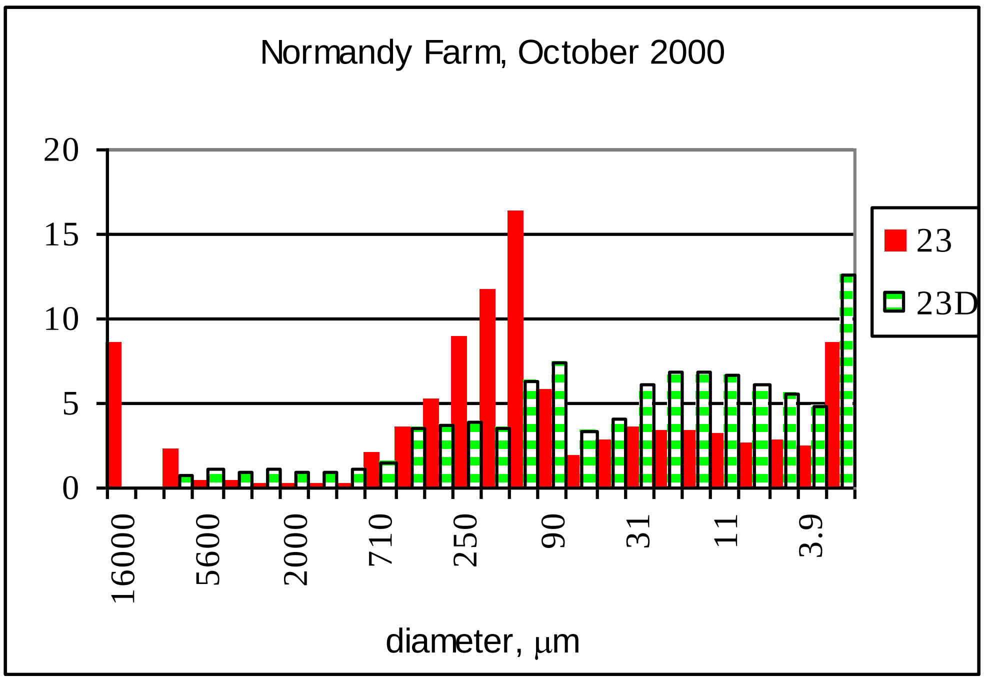

Figure 5. Sediment particle –size histograms for two stations in Normandy Fram Lagoon, Hampshire, showing bimodality with peaks in the fine sand and the silt-clay fractions.

The third type of substratum found in most coastal saline lagoons is the range of hard substrata which includes any size of rock (and its anthropogenic equivalents), plants, most significantly stems of reeds, and allochthonous wood. Certain lagoonal specialist species are associated with hard substrata, almost non-selectively, including the encrusting bryozoan *Conopeum seurati*, and the scheduled bryozoan *Victorella pavida*, as well as a possible lagoonal form of the littorinid winkle *Littorina saxatilis lagunae* (non-*Littorina tenebrosa*).

2.6 Organics

As been mentioned above, coastal saline lagoons are sinks for organic matter, as the input of such material is greater than its output because of the nature of the lagoon hydrodynamics, and further organic material is generated within the lagoon. As a result, lagoonal sediments commonly have an organic content of 10 to 15% by weight, compared with 3 to 8% in coastal muddy-sands.

Equally, this organic loading encourages seasonal growth of annual algae and phytoplankton (see above). On the one hand , such lagoons may be regarded as naturally “eutrophic” (more correctly hypertrophic). On the other hand, concerns expressed over “eutrophication” of lagoons are unfounded, as this is their natural state, and the associated community is inevitably adapted to such conditions.

2.7 Chapter Summary

It can be seen from the foregoing that the overall lagoonal habitat is naturally very variable, more so than any other aquatic habitat. This variation occurs both in space, over small to large distances vertically and horizontally, and in time, from short-term (minutes, hours), through medium-term (days, spring-neap cycles) to long term (seasonally, annually, and longer).

While some of the parameters showing natural variation are interrelated, they can all also vary independently. The overall pattern is unpredictable except in the most general sense, and is likely to be unique to each lagoon (or interconnected lagoonal-system).

It is against this natural background that attempts to define ecological status *sensu* the Water Framework Directive must be made.

3. Habitat preferences of lagoonal specialist species

A significant reason behind the conservation priority of coastal saline lagoons is the presence of associated specialist, and often statutorily protected, species. In order to determine the likely community associated with a particular saline-lagoonal habitat, it would help to have an understanding of the habitat preferences of the specialist lagoonal species.

Unfortunately, there has, to date, been little intensive study of the habitat tolerances of such species (principally owing to the lack of funding for such basic biological research). What knowledge we have is largely derived from circumstantial evidence of the conditions in which these species have been found to exist (or flourish, or decline) in the field.

As the tolerances of species associated with lagoons of extremely low salinity are not understood in distinction from freshwater habitats (the latter commonly defined as waters of 0 to 2‰), the present discussions will be limited to species of saline waters, from the brackish to the hyperhaline.

The specialist species of Table 1 fall into two categories. Those specifically associated with hypohaline waters, and which have (in cases) also been recorded in estuarine conditions of low hydrodynamics (e.g. *Alkmaria romijni*), tend to be restricted to lagoons whose salinity range is predominantly below that of full-strength sea-water.

The other, and larger, category of specialist lagoonal species comprises those which are restricted to fully-saline sea-water habitats when found outside lagoons, or (when not known outside lagoons) are related most closely to species from fully-saline habitats. For example, the amphipod *Gammarus insensibilis* is most-closely related to *G. locusta*, rather than any of the more estuarine (or freshwater) members of the genus. In other words, the large majority of specialist lagoonal species are marine rather than estuarine in origin, and indeed appear to prefer conditions closest to 35‰, although they are of course tolerant of a range around this concentration. Specific laboratory studies have been undertaken on UK population of the starlet sea-anemone, *Nematostella vectensis*, which have shown that this species will cease feeding and become quiescent below the sediment surface at salinities below 10‰ and above 40‰ (M. Sheader, pers. comm.).

Otherwise, from the circumstantial evidence of their occurrence, we may tabulate the preferred ranges of lagoonal specialist species (see Table 2).

Species	Tolerated	Preferred
Lamprothamnium papulosum	8-32	8-28
Chara canescens	<1-34	4-20
Tolypella nidifica	2-18	4-15
Ruppia spp.	0-44	
Clavopsella navis	8-50	28-38?
Gonothyrea loveni	15-?	
Nematostella vectensis	5-52	16-36 (feeding)
Conopeum seurati	5-40	
Victorella pavida	3.5-25	
Armandia cirrhosa	25?-41	25-35
Alkmaria romijni	<5?-48	5-20
Ventrosia ventrosa	4-40	
Hydrobia acuta	10-50	
Cerastoderma glaucum	5-40	10-35 (active)
Idotea chelipes	5-40	15-40
Gammarus insensibilis	10-58	15-40
Gammarus chevreuxi	1-15	
Corophium insidiosum	15-40	

Table 2. Preferred or tolerated salinity ranges (‰) for some lagoonal specialist species. Note that data for many species are limited. After Bamber *et al*. (2001).

There is less information on the tolerances of extremes of other conditions, except that these species survive successfully within the ranges found in the field, for example of pH between 6.5 and 9.5, of temperature extremes from freezing to >35ºC, in conditions of near anoxia, and during levels of high organic loading: the duration of tolerance to the extremes of these conditions are unknown.

Generally, salinity conditions ranging between 20 and 40‰ are entirely acceptable for the upper-range specialist species apparently indefinitely, while a slightly lower range is preferred by such species as *Alkmaria romijni*, and it is these bounds which are generally regarded as the ideal conditions for a lagoonal habitat. Equally, the very presence of variability in the various parameters is also considered essential, as it is these very fluctuations which generate the environmental stress which eliminates many non-specialist species which might otherwise out-compete the lagoonal specialists.

Note, for example, that the two UK species of *Cerastoderma*, the edible cockle *C. edule* and the lagoon cockle *C. glaucum*, are clearly closely-related (sibling) species, yet *C. edule* never occurs in lagoons, while *C. glaucum* has only rarely been recorded outside lagoons, and then at sites in close proximity to lagoons (perilagoonal).

4. Occurrence and geographic distribution of lagoonal specialist species

The geographic distribution around the UK of the species listed in Table 1 is fairly well known. Few are widespread, but notably the lagoon cockle *Cerastoderma glaucum* has been recorded from all coasts of the UK. The foxtail stonewort, *Lamprothamnium papulosum*, has a restricted distribution from the central southern coast of the English Channel via Ireland to the Outer Hebrides. Otherwise, the specialist species tend to be restricted to southern and eastern coasts of England, where there is admittedly a greater area overall of lagoonal habitat. Some of these species, for example *Gammarus insensibilis* and *Hydrobia arcana* (including *H. neglecta*) are found elsewhere on the coasts of Atlantic Europe and into the Mediterranean, so a southeastern-UK distribution is perhaps a logical extension of such a habitat range.

At the more local level, the species found in lagoons is much less predictable, and recruitment of specialist lagoonal species appears to be entirely stochastic.

There are a number of examples of adjacent lagoons which have a dissimilar specialist fauna. For example, the classical percolation lagoons of Shingle Street, Suffolk, mostly support populations of the lagoonal hydrobiid snail *Ventrosia ventrosa*, often together with *Hydrobia arcana*, and a number of them support the cockle *Cerastoderma glaucum* and the lagoonal isopod *Idotea chelipes*; but only one has ever had a population of *Gammarus insensibilis* (and when last visited in the late 1980s, that lagoon had been lost to natural coastal processes). Similarly, of the sequence of more than 20 lagoons or lagoonal pools north of Dunwich, also on the Suffolk Coast, only one supports a successful population of the lagoon cockle, *C. glaucum*.

Indeed, the process by which lagoonal specialist species recruit to new or adjacent lagoons remains unknown. Almost all of the species in Table 1 have no dispersive larval stage. The stochastic nature of such recruitment is exemplified by the few new lagoonal habitats which have been studied. Cams Hall Golf Course lagoon, Hampshire, was created in the 1990s as a “water-feature” adjacent to the fourth hole. Within the first year the lagoon cockle, *C. glaucum*, had colonized the lagoon, and by year four the alga *Chaetomorpha linum* and then rare opisthobranch mollusc *Haminoea navicula* were also present, but no other lagoonal specialists were.

5. Coastal saline lagoons – a summary

A number of things are hopefully evident from the foregoing in the context of the natural conditions of the coastal-saline-lagoonal habitat.

- Coastal saline lagoons are saline water bodies with low hydrodynamics.
- The essential habitat of coastal saline lagoons is sublittoral.
- Their environmental conditions are inherently extremely variable, in space and time, in the short to long term. Such variation is unique to lagoons.
- This variability imparts comparatively severe environmental stresses, which themselves are responsible for the development of a specialist community in lagoons.
- These specialist species are mainly restricted to certain stretches of the UK coastline, probably owing to zoogeographic considerations rather than availability of habitat.
- The process of recruitment to lagoons is unknown. Therefore, the suite of species present in any given lagoon is unpredictable.

In the light of this, we may now see how the Water Framework Directive is applicable to coastal saline lagoons.

6. The Water Framework Directive: which of the various categories of aquatic habitat encompass coastal saline lagoons?

6.1 Definitions of water bodies in Article 2.

Within the definitions of Article 2 of the Water Framework Directive, coastal saline lagoons are **surface waters**, and they are **inland waters** ("on the landward side of the baseline from which the breadth of territorial waters is measured"). The four categories of surface water, defined under Article 2 of the Directive, are rivers, lakes, transitional waters and coastal waters.

Lagoons are not **rivers**.

Lagoons do fit into the definition of **lakes**, although it is evident from elsewhere in the Directive that this category is used to refer to freshwater habitat: the definition in Article 2 is thus inadequate and incorrect.

Some (but not all) lagoons do fit into the definition of **transitional waters**, defined as being both "in the vicinity of river mouths" and "substantially influenced by freshwater flows". However, as we have seen above, many lagoons are not "substantially" influenced by freshwater flows: indeed, some are not influenced at all by freshwater flows. Furthermore, many lagoons are not in the vicinity of river mouths, however extremely the word "vicinity" is stretched. Bryher Lagoon, on the Scilly Isles, (Plate 1) is an example which fits neither of these definitions.

Taken literally, lagoons can be fitted into the definition of **coastal water**, as there is no landward limit to coastal water other than the seaward extent of transitional water. Article 3 of the Directive states that "Coastal waters shall be identified and assigned to the nearest or most appropriate rive basin district or districts.". It is unclear how this might be applied to the likes of Bryher Lagoon, but presumably Natural England have a similar problem with the Scilly Isles as a whole.

Within the *spirit* of the Directive, **specific lagoons are either transitional waters or coastal waters**.

Equally, the majority of lagoons are "**artificial water bodies**", and may be physically modified, but not "**heavily modified water bodies**". This may pose problems for the spirit of the definitions of ecological status. In practice, however, it is commonly the very artificiality of the seawater-exchange apparatus, usually an anthropogenic modification, which has allowed the lagoon to exist or persist.

The man-made sluice at Cemlyn Lagoon, Anglesey, allows retention of more water in the lagoon at low tide, having been designed for the benefit of nesting and roosting birds, but in practice maintaining a larger volume and area of the lagoon habitat to the benefit of that habitat and of the associated communities. Indeed, a large number of perfectly good lagoons owe their existence to artificial sea-walls and similar (Aberthaw Lagoon; Keyhaven-Lymington Lagoons), are entirely artificial creations (King's Marsh Lagoons, Dunwich Lagoons, Moulton Marsh Lagoons), or are modifications of existing water-bodies (Cams Hall Lagoon; Gilkicker Lagoon). The artificial modifications to all of these sites have benefited their ecological status as lagoons.

Nevertheless, we may disregard the distinction of artificial, modified lagoons, as the necessary measures defined in Article 4 1a(ii) (all bodies of surface water) and 1a(iii) (artificial and heavily modified bodies of water) are essentially the same other than the requirement for restoration. Annex II 1.1 (v) allows the inclusion of all lagoons into the processes relevant to either transitional waters or coastal waters.

6.2 Ecoregions and surface water body types.

The relevant "Ecoregion" for any lagoon or lagoonal system may be simply fixed from the listing given in Annex II 1.2.3 and 1.2.4 of the Directive.

The relevant "Type" "Based on mean annual salinity" is an unfortunate category for lagoons, as the mean salinity hardly reflects the salinity conditions of the site, and it may be difficult to determine, owing to the cost implications of (perhaps) monthly readings of salinity around the tidal cycle to generate sufficient data. The ideal conditions defined by Bamber *et al*. (2001) are for a salinity range between 20 and 40 *for most of the time*, thus habitats which are both polyhaline and euhaline within the definitions given in Annex II.

The relevant Type "Based on mean tidal range" (transitional waters) is **microtidal**; the relevant type "Based on mean depth" (coastal waters) is **shallow waters**.

6.3 Reference conditions.

The establishment of "type-specific reference conditions" (Annex II 1.3) is again challenging for lagoons. These will need to be either wide-ranging for a broad typing of lagoonal habitats, or alternatively appropriate to specific lagoons if they are treated on an individual basis.

Indeed, this process is a major stumbling block for coastal saline lagoons, which will have to be treated in isolation from other transitional or coastal waters.

Multivariate community analysis of the benthos of a number of lagoons and paralagoonal habitats in England and Wales (Bamber, in litt.) indicated two broad classes of lagoons which were regarded as in "good condition" (Fig. 6). These were higher-salinity lagoons, mainly found in England, and lower-salinity lagoons, mainly found in Wales. The former category includes a number of sites supporting scheduled lagoonal specialist species, and reflects the lagoonal type where salinity broadly stays within the range of 20 to 40‰. Many of these lagoons have no freshwater ingress other than by rainfall. The lower-salinity lagoons, while still "good condition", appear to be more heavily influenced by freshwater input (or retention), particularly by heavier annual rainfall; their salinity often drops towards 0‰ on a seasonal basis, rising to the upper-twenties during the dry season. Type-specific reference conditions for these two groups of lagoons in relation to salinity would have to be different.

Equally, while the coastal saline lagoons of England and Wales essentially support the same two biotopes (or three when including the nekton), the communities which they support are not the same, either between the two countries (hence the split in Fig. 6), or between "good" lagoons within the same county or even adjacent lagoons (see above, Section 4). It would thus be prohibitive to define reference conditions for any large class of lagoons pertaining to the species present.

Nevertheless, the species assemblage present, and particularly whether there are lagoonal specialists present, is undoubtedly an important criterion for considering a lagoon "good", and as such an index based on the relative dominance of specialist species was proposed by Bamber *et al*. (1992).

Note that the plankton within a lagoon is not relevant, either as a significant food-resource or as a recruitment pathway.

7. The Water Framework Directive: Ecological Status

7.1 What is good ecological status.

In other words, can we define a generalized “good status” for coastal saline lagoons?

For a waterbody in the terms of the Water Framework Directive to be of “high ecological status”, it is required that “there are no, or only very minor, anthropogenic alterations to the values of the physico-chemical and hydromorphological quality elements for the surface waterbody type from those normally associated with that type under undisturbed conditions. The values of the biological quality elements for the surface waterbody type reflect those normally associated with that type under undisturbed conditions, or show no, or only very minor, evidence of distortion.”

For a waterbody to be classified as of “good ecological status”, then “the values of the biological quality elements for the surface waterbody type show levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface waterbody type under undisturbed conditions.”

As the majority of coastal saline lagoons are man-made, finding undisturbed conditions is unlikely. Indeed, removal of site management will result in the loss of lagoonal habitat at some sites (as has happened recently at Bembridge, Isle of Wight).

The thesis of Bamber *et al*. (1992) was that “good” lagoons were those supporting a good representation of lagoonal specialist species, on the basis that the very presence of these species demonstrates that the lagoon is in good condition.

Unfortunately, this approach would preclude lagoons which are physiographically appropriate, and may be relatively uninfluenced by anthropogenic interference, maintaining a community appropriate to that site, but not including specialist species. We have already seen that most of these lagoonal specialists are restricted in distribution to the southern and south-eastern coasts of England.

Longer-term monitoring of some lagoons has demonstrated that the species present can show apparently-natural stochastic variability – apparent good or bad years – without apparent relationship to the habitat conditions.

Nevertheless, where such data exist for a specific lagoon, then it is relatively straightforward to define “good condition”, based on an assimilation of the habitat history as well as an understanding or the range of variation present naturally in the lagoon, both as shown by the community and as shown by the environmental conditions.

In other words, for any lagoon, a baseline of conditions is required against which it is possible to judge (or arbitrarily define) what is likely to be the “worst-state” of “good condition”; thereafter it is possible to assess whether the site is maintaining condition, declining or improving. From the foregoing, this baseline state is likely to be different for each lagoon, or at least different for a large number of subgroups of lagoon – not necessarily geographically associated.

In defining a suitable typology of classes of lagoons, the standard five physiographic types defined under the UK HAP are not entirely appropriate. Critical characters are the degree of water exchange (quantity and frequency), the degree of freshwater input (which may be only rainfall), the size and aspect-ratio of the basin (insofar as it affects the water turbulence and mixing – see Bamber *et al*., 1992) and the latitude and longitude (insofar as that affects the biogeography of the species likely to be present). Equally, the salinity regime of the saline-water source will influence that of the lagoon, and the local tidal range, along with the tidal height of any weir or sill, will influence the degree of water exchange on each tidal cycle.

It is considered that data available at present do not allow such a typology at present.

7.2 "Good" and "bad" lagoons.

The analysis shown in Figure 6 affords the opportunity to compare what are currently accepted as good or poor lagoons. The data derive from quantitative samples (0.05 m^2) of the benthos, sieved across a 0.5 mm mesh, and the analysis is based on a standardized set of 43 species.

"Carew" is a freshwater sample; "InlSea" is a paralagoonal estuarine sample (not a lagoon).

Cluster A is of higher salinity lagoons, divided into subcluster A1 – "good" lagoons and subcluster A2 – "poor" lagoons. These lagoons are dominated by chironomids and the oligochaete *Tubificoides pseudogaster*, and characterized by a diversity of peracarid crustaceans (isopods and amphipods) and the presence of the lagoon cockle (*Cerastoderma glaucum*); the subcluster A2 sites had poor or no populations of these crustaceans nor the lagoon cockle. The A2 sites generally have a lower salinity regime than do the more ideal A1 lagoons.

Cluster B is of lower salinity lagoons, divided into subcluster B1 – "good" lagoons and subcluster B2 – "poor" lagoons. These lagoons are dominated by chironomids, ragworm (*Hediste diversicolor*) and the oligochaete *Heterochaeta costata*, and characterized by a diversity of molluscs, including the cockle and hydrobiid snails, while the only characterizing amphipod is *Corophium volutator*; the subcluster B2 sites lack the molluscan diversity.

While salinity is evidently the driving parameter in these lagoonal communities, it is not the only one. Departure from the "good" standard may be the result of a number of factors, such as the age of the lagoon (the time available for colonization), the hydrodynamics of the lagoon (higher rates of water-mixing preclude certain species from the community), and zoogeography.

A second community within the lagoons is that of the submerged plants (the ENLag.Veg biotope of Bamber, 1007). The good lagoons tend to support submerged *Chaetomorpha linum* (where the salinity is high enough) and tasselweeds (*Ruppia* spp.), as well as opportunistic annual algae such as *Enteromorpha* and *Cladophora* species. Clearly associated with these plants are many of the amphipods and isopods in lagoons, as well as hydrobiid snails, a species of nemertean, and juvenile lagoon cockles.

The presence and diversity of this biotope again accords with the "good" and "poor" lagoons shown in Figure 6. Unfortunately, a similar analysis is not possible owing to the difficulty of obtaining quantitative samples of this habitat.

Nevertheless, the presence or absence of this biotope, and its species richness, may offer a proxy indicator of whether a lagoon is "good" or "poor".

7.3 Application of the Infaunal Quality Index (IQI) to coastal saline lagoons.

The Infaunal Quality Index (IQI) is used as an ecological classification index for benthic communities within the Water Framework Directive, from which to determine “good” ecological status (or otherwise). It is necessary to address the IQI in terms of its applicability to lagoons.

The IQI is derived from three community statistics, the AZTI Marine Biotic Index (AMBI), Simpson’s Evenness (1-λ’), and the number of taxa (S). These individual components (metrics) have been weighted and combined within the multimetric, in an attempt to describe best the changes in the benthic invertebrate community resulting from anthropogenic pressure.

Looking at its components:

(a) AMBI (Borja *et al.* 2000) describes the response of soft-bottom communities to man-induced changes based on the proportions of individual abundance in five ecological groups, which are related to the presumed degree of sensitivity/tolerance of a species to an environmental stress gradient, specifically organic content. It assumes that opportunistic species are more tolerant. In practice the tolerance of most species is not known, but is assumed from the circumstantial evidence of their occurrence in relation to organic gradients, or from the assumed tolerance of *closely-related species*.

As described above (2.6), coastal saline lagoons are naturally organically richer than comparative habitats (hypertrophic), and the species living within them are naturally adapted to such conditions. Thus, deriving their tolerance from closely-related species is irrelevant: the lagoon cockle, *Cerastoderma glaucum*, is a sibling species to the edible cockle, *C. edule*, yet the latter does not tolerate lagoonal conditions, and should be more highly ranked on an AMBI score; however, all *Cerastoderma* species are scored as III. Similarly, all *Corophium* species have a ranking of III, despite the lagoonal specialist *C. insidiosum* being less tolerant of poor (highly organic) sediment conditions than *C. volutator*, while *C. affine* is intolerant of such conditions.

This reflects a further issue with the AMBI, that is the truncation of the species list for analysis. As well as previous examples, there are differential presences of closely-related species within lagoons, for example oligochaetes (see above), yet all oligochaetes are ranked V on the AMBI scale. It may, however, be appropriate to remove chironomids from the analysis, as distinguishing them to the species level (to discern their environmental tolerance) is prohibitively difficult as larvae, and their aerial access suggests that their presence may well be independent of ecological status.

Having said that, there is a case for ranking all lagoonal species at III, which would preclude the sensible use of the Index.

(b) Evenness is a measure of the distribution of individuals across the species complement (thus a measure of dominance). Higher evenness (lower dominance) is presumed to be one component of higher diversity (see also Shannon-Weiner diversity, which integrates evenness and species richness). Lagoonal communities are commonly of low diversity (owing to their low species richness), but those species present are equally commonly in high abundance. Lagoonal communities will always have a low evenness.

The Simpson’s Index ranges from 0 (very low evenness, total overdominance – “bad”) to 1 (high evenness, low dominance – “good”). Looking at the lagoons used in the analysis for

Figure 6, the Simpson's index for higher salinity lagoons ranges from 0.33 to 0.83 for the good A1 lagoons, and from 0.05 to 0.60 for the poor A2 lagoons; similarly the ranges for the lower salinity lagoons are 0.63 to 0.83 for the good B1 lagoons, and 0.22 to 0.80 for the poor B2 lagoons: i.e. there is broad overlap in all categories. Note that the index for the paralagoonal estuarine site InlSea is 0.87.

This index would therefore not be expected to contribute to a classification of lagoonal ecological status.

(c) The number of taxa within a lagoon is commonly low in comparison with habitats such as estuaries or rock pools, but is also unpredictable owing to the serendipity of colonization. Again, analyzing the data for Figure 6, the number of taxa for higher salinity lagoons ranges from 6 to 15 for the good A1 lagoons, and from 2 to 4 for the poor A2 lagoons; similarly the ranges for the lower salinity lagoons are 8 to 15 for the good B1 lagoons, and 3 to 10 for the poor B2 lagoons. There is better distinction here than was found for evenness, although still some overlap.

Note that the number of taxa for the paralagoonal estuarine site InlSea is 25. Thus the apparently inevitable low species richness found even in "good" lagoons would tend to define them as of poor ecological status, even without any deleterious anthropogenic organic impact.

The Figure 6 data, together with more recent data from Cemlyn and Pickleridge Lagoons, were analyzed using the IQI by Lucie Oliver (CCW). The results are shown in Figure 7.

Notably, all of the lagoonal sites fall between the Moderate and Bad boundaries, generally averaging around the Moderate / Poor boundary. As a generality, the "Good" lagoons tend to lie at or above this boundary, the "Poor" lagoons at or below it, suggesting that there is some concordance with ecological perceptions of the sites.

Examination of the IQI data sheet confirms that these comparatively low IQI scores are caused by the relatively low numbers of taxa in the community, and by the dominance of a few of these Group III 'tolerant' taxa, both normal attributes of a saline-lagoonal community.The Infaunal Quality Index thus appears to be inappropriate as an ecological classification index for lagoonal benthic communities when based on generalized rules derived from other saline habitats, as it would give a low range of distinction, and tend to classify all lagoons as "poor". Whether redefining quality boundaries for saline lagoons would work is open to debate, as there is no clear distinction in the results shown in Figure 7.

8. What can we conclude for coastal saline lagoons?

The spirit of the Water Framework Directive is to determine a yardstick for a given habitat (or site), against which its conditions at present or in the future may be judged

The environmental conditions, and to a lesser degree the associated community of coastal saline lagoons are variable, and both are, to an extent, unpredictable.

The inevitable conclusion is that, as a starting position, **"good condition" must be defined on a site-specific basis for each lagoon**, and this condition must include the range of variation experienced naturally.

Subsequently, where it is found that associated lagoons, perhaps those which are contiguous, have the same baseline of good condition, then **lagoons may be grouped** for more efficient management assessment.

Note that normative definitions of ecological-status classifications become challenging when assessing whether "biological quality elements" deviate slightly, moderately or substantially from those "normally associated" with the lagoon under "undisturbed conditions", owing to the degree of the natural variability of these habitats.

Given this basis, we may then consider the specifics under the Water Framework Directive in terms of the coastal saline lagoon habitat – irrespectively of whether they occur as transitional waters or coastal waters.

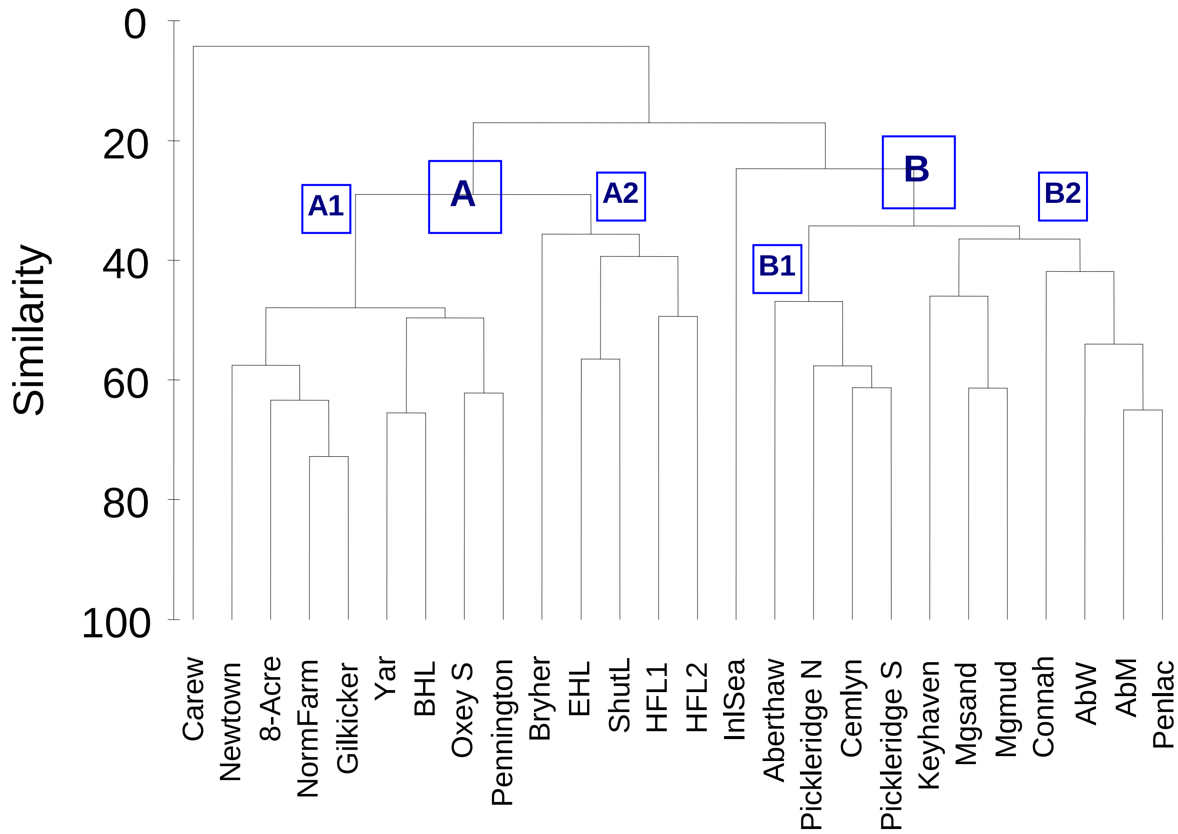

Fig. 6. Multivariate community analysis of the benthos of twenty-six lagoons or paralagoonal habitats, showing higher-salinity (A) and lower-salinity (B) clusters, and subclusters referred to in the text.

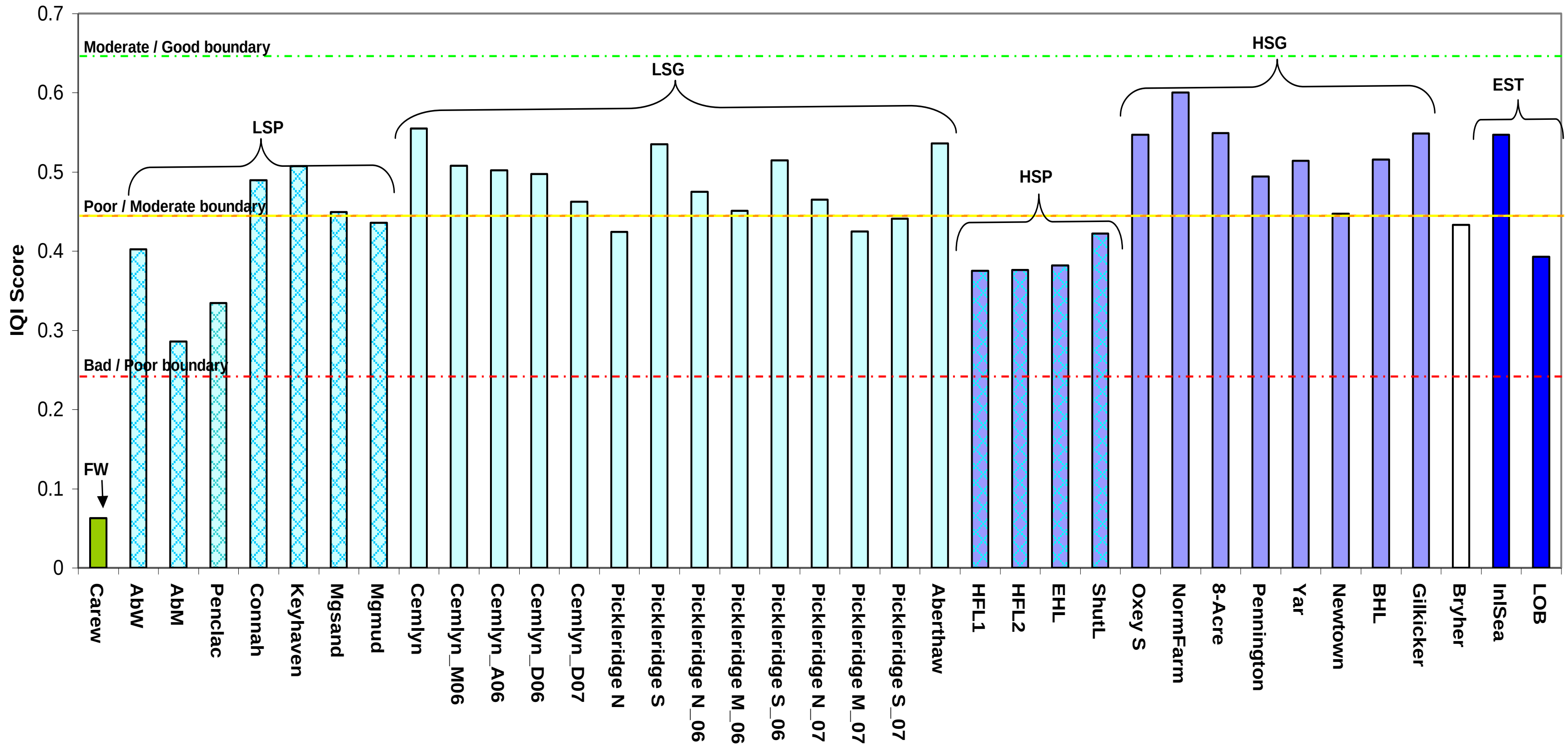

Fig. 7. IQI analysis of the twenty-six lagoons or paralagoonal habitats shown in Fig. 6, plus more recent samples from Pickleridge and Cemlyn, showing higher-salinity (HS) and lower-salinity (LS) sites, separated into "good" (suffix G) and "poor" (suffix P) lagoons. Fw – freshwater; EST – estuarine. The IQI Good – Moderate – Poor boundaries derived from the WFD assessment of fully-marine muddy-sands / sandy-muds are shown.

9. Annex V of the Water Framework Directive

9.1 Section 1.1 Quality elements for the classification of ecological status

Biological elements

Composition and abundance of submerged aquatic flora, when present

Composition and abundance of the fauna associated with the submerged aquatic flora, when present

Composition and abundance of benthic invertebrate fauna

Composition and abundance of nektonic crustaceans [where specialist species have been recorded; this may be regarded as not necessary, largely relating as it does to the conservation of a single species, *Paramysis nouveli*]

Note that it is not considered of any value to monitor or judge the phytoplankton or fish fauna of a lagoon.

Hydromorphological elements supporting the biological elements

Hydrological regime

Quantity and dynamics of saline water exchange

Quantity and dynamics of freshwater input and output

Turbulence (water-mixing)

Morphological conditions

Structure and integrity of the lagoon banks

Structure and integrity of the saline-water inlet/outlet

Chemical and physico-chemical elements supporting the biological elements

General

Salinity, including range

Specific pollutants

Pollution by all priority substances identified as being discharged into the body of water

Pollution by other substances identified as being discharged in significant quantities into the body of water

Note that it is not considered necessary to monitor or consider nutrient loading (although subjective circumstantial evidence suggests an upper limit of 1.0 $mg.l^{-1}$ phosphate for the survival of charophytes), nor pH (which can naturally range from <7 to >9 in lagoons without deleterious impact), nor temperature (again showing a wide natural variation, including surface freezing), nor turbidity (rarely an issue in the low hydrodynamics conditions of lagoons).

9.2. Section 1.2 Normative definitions of high, good and moderate ecological status

General: deviation must be defined/assessed in the light of the site-specific history and wider experience of lagoonal habitat variability.

Biological quality elements

Element	High status	Good status	Moderate status
Submerged aquatic flora [including both algae and seagrasses]	The taxonomic composition is within the range associated with undisturbed conditions for the lagoon. The macrophyte abundance is within the range associated with undisturbed conditions for the lagoon.	There are slight changes in the composition and abundance of the submerged macrophyte species compared with the ideal site-specific community. [Annual algae may not recur, tasselweeds or *Chaetomorpha* may be reduced in area/volume, or show reduced condition]	There are moderate changes in the composition and abundance of the submerged macrophyte species compared with the ideal site-specific community. [Annual algae may not recur, tasselweeds or *Chaetomorpha* may be absent or show poor condition]
Fauna associated with the submerged aquatic flora	The taxonomic composition is within the range associated with undisturbed conditions for the lagoon. The level of diversity of invertebrate taxa is within the range associated with undisturbed conditions for the lagoon.	There are slight changes in the composition and diversity of the fauna associated with the submerged macrophyte species compared with the ideal site-specific community. [Certain species may be reduced in abundance or frequency around the lagoon]	There are moderate changes in the composition and diversity of the fauna associated with the submerged macrophyte species compared with the ideal site-specific community. [Certain, but nor all, species may be absent]
Benthic invertebrate fauna	The taxonomic composition is within the range associated with undisturbed conditions for the lagoon. The level of diversity of invertebrate taxa is within the range associated with undisturbed conditions for the lagoon.	There are slight changes in the composition and diversity of the benthic invertebrate fauna compared with the ideal site-specific community. [Certain species may be reduced in abundance or frequency around the lagoon]	There are moderate changes in the composition and diversity of the benthic invertebrate fauna compared with the ideal site-specific community. [Certain, but nor all, species may be absent, or with reduced reproduction]

Nekton	The species associated with undisturbed conditions for the lagoon are present in successful breeding populations.	There are slight changes in the composition, density and condition of the species associated with undisturbed conditions for the lagoon [species are present but in reduced numbers]	There are moderate changes in the composition, density and condition of the species associated with undisturbed conditions for the lagoon [species are present but in very reduced numbers, or with reduced reproduction.]

Poor status for these elements would be indicated by significant reduction in diversity, significant losses of species.

Bad status would be indicated by absence of most or all species, failure in reproduction.

Hydromorphological quality elements

Element	High status	Good status	Moderate status
Hydrological regime: Quantity and dynamics of saline water exchange	The quantity and dynamics of the saline-water flow into and out of the lagoon correspond totally or nearly totally to undisturbed conditions for the lagoon.	There are slight changes in the quantity and dynamics of the saline-water flow into and out of the lagoon compared with the undisturbed conditions for the lagoon. [the salinity of the lagoon approaches the acceptable limits of the range of that lagoon for a significant proportion of the time]	There are moderate changes in the quantity and dynamics of the saline-water flow into and out of the lagoon compared with the undisturbed conditions for the lagoon. [the salinity of the lagoon exceeds the acceptable limits of the range of that lagoon for a significant proportion of the time]
Hydrological regimes: Quantity and dynamics of freshwater input and output	The quantity and dynamics of the freshwater flow into and out of the lagoon correspond totally or nearly totally to undisturbed conditions for the lagoon.	There are slight changes in the quantity and dynamics of the freshwater flow into and out of the lagoon compared with the undisturbed conditions for the lagoon. [the salinity of the lagoon approaches the acceptable limits of the range of that lagoon for a significant proportion of the time]	There are moderate changes in the quantity and dynamics of the freshwater flow into and out of the lagoon compared with the undisturbed conditions for the lagoon. [the salinity of the lagoon exceeds the acceptable limits of the range of that lagoon for a significant proportion of the time]
Hydrological regime: Turbulence (water-mixing)	The degree of wave- or wind-induced water-turbulence correspond totally or nearly totally to undisturbed conditions for the lagoon.	There are slight increases in the degree of wave- or wind-induced water-turbulence compared with the ideal site-specific conditions for the lagoon. [the water quality parameters show reduced variation with space or time]	There are moderate increases in the degree of wave- or wind-induced water-turbulence compared with the ideal site-specific conditions for the lagoon. [the water quality parameters show little variation with space or time]
Morphological conditions. Structure and integrity of the lagoon banks	The structure and integrity of the lagoon banks are in such a condition that they maintain totally or nearly totally the extent and integrity of the undisturbed conditions for the lagoon.	There are slight changes in the structure and integrity of the lagoon banks compared with their normal status for the lagoon, which threaten the extent of or integrity of undisturbed conditions for the lagoon. [the banks of the lagoon show signs of degradation which may lead to loss of habitat or interruption of habitat conditions]	There are moderate changes in the structure and integrity of the lagoon banks compared with their normal status for the lagoon, which interfere with the extent of or integrity of undisturbed conditions for the lagoon. [the banks of the lagoon show signs of degradation which are leading to loss of habitat or interruption of habitat conditions]

Morphological conditions. Structure and integrity of the saline-water inlet/outlet	The structure, function and integrity of the saline-water inlet/outlet are in such a condition that they maintain totally or nearly totally the extent and integrity of the undisturbed conditions for the lagoon, particularly the salinity regime.	There are slight changes in the structure, function and integrity of the saline-water inlet/outlet compared with their normal status for the lagoon, which threaten the conditions of the lagoon. [the salinity of the lagoon approaches the acceptable limits of the range of that lagoon for a significant proportion of the time]	There are moderate changes in the structure, function and integrity of the saline-water inlet/outlet compared with their normal status for the lagoon, which threaten the conditions of the lagoon. [the salinity of the lagoon exceeds the acceptable limits of the range of that lagoon for a significant proportion of the time]

Physicochemical quality elements

Element	High status	Good status	Moderate status
Salinity, including range	The salinity range within the lagoon corresponds totally or nearly totally to undisturbed conditions for the lagoon.	There are slight deviations in the salinity range within the lagoon compared with the undisturbed conditions for the lagoon. [the salinity of the lagoon approaches the acceptable limits of the range of that lagoon for a significant proportion of the time]	There are moderate changes in the salinity range within the lagoon compared with the undisturbed conditions for the lagoon. [the salinity of the lagoon exceeds the acceptable limits of the range of that lagoon for a significant proportion of the time]
Pollution by all priority substances identified as being discharged into the body of water	Concentrations close to zero or at least below the limits of detection of the most advanced analytical techniques in general use	Concentrations not in excess of the standards set in accordance with the procedure detailed in Water Framework Directive section 1.2.6 without prejudice to Directive 91/414/EC and Directive 98/8/EC (<EQS)	Conditions consistent with the achievement of the values specified above for the biological quality elements [NB lagoonal ecosystems are believed to be generally more tolerant of pollutants than other ecosystems]
Pollution by other substances identified as being discharged in significant quantities into the body of water	Concentrations remain within the range normally associated with undisturbed conditions (Background levels = bgl) [NB lagoonal ecosystems are believed to be generally more tolerant of pollutants than other ecosystems]	Concentrations not in excess of the standards set in accordance with the procedure detailed in Water Framework Directive section 1.2.6 without prejudice to Directive 91/414/EC and Directive 98/8/EC (<EQS)	Conditions consistent with the achievement of the values specified above for the biological quality elements [NB lagoonal ecosystems are believed to be generally more tolerant of pollutants than other ecosystems]

Poor status would be indicated by the habitat conditions being predominantly outside the range of "undisturbed conditions for the lagoon" and being such that they would continue to deteriorate without remedial action, bad status that they already have deteriorated to conditions outside those typical of the "normal, undisturbed" conditions for the lagoon.

Thus, salinity would be predominantly outside the range of 10 to 30‰ for lower salinity lagoons, or 20 to 40‰ for higher salinity lagoons, for example because of a failure in the integrity of the saline-water inlet/outlet, or other change in the saline-water exchange. Disruption of the lagoon-bank integrity allows loss of water, and thus sublittoral habitat, or reduced isolation from adjacent freshwater sources. Destruction of surrounding structure, or widening of the inlet may enhance wind- or wave-induced turbulence, mixing the waters and removing the stress-conditions considered important for the success of lagoonal species.

9.3 Section 1.2.6 Procedure for the setting of chemical quality standards by member states

Care needs to be taken over the criteria used for these standards. It is known that lagoonal species (all of those categorized in species suites II, III, IV and V of Bamber *et al*., 1992) are stress-tolerant, and thus more tolerant of environmental stressors than are species from estuaries or the open sea. However, data on pollution tolerance are absent for many of these species, and for any of the lagoonal specialists (although some data may be available for the starlet sea-anemone, *Nematostella vectensis*, which is used for laboratory-based pollution-monitoring and toxicology in the USA). Thus, while EQSs may exist for closely related (congeneric) species, they are likely to be more stringent than is necessary for lagoonal specialist species.

While this suggests that such EQSs will more than protect the species of concern in lagoons, adherence to them may require excessive response to impacts, and thus excessive costs.

9.4 Section 1.3 Monitoring

Overall monitoring as suggested in Section 1.3 of the Water Framework Directive is applicable.

However, again the inherent natural variability of the habitat must be appreciated. Some degree of intensive monitoring is thus required. Fore example, the pattern of salinity around a tidal cycle, as well as between wet and dry seasons, needs measurement.

Equally, as comparatively small habitats, vulnerable to interference with the saline-water inflow/outflow, lagoons are sensitive to threats to their integrity in the short term. In fact, the wording of Section 1.3.4 of the Water Framework Directive does account for this.

There has long been debate over the timing (frequency) of monitoring, owing to the conflict between increased frequency and increased costs. The optimal answer is – as frequently as possible. The standards laid down in the table of Section 1.3.4 of the Water Framework Directive for the four surface-water habitats defined within the objective are not ideal for lagoons.

As stated above, monitoring of phytoplankton is irrelevant.

Triennial monitoring of the other biological components is likely to be too infrequent: annual would be a minimum suggested requirement.

Six-yearly monitoring of the morphology is too infrequent: annual would be a minimum suggested requirement.

Monitoring of thermal conditions, oxygenation, nutrient status and acidification are probably entirely unnecessary. The suggested regime for other physico-chemical parameters appear adequate, and hydrology should be monitored on a similar basis.

Protocols for monitoring coastal saline lagoons are given as Section 5 in Bamber *et al*. (2001). These protocols cover techniques, targets and timing. They are distinct from, for example, the EA protocols for benthic or plant-associated sampling and processing, as those are not as appropriate to lagoons, nor do they prioritize sufficiently the minimal disturbance necessary for the sensitive lagoonal habitats and species.

It is important to remember that some of the species present in lagoons are protected under Schedules 5 and 8 of the Wildlife & Countryside Act, and any monitoring which involves taking or killing of these species, or interference with their habitat, can only be undertaken under the aegis of an appropriate Licence (obtainable from CCW or NE).

Equally, it is important that the fauna (other than chironomids) is distinguished to species level, as there is relevance to the presence or absence of a number of similar species, such as the sibling species of cockles, the four or five species of hydrobiids potentially occurring in lagoons, and the congeneric amphipods (*Corophium* and *Gammarus* species) or isopods (*Lekanesphaera* or *Idotea* species). Valuable texts for identification of the species likely to occur in lagoons are available, for example Barnes (1994), Graham (1988) and Lincoln (1979). In the context of non-specialist staff being involved in Water Framework Directive monitoring, there is a clear requirement for training.

10. Monitoring considerations

There are some feasible baseline considerations in relation to Water Framework Directive monitoring for coastal saline lagoons.

Initially, the integrity of the lagoon itself needs to be established (qualitative physical assessment):

- does the lagoon contain water (the lagoonal community is *sublittoral*)?
- are the surrounding banks of the lagoon in normal good condition?
- is the sluice/weir/inlet operating within its required bounds (i.e. maintaining but not exceeding the required exchange of water)? Note that this category may include percolation springs.
- is there any apparent anthropogenic interference to the normal condition of the lagoon?

The water quality is hard to assess on a one-off visit. As a minimum, the salinity needs to be measured: if the salinity lies outside the normal required range for good condition of the habitat, a requirement for more intensive monitoring may be indicated (note the previous weather conditions).

The submerged plants of the lagoon should be assessed visually (presence/absence, abundance, condition), appreciating the seasonal decline in condition of, for example, tasselweeds. The associated fauna can be qualitatively assessed visually and in situ, returning the material to the lagoon (unless certain species, such as *Gammarus* spp., need microscopic examination). In a good lagoon, there should be a diversity of amphipods, isopods and molluscs associated with the plants.

The benthic fauna requires sampling and processing; the standard technique involves a 0.05 m^2 sample (e.g. 10 cores of 0.005 m^2), sieved across a 0.5 mm mesh (a 1.0 mm mesh is too coarse). It may be necessary to sample at more than one location within the lagoon, owing to size of the lagoon, or to patchiness of the habitat. Species (other than chironomids and enchytraeid oligochaetes) should be distinguished to species. However, indications of an appropriate diversity of peracarid crustaceans or of molluscs may be considered a valuable standard for good ecological status (see 7.2 above).

Sampling strategy should relate to previous surveys of the lagoon, if any.

To repeat, sampling should be carried out only with a licence, unless there are very good reasons to presume that no scheduled species will be present.

Monitoring of the fish species is pointless. The fish species occurring in lagoons (typically three-spined stickleback, common goby [*Pomatoschistus microps*], European eel, mullet and flounder) are serendipitous, and typical of estuarine habitats. Their presence or absence is not indicative of ecological status.

The only nektonic species of note is the mysid *Paramysis nouveli*, which appears to be rare and restricted to lagoons in the UK: some net-sweeping is in order if mysids are observed in the water column, but common estuarine species such as *Praunus flexuosus* and *Neomysis integer*, neither of which is indicative or ecological status, are the likely inhabitants.

Monitoring of plankton is pointless: the benthic species characteristic of lagoons do not have a significant planktonic larval phase; there are no known species of the holoplankton (the permanent plankton, including copepods, cladocerans, dinoflagellates, etc.) which are either characteristic of lagoons or indicative of ecological status; phytoplankton blooms are a normal occurrence in lagoons, but the species responsible are unknown (unstudied).

11. Conclusions

Overall, the Water Framework Directive was formulated without consideration for the particular conditions of coastal saline lagoons, viz. their inherent variability over ranges of scale and duration, both in space and in time, which are not experienced in other aquatic habitats. A similar conclusion was alluded to (but not confidently stated) by contributors to the congress on European transitional waters held in Naples in November 2007 (see Cognetti & Maltagliati, 2008, *et. seq*.).

Perhaps owing to their geographic isolation, even given a similar habitat regime, the community present in lagoons is only predictable in the vaguest sense, and the species present show stochastic variation in both recruitment and occurrence. Conversely, by their very nature, the species concerned are more tolerant of environmental stress.

Therefore, it is possible to reformulate the standards laid down in the Water Framework Directive to be appropriate to coastal saline lagoons, while remaining within the spirit of that Directive. This is what has been attempted above. However, the detail of the comparators for each site – i.e. the "undisturbed conditions" for the lagoon – must be defined on a site-specific basis, and therefore have only been defined loosely herein.

Equally, a wider understanding of variability in both habitat conditions and community structure may be a necessary referent for addressing the degree of change which is acceptable before the status of the habitat drops from one status category to another.

Having said that, it should be possible to formulate a preliminary site-assessment protocol based on the considerations listed in section 10 above, from which to determine the necessity of more intensive monitoring.

Differences between the Water Framework Directive assessment criteria and those under the "Habitats Directive" relate purely to the presence and condition of scheduled species in the lagoons. However, ideal habitat conditions for those species do not differ significantly from those required by other lagoonal taxa. While the presence or absence of specialist species might be considered outside the terms of the Water Framework Directive, in fact this is a non-sequitur, as the species present in any habitat are specialists to that habitat, and, to risk a circular argument, the plant and animal species present in lagoons are almost inevitably largely specialists to that habitat.

Finally, it must be appreciated that lagoons by their very nature are naturally temporary habitats, and some decline in their status is inevitable with time, and on a shorter timescale than may be the case for freshwater lakes or estuaries. The implications of this natural decline in condition over time are beyond the scope of this assessment.

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PLATE 1. Bryher Lagoon, Scilly Isles.

Annex 1

Summary Note of Workshop on Coastal Lagoons and the WFD

Tuesday 21st October 2008. Natural England, Northminster House, Peterborough.

Attendance

Roger Bamber (Assoc. Natural History Museum), Michael Coyle, Ian Reach Stewart Clarke, Graham Weaver, Glen Cooper, Sue Rees, Conor Donnelly (Natural England), Alison Miles, Steve Coates, Graham Phillips, Steve Colclough (Environment Agency), Lucy Oliver (CCW/EA), Stewart Angus (SNH), Michael McAliskey, Peter Moorehead, Stephanie Bennet (NIEA), Naveed Bhatti (SEPA), Bernard Dudley (CEH), Robert Wikes (Irish EPA)

Aim

The aim of the workshop was to bring together a broad range of scientific experts to discuss how coastal lagoons can be classified under the Water Framework Directive.

The day was split into two parts. Firstly, a session which described what lagoons are, where they occur, why they are important, and how they are currently monitored and assessed under conservation drivers. The second session explored the requirements of the Water Framework Directive, the challenges to meet those requirements for lagoons, and discussions on how to take this work forward.

Session 1: Definition of coastal lagoons and how conservation agencies assess condition.

Introduction to coastal lagoons and how SSSI / N2K condition is assessed in England

(Ian Reach, Natural England)

This presentation provided an overview of how coastal lagoons are defined and typed according to the degree (and mode) of exchange with sea water. There are approximately 5200 ha of coastal lagoon in the UK making it a relatively scarce habitat. Importance is reflected by the fact that they are priority habitats under Annex 1 of the Habitats Directive (SAC features), support birds of international importance (SPAs), notified as SSSIs, BAP priority habitats, and often contain species protected under schedules 5 & 8 of The Wildlife & Countryside Act, as amended.

Of particular conservation interest, is the (lagoonal) specialist species living in these habitats.

Monitoring and reporting the condition of lagoons is undertaken through the JNCC common standards monitoring (CSM) guidance. This requires a consideration of a lagoons physical structure (eg extent), its chemical composition (eg salinity) and biotopes. Currently in England, only 7% of coastal lagoons are reported to be in unfavourable condition. Known pressures include coastal squeeze, inappropriate coastal management, and diffuse pollution.

Assessing condition of SSSI/N2K coastal lagoons in Wales

Lucy Oliver (Countryside Council for Wales / Environment Agency)

This presentation identified the location of lagoons distributed throughout Wales. Three (of the six) SAC lagoons are subject to relatively intense monitoring. The remainder of the presentation focused on the case study of Cemlyn lagoon (situated in Anglesey). This lagoon is monitored in order to provide a baseline data set, assess temporal and spatial variability of this habitat, and inform management.

Data are available from CCW's continuous data loggers collecting physico-chemical parameters, in addition to annual biological monitoring. Some of the conclusions from the monitoring were that:

- Salinity is highly temporally variable and it is not possible to assess condition based on this alone. The data validate the requirements to use continuous data loggers rather than relying on spot samples
- Benthic invertebrate community data are also highly variable although lack of significant structure suggests that the lagoon is home to a single community. Given the spatial variability, it appears appropriate to continue monitoring at the 3 CCW stations.
- It is still difficult to make practical management decisions based on biological and chemical data collected.

Session 1: Summary points from discussions

- It should be noted that work under the WFD will create more lagoons. Lagoon creation has historically focused on providing habitats for birds, but lagoons can also be created with fisheries in mind.
- The Environment Agency (EA) is also considering the use of barriers with adjustable sluices, to enable a small controlled amount of "leakage" which could improve habitat conditions for certain species.
- It was re-iterated that salinity can reach massive levels in lagoons (>40psu), depending on the season and the nature of the hydrological regime (exchange). This will have an impact on "type-based reference conditions".
- In Scotland, monitoring is not focused on specialist species (as it should be) and there is a real need to understand where these species are, where they are under threat, and how lagoons will adapt to climate change (from isostatic rebound).
- In Northern Ireland, the NIEA is monitoring (3) lagoon water bodies using WFD classification tools.
- The group agreed that just because current WFD classification tools may not be for the purpose of assessing lagoons, this should not be used as a barrier for monitoring and collecting data. This is consistent with logic applied to lakes under the WFD. Boundary criteria which delineate "classes" may be different, but monitoring methods are agreed and consistently applied.
- Clarification was sought on whether CSM data are in a standardized format ie can EA use data which have been consistently gathered by the UK conservation agencies. It was clarified that the JNCC CSM provides a framework for monitoring and assessment, but there will be variations in local application, and hence collection of data.

Session 2: Presenting the NHM study

Background to study on coastal lagoons and the WFD

Michael Coyle (Natural England)

This presentation outlined the requirements of the WFD in relation to coastal lagoons. Coastal lagoons can be "protected areas" – if they are components of water-dependent N2K sites. The objectives would be to achieve favourable conservation status. In addition, lagoons could be "water bodies" if judged to be "significant or discrete". Water bodies are required to reach good ecological status. Whether they are protected areas or water bodies, the WFD requires lagoons to be monitored assessed and reported against.

Monitoring and assessment of lagoons under conservation drivers are currently not WFD compliant. WFD classification tools developed for transitional and coastal waters may not be appropriate for lagoons. In which case, there was a need for considering how lagoons should be monitored under the WFD and whether there was scope in integrating assessments which could serve the requirements of both directives.

Presentation of Coastal lagoons and the Water Framework Directive

Roger Bamber (Scientific Associate of the Natural History Museum)

This presentation considered how lagoons fit in the WFD, identified some key issues, and suggested how lagoons should be assessed. The key points to note (which are expanded on in the final report) were:

Key issues:

- The environmental conditions in lagoons are inherently extremely variable, in space and time, in the short to long term. Such variation is unique to lagoons.
- This variability imparts severe environmental stresses, which itself, is responsible for the development of a specialist community in lagoons.
- These specialist species are mainly restricted to certain stretches of the UK coastline, probably owing to zoogeographic considerations rather than availability of habitat.
- The process of recruitment to lagoons is unknown. Therefore, the suite of species present in any given lagoon is unpredictable.
- The essential habitat of coastal saline lagoons is sublittoral.

Lagoons and the WFD:

- Lagoons do not fit easily within the descriptions of water body characteristics; however, within the spirit of the WFD they can be classed as "transitional or coastal".
- With regard to lagoon "type" they can be classed as euhaline and polyhaline (ideally 20 to 40), microtidal and shallow.
- The majority of lagoons are "artificial water bodies", and may be physically modified, but not "heavily modified water bodies".
- As a starting position, "good condition" must be defined on a site-specific basis for each lagoon, and this condition must include the range of variation experienced naturally.
- Where it is found that associated lagoons have the same baseline of good condition, then lagoons may be grouped for more efficient management assessment.
- In assessing the lagoon, its physical integrity must first be established (qualitative assessment). For example, does the lagoon contain water? Are the surrounding banks of the lagoon in normal good condition? Is the sluice/weir/inlet operating within its required bounds (maintaining

required exchange of water)? Is there any apparent anthropogenic interference to the normal condition of the lagoon?

- Current WFD tools used to classify benthos would be expected to give a "pessimistic" view of a lagoon's benthic quality. This is because it is expected that lagoons will naturally be organically enriched, have low diversity and low taxa counts.
- It is possible to reformulate the standards laid down in the WFD to be appropriate to coastal saline lagoons, while remaining within the spirit of that Directive. However, the detail of the comparators for each site – i.e. the "undisturbed conditions" for the lagoon – must be defined on a site-specific basis.
- It was considered that fish were not an appropriate quality element to monitor: the fish present in smaller lagoons are opportunistic, common species (3-spined stickleback; flounder; eel), and their presence is not an indicator of quality.
- Finally, it must be appreciated that lagoons by their very nature are naturally temporary habitats, and some decline in their status is inevitable with time, and on a shorter timescale than may be the case for freshwater lakes or estuaries

Session 2: Summary points from discussions

- The EA has undertaken further work on applying the WFD benthic classification tool to coastal lagoons. The results were compared with an expert opinion on which lagoons were considered "good" and "poor". The EA confirmed that results based on the WFD tool did give an overly pessimistic view, however, results largely agreed with the quality split identified through expert opinion. It was considered that with further refinement of the WFD tool, there was scope for the tool to be applied to lagoons. The EA made a plea for any data to help assist with further testing.
- The EA questioned the assertion that fish were not an appropriate quality element to measure. Some lagoons will provide important nursery grounds for fish and would benefit from certain level of protection. It was agreed that this reflects how site specific assessment and management may be required.
- It was observed that variability is also a characteristic of lakes. The WFD Lakes task team has acknowledged this by advising that some targets will be required to be site-specific.
- The technical groups implementing the WFD need to review Annex II 1.3, which allows for biological quality elements to be dropped from classification if there is a large natural variability, and setting of reference conditions is not possible. The group acknowledged that setting reference conditions are possible, but at the site level.
- Further work could be undertaken to establish additional "types" which could further tackle the issue of variability and lead to the development of common reference conditions. This required a comprehensive collation of all available data (physical, chemical and biological) to identify parameters which drive biological distributions.
- There was scope to consider paleoecological studies which could be used to hindcast and identify the historic biological quality with associated physico-chemical conditions. This could inform the setting of reference conditions.
- The group discussed that a pragmatic approach may need to be taken with lagoons. Although, classification of ecological status is challenging, this should not prevent competent authorities in managing pressures to prevent deterioration, and in some cases allow restoration - particularly if physical structures are causing obvious adverse effects (eg loss in extent). One suggestion was that competent authorities could focus primarily on operational / investigative monitoring.
- The group discussed whether the UK could be informed by other EC member states work in assessing lagoons. However, the UK has a particular type of (smaller) lagoons, which are not common elsewhere in Europe.

- Monitoring resource – This is always likely to be an issue, with currently only approximately 25% of water bodies will be monitored in the UK.

Summary of Workshop conclusions and next steps

- WFD classification tool requirements for lagoons will continue to be developed through the UK TAG marine task team. Future work is likely to include:
    - Collation of all relevant monitoring data available to inform status in first river basin plans;
    - Consideration of further research to identify potential typologies.
    - Further testing and refining of the WFD IQI tool;
- More direct links should be made with The UK Saline Lagoon Working Group to discuss future research proposals.