Seasonal changes

and biological classification

of Irish coastal lagoons.

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Seasonal changes and biological classification of Irish coastal lagoons

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Abstract

Surveys of coastal lagoons in Ireland were carried out in 1996 and 1998 and in 2002-3. Eighty-nine lagoon sites (totaling 103 lagoons) have now been identified in Ireland, covering an area of almost 2,600ha.

Four lagoons in a climatically similar area but differing in salinity regime and morphological type (L. Gill, Co. Kerry; L. Murree, Co. Clare; Loch an Aibhnín, Co. Galway; Lough Athola, Co. Galway) were sampled seasonally between June 2002 and September 2003, using a combination of sweep-netting, sediment cores, light-traps and visual searches. The low salinity lagoon (L. Gill) experienced the greatest seasonal changes in floral and faunal species presence/absence and abundance throughout the year. The highest salinity lagoon (L. Athola) showed changes in marine algal presence/absence and abundance in 2003 but not in 2002. In the mid-salinity lagoons (L. Murree, L. an Aibhnin) with characteristic environmentally-tolerant lagoonal biota, seasonal changes were least apparent.

Multivariate analysis of faunal and floral abundance and presence/absence from stations (n=112) in 28 lagoons surveyed in 2002 and 2003 reveals a grouping of low salinity *Potamogeton/Ruppia* lagoons, one of mid-salinity *Ruppia/Chaetomorpha* and two higher salinity groups, comprising a *Ruppia/Zostera* group and a largely unvegetated “estuarine” lagoon type. Analysis of presence/absence faunal (n=456 taxa) and floral (n=149 taxa) data from 60 lagoons (including lagoons surveyed in 1996 and 1998) reveals these same four main groups, plus a fifth “mixed community” lagoon type.

On a world scale, coastal lagoons are relatively rare in Europe and particularly on the Atlantic coast. Many of the Irish lagoons are of a rare type in Europe and harbour rare and threatened species. Fortunately, most of these are in relatively natural condition and appear to be better protected than those in many parts of Europe. Recommendations for management and monitoring are discussed.

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CHAPTER 1

1. General Introduction

1. General Introduction

1.1 Background

The word **lagoon** is defined in the Concise Oxford Dictionary as “a stretch of salt water separated from the sea by a low sandbank, coral reef etc.”. However, in the United States, Australia and New Zealand, “lagoon” refers to a small freshwater lake near a larger lake or river, and may also refer to “the enclosed water of an atoll” or “an artificial pool” for water treatment or retention. **Coastal lagoons**, the subject of this thesis, are referred to by Barnes (1980, 1994c) as **“shallow, virtually tideless, pond- or lake-like bodies of coastal saline or brackish water that are partially isolated from the adjacent sea by a sedimentary barrier, but which nevertheless receive an influx of water from that sea”**. This is essentially a geographers’ definition based on hydro-geomorphology. Similar definitions are used, for example, by Colombo (1977), Lasserre (1979), Phleger (1981) and Bird (1984) and describe in a classical sense the coastal lagoons that are common and extensive in many parts of the world. However, it is difficult to define precisely even a simple coastal lagoon and, according to Mee (1978), no clear distinction can be drawn between lagoons, estuaries and bays. Pritchard’s (1967) definition of an estuary as “a semi-enclosed coastal body of water which has a free connection with the open sea and within which seawater is measurably diluted with fresh water from land drainage” could equally apply to many of the classic sedimentary lagoons, hence the terms “lagoonal estuary” and “estuarine lagoon” used in some descriptions.

One of the major complications in defining lagoons and estuaries is that these systems may be quite different in one part of the world to another. In macro-tidal regions, such as the Atlantic coast of Europe, the essential difference between an estuary and a coastal lagoon in this classical sense is that estuaries are subject to extreme diurnal changes in water level, such that estuaries are drained almost completely of water at low tide, whereas lagoons are subject to a restricted tidal influence and contain permanent water. In microtidal parts of the world, which includes the Mediterranean and Baltic Seas of Europe, these tidal differences are far less noticeable and the essential thing about lagoons is the presence of a sedimentary barrier which restricts the tidal exchange in a lagoon to a greater degree than in an estuary, coupled with the fact that estuaries in general are the parts of rivers which come into contact with the sea, whereas lagoons are "pond- or lake-like" bodies of water.

The Habitats Directive

Coastal lagoons are, however, generally much more easily recognised than defined and are among the most endangered wetland habitats in Europe (Healy 2003). In recognition of this, the European Habitats Directive (CEC 1992) listed coastal lagoons (Code No.1150) in Annex I as a "priority habitat" in "special need of protection" due to the fact that so much of the habitat in Europe had, for a variety of reasons, disappeared or been degraded.

The interpretation manuals of the Habitats Directive (CEC 1996,1999, 2003) define coastal lagoons as: **"expanses of shallow coastal salt water, of varying salinity or water volume, wholly or partially separated from the sea by sand banks or shingle, or, less frequently, by rocks. Salinity may vary from brackish water to hypersalinity depending on rainfall, evaporation and through the addition of fresh seawater from storms, temporary flooding by the sea in winter or tidal exchange. With or without vegetation from *Ruppietea maritimae, Potametea, Zosteretea* or *Charetea* (CORINE 91:23.21 or 23.22)."**

It was realised that certain lagoon types in Europe were not covered by the definitions which refer only to the classic sedimentary lagoons, and which have become known as "true" lagoons. The definition proposed by the Habitats Directive has a slightly broader meaning than previously in that the barrier may be composed of shingle and rock. Amended versions of the interpretation manual also allowed inclusion of artificial lagoons such as **"salt basins and salt ponds…providing that they had their origin on a transformed old natural lagoon or on a salt marsh, and are characterised by a minor impact from exploitation"**. Unusual types, such as the Baltic **"flads and gloes"** were also included as the European Union was enlarged. Member States may interpret the definition as they think best in the interests of nature conservation, and for this reason, the brackish 'rocky' water bodies in Western Scotland known as "obs" have been accepted as coastal lagoons in the U.K (e.g. Covey 1999), as have similar lagoons on the west coast of Ireland during the Irish lagoon surveys. With the extra interest in coastal lagoons and brackish water ecology stimulated by the Habitats Directive it has become increasingly apparent that while a coastal lagoon may harbour characteristic lagoonal biota, similar equally interesting lagoonal biota may exist in many other habitats still not covered by the Habitats Directive definition (Barnes 1991a, Healy 2003). The "true" sedimentary coastal lagoons are worthy of protection as interesting and valuable coastal landforms in themselves but the Directive was intended to give protection to the biological community which the habitat contains. For this reason, certain "lagoonal habitats" recognised by characteristic fauna and flora, though not strictly covered by the official definition, have been regarded as coastal lagoons in Ireland and other Member States in order to give protection to rare and threatened, otherwise unprotected, lagoonal communities. In order to overcome this problem in the UK, Bamber *et al.* (2001b) have proposed the following definition: **"areas of typically (but not exclusively) shallow, coastal saline water, wholly or partially separated from the sea by sandbanks, shingle or less frequently, rocks or other hard substrata. They retain a proportion of their water at low tide and may develop as brackish, fully saline or hypersaline water bodies."**

The essential parts of this definition are the presence of a barrier "of some sort" (Lankford 1977), weak tidal influence (low hydrodynamics), and permanent brackish water. Brackish in this context means any combination of fresh and seawater, including concentration above normal sea water levels, owing to evaporation in a water body containing seawater with restricted tidal influence. This definition distinguishes coastal lagoons from freshwater coastal lakes on one hand and estuaries and tidal pools on the other, but where exactly to draw the line is not defined.

Irish lagoon surveys

The southern part of the east coast of Ireland from just north of Wicklow town to Wexford Harbour once consisted of a series of stream catchments, each with a coastal barrier which in many cases impounded a lagoon (Carter *et al.* 1984). All of these were drained in the nineteenth century (Healy 2003) and many other parts of the coast, especially around Cork and Dublin harbours were probably also reclaimed. Apart from their potential for drainage, there has been little interest shown in coastal lagoons in Ireland until recently, although the larger ones were known to be important areas for birds (Hutchinson 1979, 1989; Grimmet and Jones 1989, Sheppard 1993).

However, the Directive obliges all member states to protect "representative" examples of Annex I habitats in their national territories within Special Areas of Conservation (SACs) and to monitor these selected sites to ensure that their conservation value is maintained. Furthermore, even those not protected within SACs are still regarded as Annex I Priority Habitats and entitled to protection.

Before the Habitats Directive, only four lagoons were at all well known in Ireland (Lady's Island Lake, Tacumshin Lake, Lough Murree, Furnace Lough). Very few biological studies had been published, apart from a study of *Neomysis integer*, in L. Furnace, Co. Mayo (Parker 1977, Parker and West 1979), a phytoplankton study of Lough Murree, Co. Clare (Pybus and Pybus 1980), and three publications concerning

Lady's Island Lake, Co. Wexford (Healy *et al.* 1982, Norton and Healy 1984, Healy 1997). Under the obligations of the Directive, the National Parks and Wildlife Service (NPWS) of the Irish Government commissioned a series of surveys of coastal lagoons in Ireland in order to compile an inventory of lagoons in the country for selection of representative examples for designation as, or within, SACs.

Surveys were carried out in 1996 (Good and Butler 1998, Hatch and Healy 1998, Healy and Oliver 1998, Oliver and Healy 1998), and 1998 (Healy 1999a,b; Oliver 1999, Roden 1999, Good and Butler 2000). An inventory of approximately 100 lagoons was compiled as a result of these surveys and 36 of the higher conservation value lagoons were sampled over a 1-4 day period, depending on the size of the lagoon. The remaining sites were only visited briefly and many of the sampled sites were only visited once, giving only a "snapshot" impression of biota and environmental conditions.

This study was again funded by the NPWS, based on fieldwork carried out in 2002 and 2003. The principal objectives were to:

1. Select four different lagoon types and sample fauna and flora seasonally to gain some understanding of seasonal changes which may occur, in order to design appropriate monitoring procedures.

2. Sample an additional 24 lagoons to produce a total data set from 60 lagoons, which could be analysed statistically to produce a biological classification of Irish coastal lagoons.

3. Use the information collected from the 60 lagoons sampled, together with others visited briefly, to compare with information available concerning lagoons in other Member States in order to put the Irish lagoons into a European context.

At the time of writing 89 lagoon sites are recognised in the Republic (Chapter 4), though some of these sites comprise clusters of very small lagoons (totalling 103 lagoons). Fifty eight of these lagoons have now been surveyed (plus two in Northern Ireland). Of the 89 lagoon sites, the number surveyed is only 65% of the total number in the country, but most of the remaining lagoons are very small and the 65% of total number represents a high percentage (86%) of the total area of total habitat within the country.

1.2 Seasonal changes (Chapter 2)

In additional to protecting representative examples of coastal lagoons within SACs, the Directive also obliges member states to monitor the selected sites for "favourable conservation status", which is defined according to pre-determined conditions of a species or habitat. In order to identify any changes in the biological community caused by human effects it is essential to appreciate natural seasonal and inter-annual changes in the plant and animal communities within lagoons, and to design appropriate monitoring programmes in the light of this variability. While there is a great deal known about population changes in freshwater and marine systems, very little is known about temporal variations in temperate coastal lagoons.

In lakes and rivers, for example, the abundance and diversity of phytoplankton species increases from winter to autumn then falls and can be viewed as a regular cyclic change in which a tendency for the community to achieve some sort of equilibrium is regularly frustrated by the change in weather which ultimately drives the change (Porter 1977, Moss 1980). Many of the aquatic angiosperms such as *Potamogeton* spp. are described as rhizomatous perennials (Webb *et al*. 1996, Preston and Croft 2001), which largely die back through the winter, develop again in the spring, only flower and fruit during summer and early autumn before dying back again through the winter. Similarly many freshwater aquatic insects, such as corixids build up populations through the summer and decline in winter. In Britain, populations of *Sigara lateralis*, for example, have two generations in the year, and do not peak until late summer and mostly only females of this species survive the winter (Southwood and Leston 1959, Savage 1989).

On marine rocky shores, Lewis (1964) describes how seasonal changes intensify the tidal effects of submersion/emersion storms, drought and rainfall on intertidal species. The dominant black lichens and littorinids have a remarkable ability to withstand such a range of conditions and appear to show little seasonal change in distribution. However, the delicate and short-lived algae tend to grow in the winter or spring, and die away or "migrate" downshore as the summer advances. Being short-lived they flourish rapidly and erratically. Many of the perennial algal species often die back or are severely damaged by storms in the winter. Algae with thin membranous parts may lose these in the autumn and winter storms, leaving only the tougher midrib or stipe (e.g. *Membranoptera, Delesseria*) (Hiscock 1979, 1986). Other seasonal changes that occur among the algae are the relatively sudden appearance of annuals such as *Nemalion* and *Dumontia*; the winter "migrations" of *Porphyra* upshore and of some pool algae downshore; the autumnal depopulation of much of the *Fucus* and *Laminaria*, and the temporary dying back of *Gigartina* and *Laurencia* in early winter to perhaps only a basal disc (Lewis 1964). The offshore/onshore migrations of commercial species such as the highly mobile prawns, crabs and lobsters are well known to biologists and fishermen. But many other less mobile species such as the echinoderms *Echinus esculentus, Psammechinus miliaris, Asterias rubens* and *Henricia sanguinolenta* may also extend further up the shore in their summer seasonal migrations (Lewis 1964).

In both the freshwater and marine systems life histories of species and seasonal changes in the community are far better understood than in temperate lagoonal habitats. Of the studies conducted in European lagoonal habitats, most are concerned with lagoons in the micro-tidal Mediterranean and Baltic Seas. These two areas in many ways are two climatic extremes, both of which are likely to experience very different seasonal changes to lagoons in the temperate/oceanic conditions prevailing in the Britain and Ireland. Much of the Baltic coastal area freezes over and day length is extremely short in the winter causing a severe reduction in metabolic rates, widespread mortalities or migration (Segerstråle 1957, Verhoeven 1980b). These conditions extend to a decreasing degree to the SW Netherlands (Verdonschot *et al.* 1982). At the other extreme, many lagoons in the Mediterranean (Amanieu *et al.* 1977, Sacchi 1979, Marchini *et al.* 2004), and on the Atlantic coast of Portugal (Fonseca *et al.* 1989, Costa *et al.* 2003) and southwest France (Amanieu 1967, Labourg 1978) may undergo dystrophic crises in the summer resulting from high nutrient, temperature and salinity levels that also cause declines or mortalities and/or migration of the biota followed by regrowth or colonisation in the autumn through to the following summer.

There is a certain amount of information available concerning year-to-year variations in abundance and population dynamics of selected species, but very little of changes in communities between seasons in lagoons of the temperate/oceanic region. Of the few seasonal studies carried out in lagoons in the U.K., are those of Swanpool in Cornwall (Barnes *et al.* 1971, Dorey *et al.* 1973, Crawley *et al.* 1979), a brackish pond in Hampshire (Bamber *et al.* 1991a) and a four year study of invertebrates by Mason (1986).

The only published studies in Ireland are of population trends of *Neomysis integer* in Lough Furnace by Parker and West (1979), the ecology and reproductive biology of *Lekanesphaera hookeri* in Lady's Island Lake (Norton and Healy (1984), phytoplankton in relation to water chemistry in Lough Murree (Pybus and Pybus 1980) and long-term changes over a 20-year period in Lady's Island Lake by Healy (1997). There is a noticeable lack of seasonal information available. Part of this study was therefore to sample a selection of lagoon types seasonally in order to more fully appreciate seasonal changes in community structure occurring in Irish coastal lagoons and to suggest how such changes may affect future monitoring programmes of protected areas.

Four coastal lagoons on the west coast of Ireland (Lough Gill, Co. Kerry; Lough Murree, Co. Clare; Loch an Aibhnin and Loch Athola, Co Galway) were chosen for this study. The four lagoons are all in a climatically similar area, but represent a range of lagoon types in terms of geomorphology, degree of contact with the sea, salinity, substrate type and degree of "naturalness". Results of the investigation into seasonal changes in these four different lagoon types are described in Chapter 2.

1.3 Classification of lagoons (Chapter 3)

Having compiled an inventory of coastal lagoons in the country, it would be very useful to have a system which helps to describe and classify them.

Coastal lagoons are one of only seven marine habitats listed in Annex I of the European Habitats Directive (92/43/EEC) compared with almost two hundred terrestrial habitats, and they are the only one of the seven habitats that is listed as a "priority habitat" in "special need of protection". The terrestrial habitats listed in Annex I are well studied and their characteristic flora is well defined and easily recognised by an experienced fieldworker but the marine habitats are far less well known.

Historically, the emphasis in the classification of brackish waters was in relation to salinity (e.g. Redeke 1933, Aguesse 1957, Heerebout 1970, Remane and Schlieper 1971) and attempts were made to relate the distributions of species to different salinity zones (e.g. Dahl 1956, D'Ancona 1959, Segerståle 1959, Den Hartog 1974, Heerebout 1974, Parma & Krebs 1977). Salinity zones were standardised by the Venice system (Anonymous, 1959) and most researchers in brackish waters have continued to use this system, though not always adhering strictly to the defined salinity boundaries. Salinity is generally regarded as a "master factor" (Heerebout 1970, Den Hartog 1974) in determining species distributions and typology of brackish waters, or at least a powerful surrogate for covariables of salinity and studies of brackish water species in relation to salinity regime continue to the present day (e.g. Healy 2003, Bamber 2004). However, it is difficult to decide which measure of salinity is the most appropriate measure to use (mean, minimum, maximum, range, frequency of change, occasional extreme values) and to collect sufficient data, in order to show how salinity affects the inhabitants of the system.

The Habitats Directive definition of a coastal lagoon is based largely on geomorphology and when describing lagoons, they are most often classified according to morphological types (Barnes 1989a, Bamber *et al*. 2001b, Covey *et al*. 1998, Healy 2003). While this is a convenient way to describe many of the sites, there is a certain amount of difficulty involved in describing lagoons which have a combination of geomorphological features, or are unusual lagoon types not covered by the definition. Furthermore, the morphological type of lagoon often bears no relationship to the biological community it contains. The Directive was intended to give protection to the biological community which the habitat contains, and it would be very useful to have a biological classification of lagoons, regardless of salinity, hydrology or morphology, using species or communities as indicators of complex conditions.

Verhoeven (1980a) produced a biological classification of "*Ruppia* based communities" in several parts of Europe and many of the areas he studied were lagoons. Lagoons are listed in the marine biotope classification of Britain and Ireland (Connor *et al.,* (1997a,b), and Scotland (Covey and Thorpe 1994) which is based at least partly on the biological community but in combination with substrate, exposure and tidal position. The biotopes within lagoons are described, but the classification of the lagoon itself still relies heavily on salinity or geomorphology, rather than on the biological community, which the Habitats Directive is intended to protect.

The objective of the study described in Chapter 3 was to analyse faunal and floral data collected from the 28 lagoons sampled in 2002 and 2003, and combine this with data collected in previous surveys (1996 and 1998) to classify the lagoons based on the fauna and flora that they contain.

1.4 Irish lagoons in a European context (Chapter 4).

Until recently, information concerning the distribution of coastal lagoons in Europe was only available for Denmark (Muus 1967a), Italy (Sacchi 1979, Ardizzone *et al.* 1988) and Mediterranean Spain (Comin and Parareda 1979). Barnes (1989a) described the coastal lagoons of Britain, but restricted his definition to natural lagoons with sedimentary barriers, while Sheader and Sheader (1989b) described the coastal saline ponds of England and Wales not included by Barnes. Based largely on surveys carried out by Sheader and Sheader (1985-1989) and Bamber and Barnes (1995-1998) a great deal more information has become available for England (e.g. Smith and Laffoley 1992, Downie 1996, Bamber 1997), Scotland (Thorpe 1998, Covey *et al.* 1998, Thorpe *et al.* 1998) and Wales (Bamber *et al.* 1999). Information is also available for most of the lagoons in Portugal (Farinha *et al*. 2001, Fonseca 2004) and for Ireland (Healy and Oliver 1998, Healy 2003); much of which is included in Chapter 4.

The aim of the Habitats Directive is to protect examples of habitats supporting important biological communities within Europe. These areas protected under the Habitats Directive (SACs), together with sites selected as Special Protection Areas (SPAs) under the previous Birds Directive (EC 1979), will together form a network of conservation areas throughout Europe known as the NATURA 2000 Network. The compilation of information concerning coastal lagoon habitat and Natura 2000 is a relatively new but ongoing process. Much of the information in other countries is still widely scattered as it has been acquired during short-term government contracts and does not appear in the primary literature. Therefore, the information is still not available for some countries but enough is now known about Irish lagoons to make general comparisons with those in many other parts of Europe.

The aims of the study described in Chapter 4, therefore, are to summarise the research carried out so far in Irish coastal lagoons and compare these with those in other European countries in relation to the various lagoon types, the amount of lagoonal habitat within each country, their characteristic fauna and flora and their conservation status, in order to put the Irish lagoons into a European context. Finally the management and monitoring of these Irish lagoons is discussed.

Barnes (1980) described coastal lagoons as a "neglected habitat". The study of coastal lagoons in Ireland has increased recently but is still very much in its infancy. With the accession of new member states into the European Union, definitions and perspectives will no doubt need to be revised again. It is hoped that this study will add to our understanding of coastal lagoon ecosystems both in Ireland and Europe and help to conserve this still threatened and still often under-valued resource.

CHAPTER 2

2. Seasonal changes in fauna and flora of Irish coastal lagoons

2.1 Introduction

Coastal lagoons were described by Barnes (1980) as a "neglected habitat" and were historically regarded as of interest primarily as sites either for intensive aquaculture or reclamation for agriculture or industry, although many of the larger lagoons in Ireland were known to be important areas for birds (Hutchinson 1979, 1989; Grimmet and Jones 1989, Sheppard 1993). In 1992 the European Habitats Directive (92/43/EEC) listed coastal lagoons in Annex I as a "priority habitat" in "special need of protection" due to the fact that so many coastal lagoons in Europe had, for a variety of reasons, disappeared or been degraded. The Directive obliges member states to protect "representative" examples of Annex I habitats within Special Areas of Conservation (SACs) but even those not protected within SACs are still regarded as Annex I Priority Habitats and entitled to protection.

Compared with terrestrial habitats, the definition of a coastal lagoon is not precise and many people are confused about what is, and what is not, a coastal lagoon under the Habitats Directive. The interpretation manual of the Habitats Directive (CEC, 1999) defines coastal lagoons as: "expanses of shallow coastal salt water, of varying salinity or water volume, wholly or partially separated from the sea by sand banks or shingle, or, less frequently, by rocks. Salinity may vary from brackish water to hypersalinity depending on rainfall, evaporation and through the addition of fresh seawater from storms, temporary flooding by the sea in winter or tidal exchange. With or without vegetation from *Ruppietea maritimae*, *Potametea*, *Zosteretea* or *Charetea* (CORINE 91:23.21 or 23.22)." This definition still leaves certain lagoon types unprotected, but it is up to member states to interpret the definition as they think best in the interests of nature conservation. In this respect, certain brackish-water bodies found in Ireland have been regarded as coastal lagoons, though sometimes not fitting comfortably within the definition.

Prior to the Directive, only four lagoons were at all well known in Ireland and only a few biological studies had been published (Parker and West 1979, Pybus and Pybus 1980, Healy *et al.* 1982, Norton and Healy 1984, Healy 1997). As a result of the Directive, the National Parks and Wildlife Service of the Irish Government commissioned a survey of coastal lagoons in Ireland to compile an inventory of lagoons in the country and to select representative examples for designation as, or within, SACs.

Surveys were carried out in Ireland in 1996 (Good and Butler 1998, Hatch and Healy 1998, Healy and Oliver 1998, Oliver and Healy 1998) and 1998 (Healy *et al*. 1999(a,b,c), Oliver 1999, Roden 1999, Good and Butler 2000). As a result of these surveys a great deal of information was gained concerning this neglected habitat and 87% of the area of lagoonal habitat in Ireland is now protected within SACs (Chapter 4).

However, the Habitats Directive also obliges member states to monitor SACs for "favourable conservation status", which is defined according to pre-determined conditions of a species or habitat. In order to identify any changes in the biological community caused by human effects it is essential to appreciate natural seasonal and inter-annual changes in the plant and animal communities within lagoons, and to design appropriate monitoring programmes in the light of this variability. While there is a great deal known about population changes in freshwater and marine systems, very little is known about temporal variations in Irish coastal lagoons, but any such temporal variation may have a large impact on results obtained for monitoring with respect to biodiversity and species encountered. The only published long term data available from Irish lagoons are studies by Parker and West (1979) who studied population trends of *Neomysis integer* in Lough Furnace, Norton and Healy (1984) on the reproductive biology of *Lekanesphaera hookeri*, the ecological study of Lough Murree (Pybus and Pybus 1980) and the long-term changes over a 20-year period in Lady's Island Lake by Healy (1997). In England, with a similar climate, there are only studies of the Swanpool, in Cornwall (Barnes *et al.* 1971, Dorey *et al.* 1973, Crawley *et al.* 1979), a four-year study by Mason (1986) and that of a brackish pond in Hampshire by Bamber *et al.* (1991a). Due to this paucity of information this study was initiated to fully appreciate seasonal changes in community structure occurring in Irish coastal lagoons and to suggest how such seasonal changes may affect future monitoring programmes of these lagoons which are Special Areas of Conservation.

2.2 Methods

Environmental parameters

Based on data available from previous surveys in 1996 and 1998, four lagoons were selected for seasonal sampling to represent a range of lagoon types and salinity regime. Four sampling stations were selected at each lagoon to reflect the spatial variation evident within the lagoon. Positions of stations were determined using a GPS Personal Navigator (Global Positioning Satellite, Garmin GPS 45). Each sampling station measured 25m x 20m, to give an area of 0.05ha. Markers were placed on shore, and notes taken of permanent landmarks in order to identify and sample the same area in each different season. Maps of each lagoon were based on scanned sections of Irish Ordnance Survey (O.S.) 6” maps and updated using aerial photographs and field observations. At each sampling station, the depth of water and substrate type were recorded, salinity was measured using a conductivity meter (WTW LF330).

Aquatic fauna

Faunal sampling at each station was mostly confined to depths of less than 1m, but additional samples were also collected by snorkelling to depths of up to 2m. Faunal samples were collected by a combination of sweep-netting, sediment cores, light-traps and timed searches. Sweep nets (1 mm. mesh, 25 x 25cm. diam., Alana Ecology) were used for a timed period of one minute and were replicated three times per station. Three sediment cores (8cm. diam., 0.005m^2) were taken at each of 3 random positions at each station, and sieved (1 mm. mesh) *in situ*. The 3 cores from each position were then combined into one, resulting in 3 sediment samples from each station. Timed searches were carried out by close inspection of stones and vegetation for a maximum duration of one hour at each station. As additional species became harder to find the “5-minute rule” was applied, such that if, in a timed period of 5 minutes, no additional species were recorded the search was terminated. Perspex light-traps were left overnight at each station: These consisted of a perspex box (25x25x25cm) containing a chemical light (Starlight). The boxes were constructed following the model of Holmes and O'Connor (1988).

Faunal samples were preserved in 70% alcohol and stored for subsequent identification. Nomenclature used in results for most of the marine fauna is that according to Costello *et al*. (2001) and Hayward and Ryland (1995) when not listed in the former. Other nomenclature used is according to Costello et al. 1989 (Amphipoda), Ashe *et al*. 1998 (aquatic insects) and Kerney 1999 (freshwater pulmonates). Certain groups were identified or certain species verified by relevant specialists: Amphipoda (D. McGrath, S. de Grave), Hemiptera (B. Nelson), Ephemeroptera (M. Kelly-Quinn), Coleoptera (G. Foster, Balfour Brown Club) Bryozoa, Oligochaeta (B. Healy).

Aquatic Vegetation

Vegetation was surveyed by a combination of wading and snorkelling. A species list was compiled at each station and an estimate of percent cover was recorded for each taxon. Species not readily identifiable in the field were collected for subsequent examination in the laboratory. Most species identifications were easily made using standard floral keys (Hiscock 1979, 1986; Webb *et al.* 1996, Moore 1986, Stewart and Church 1992, Preston and Croft 2001). Some taxa, however, are difficult to identify and considerable help was supplied by Dr. C. Roden. Using the protocol of Roden (1999), “Following Preston (1995), no attempt was made to identify non-flowering *Ruppia* to species.” Samples of *Cladophora* spp. were collected and preserved in 70% alcohol whenever encountered for later identification in the laboratory. Nomenclature follows Stace (1997) for vascular plants, Hardy & Guiry (2003) for marine algae and Bryant *et al*. (2002) for charophytes. Full species lists are presented in Appendix I.

Seasons

Sampling periods are referred to as "seasons" and were sampled at approximately 3-month intervals, representing Winter, Spring, Summer and Autumn. Loch Aibhnín and Loch Athola were sampled 6 times (June 02, September 02, December 02, March 03, June 03, September 03). It was not possible to sample L. Gill and Murree in December 02 owing to prolonged inclement weather, and these two lagoons were only sampled in five seasons (June 02, September 02, then not until February 03, May 03 and August 03).

Statistical Analysis

Faunal abundance data used for statistical analysis of the 4 lagoons is a combined abundance for all sampling methods. This combined abundance was calculated as the sum of the mean of 3 sweep-net samples, plus the mean of 3 sediment core samples, plus the total number from the light-trap samples, plus the estimated abundance from the timed searches. The first three methods (sweep nets, cores, and light-traps) resulted in counts for each species, whereas the timed searches resulted in relative abundance data. Estimated abundance in the field was on a scale of 1 – 5, based on the SACFOR scale of Hiscock (1996) for marine surveys, and suggested guidelines by Bamber (1997) for lagoonal habitats. In this study, 1 = rare, 2 = occasional, 3 = common, 4 = abundant and 5 = super-abundant. The category of "frequent" was not used in these surveys, due to the low number of samples at each station, and taxa in this category are assigned to the "occasional" or "common" category. Counts for many taxa resulted in much higher values than the relative abundance scale of 0-5, and some taxa are considerably more numerous than others. Therefore, for statistical comparability, the data were treated as follows:

1. Abundance of taxa recorded during the timed searches were recorded on a scale from 0 – 5, which was then translated into a relative abundance scale of 0 – 1000 for

each taxon, as shown in Appendix II. (similar to data-handling used by Sconfietti *et al*. (2003) and Marchini *et al*. (2004).

2. The combined count data from sweep nets, sediment cores and light traps were converted to an abundance scale of 0 – 5, and translated as in (1), into a relative abundance scale of 0 –1000 for each taxon, as above using the same table shown in Appendix II.

3. The data from the timed searches were then combined with the converted "counts", so that all faunal taxa were analysed using an abundance scale of 0 –1000.

Data were analysed using non-parametric analysis of variance (NPManova), Multi-dimensional scaling (MDS, Primer) and SIMPER (Primer). All species represented by a single occurrence were deleted from the data prior to statistical analysis, but these species were retained for species richness data. Analyses of the taxa were carried out for the 4 stations at the 4 lagoons, using: i) Fauna only, ii) Vegetation only and iii) the combination of Fauna and Flora. As numbers varied greatly from very high to very low, faunal data on the 0-1000 scale were log-transformed, floral data based on percentage cover were square root transformed. Both data sets were also converted to presence and absence, as each type of transformation can provide a different insight into the ecology of the lagoonal community. In each lagoon, the three types of analyses were performed on each type of data (presence/absence and abundance), exploring first seasonal differences, followed by a separate analysis of the data types for differences among stations in each of the lagoons.

Lagoonal specialists referred to are characteristic species listed in various publications for the United Kingdom (e.g. Barnes, 1989; Bamber, 1997) and Ireland (Oliver and Healy, 1998) and in Chapter 4.

2.3 Study sites

All four sites were located on the west coast of Ireland (Fig 2.3.1) to minimise differences in climate and tidal range and were selected to represent a range of lagoon types (Table 2.3.1).

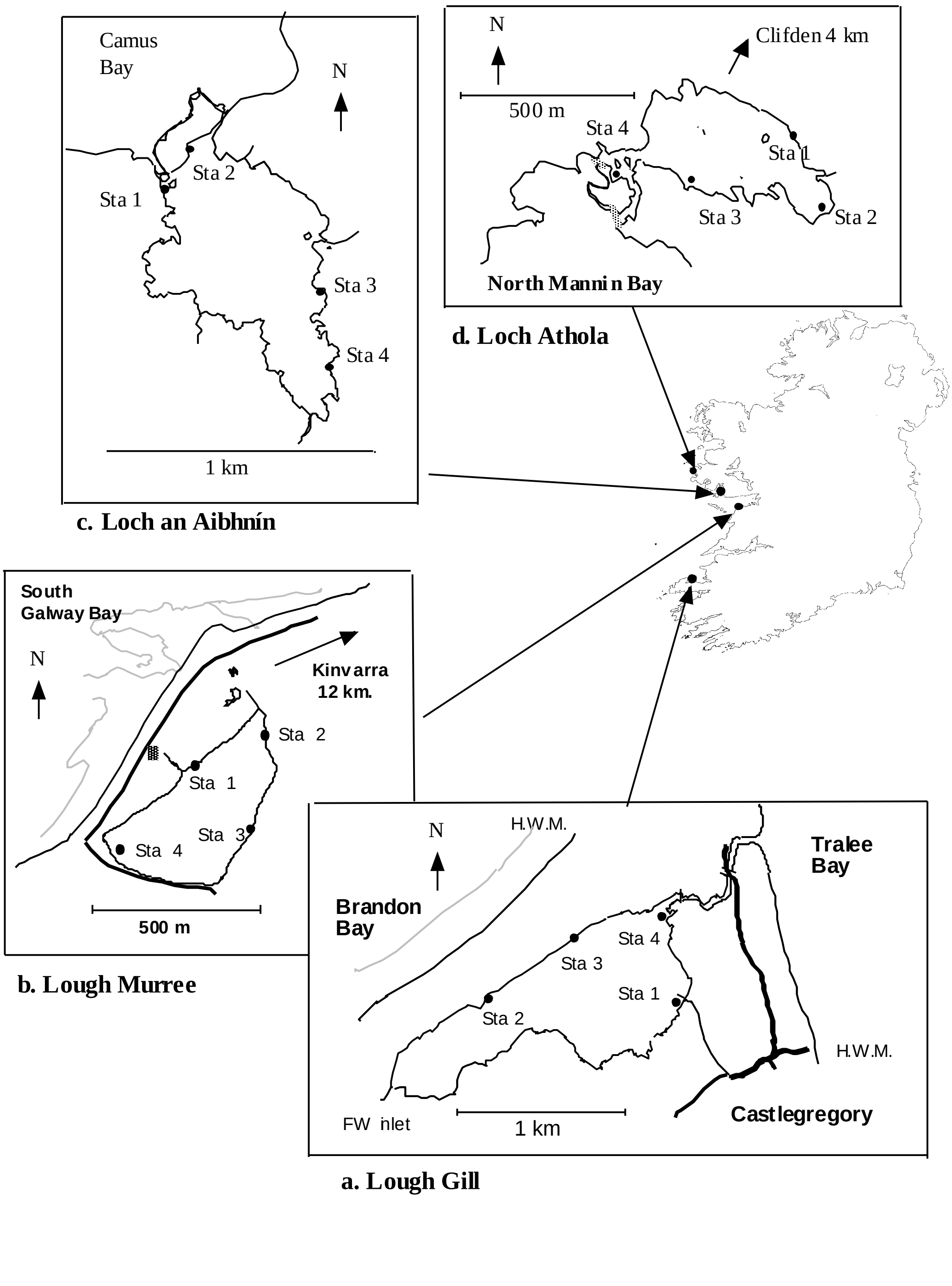

Figure 2.3.1 Location map of the 4 lagoons selected for seasonal sampling, 2002-3 (dark lines on a and b represent roads).

Table 2.3.1 Size, lagoon type, normal salinity range and substrate of the 4 lagoons selected for survey.

	Size (ha)	Lagoon type	Salinity (psu)	Substrate	Depth (m)
L. Gill	144	Sedimentary, sluiced	0-5	Sand	0.5 -1
L. Murree	13	Karst, isolated	10-15	Rock, stones, sand, mud	1-3
L. an Aibhnin	55	Silled	18-27	Granite rocks, peat	1-2
L. Athola	11	Silled	30-33	Granite, sand, peat	1-4

Lough Gill, Co. Kerry (10^0 15.6’ N; 10^0 03’ N)

Lough Gill is situated on the north coast of the Dingle peninsula (Fig 2.3.1a). The lagoon is a large, shallow natural lagoon "in a classical position" (Guilcher & King, 1961) lying between two sand barriers which form a double tombolo connecting the mainland to a group of the Magharee islands. A freshwater stream (Killiney River) enters in the southwest and a channel runs from the northeast of the lagoon to Tralee Bay, and tidal exchange is limited by a one-way sluice at the outlet and a small weir which prevents all but the highest tides from entering the lagoon. Stations were selected at the southwest end, where the freshwater stream enters (Sta. 2) and at the northeast near the outlet channel (Sta. 4). Stations 1 and 3 were midway between these. Substratum at all stations is clean, firm sand and all stations are fringed by reedbeds, with a small amount of grassland at Sta. 2, which borders the golf course.

Lough Murree, Co. Clare (52^0 09.2’ N; 09^0 07’ W)

Lough Murree is situated on south side of Galway Bay, County Clare (Fig. 2.3.1b). The lake has formed in limestone bedrock, overlain with glacial till (Lansbury, 1965) on which a cobble barrier has been deposited along the coastal side. A road now runs along this barrier between the lagoon and the sea. There is no direct communication with the sea, but seawater enters the lake by overtopping of the barrier, and percolation through subterranean fissures in the bedrock. The lagoon is often referred to as highly eutrophic, with recurrent algal blooms (C. Roden, pers. comm. and pers. obs.)

Substratum at Station 2 consisted of limestone bedrock with deep fissures and pockets of sand/silt. Substrata at other stations varied from mostly sand with occasional stones to finer mud along the shoreline. The lagoon is bordered mostly by improved pasture and arable fields.

Loch an Aibhnín, Connemara, Co. Galway (53^0 19.5' N; 09^0 34.5' W)

Loch an Aibhnín is a medium sized lagoon with a rock sill on the south side of Camus Bay (Fig 2.3.1c). Seawater enters from the North through narrow rapids from Camus Bay on spring tides and the higher neap tides and diluted seawater enters from L. Fhada and L. Tanaí to the south (Oliver and Healy 1998). Freshwater enters from a number of small streams and by long-term seepage from surrounding peatland. The lagoon is uniformly shallow (c. 2m) apart from a deeper area near the outlet (3-4m). Substratum at all stations is mostly peat, granite rocks and coarse sand and gravel with dense beds of *Ruppia* and *Zostera*. Station 1 was located at the north end of the lagoon near the rapids which flow into Camus Bay, and Station 2 was also located near where a smaller inlet to the lagoon has been partly blocked by a stone causeway. The lagoon is bordered by peat bog, granite rocks, bedrock and rough pasture. Stations 3 and 4 are at the southern end of the lagoon, furthest from the tidal inlet.

Lough Athola, North Mannin Bay, Co. Galway (53^0 28.0' N; 10^0 04.2' W)

Lough Athola is a saline lake lagoon with a natural tidal inlet through creeks in salt marsh and peat superimposed on a rock barrier. The lagoon covers approximately 10ha and is situated on the north shore of Mannin Bay (Fig 2.3.1d). The lagoon is flooded on all but the lowest neap high tides but tides are restricted by the narrow inlet. Depth is shallow (max 2-4m) and salinity is close to full seawater throughout; the lowest measured during this sample period was 33.7 psu but 27 psu was recorded at the western end in 1998 and 6 and 7 close to a freshwater inflow in June and September of 1998, respectively (unpubl. data). Substratum is mostly rock and stones overlain in many central areas by a thick layer of peaty silt and covered with mats of unattached *Chaetomorpha* or “tufty” *Cladophora battersii* (Roden 1999).

Substrata at all stations consisted of rock, stones, course sand and silty peat. Station 2 was located close to where a freshwater stream enters, and Station 4 was located at the western end of the lagoon near the tidal inflow. This lagoon was surrounded by moorland, peat cliffs, grassland and rock.

2.4. Results

The four lagoons selected for seasonal sampling vary considerably in size and lagoon type (Chapter 3) and in salinity regime and biological community (Tables 2.4.1, 2.4.2).

Table 2.4.1 Salinity range, fauna and flora recorded in four lagoons selected for survey on the west coast of Ireland. 2002-3.
(Lagoonal specialist species based on Barnes (1989), Bamber (1997), Oliver and Healy (1998), Oliver (Chapter 4). * = extreme values at inflows.

Lagoon	Salinity range min - max	Total No. of faunal taxa	Total No. of floral taxa	Lagoonal specialist faunal spp.	Lagoonal specialist floral spp.	No. of Insect taxa
L. Gill	0 - 4	52	21	2	3	25
L. Murree	10.2–12.7 *(1.7 – 24.3)	17	12	4	5	7
L. an Aibhnín	22.1 - 30.4	120	47	9	3	1
L. Athola	29 - 34	138	46	5	2	1

All species recorded are listed with authorities in Appendix I. Full species lists are presented in Appendices III-X and additional environmental data for the four lagoons is included in Appendix XI.

Lough Gill is a low salinity lagoon, with a permanent freshwater inflow and occasional saltwater inflow. Substratum consists mostly of clean sand and vegetation is dominated largely by and low salinity hydrophytes such as *Potamogeton pectinatus, P. perfoliatus* and *Myriophyllum spicatum*, but with lagoonal specialists, *Chara canescens* and two species of *Ruppia* (*R. maritima, R. cirrhosa*) more common in the central and northeast areas of the lagoon. The faunal community is dominated by insect species of Coleoptera and Hemiptera but also with freshwater species of leach (*Erpopdella octoculata, Helobdella stagnalis*), oligochaetes (*Pomatothrix bavaricus*) and freshwater snails (*Lymnaea peregra, Segmentina complanata*). In this lagoon lagoonal specialist fauna and crustaceans are generally rare.

Table 2.4.2 Dominant faunal species recorded in each of the four lagoons selected for seasonal sampling.

	L. Gill	L. Murree	L. an Aibhnín	L. Athola
Porifera			*Halichondria panicea*	*Halichondria panicea*
			Scypha compressa	
			Sycon ciliatum	*Sycon ciliatum*
Cnidaria			*Actinia equina*	
			Anemonia viridis	*Anomonia viridis*
			Anthopleura ballii	*Anthopleura ballii*
			Dynamena pumila	*Laomedia angulata*
			Gonothraea loveni	*Obelia longissima*
Hirudinea	*Erpopdella octoculata*			
	Helobdella stagnalis			
Oligochaeta	*Clitellio arenarius*	*C. arenarius*	*C. arenarius*	
	Pomatothrix bavaricus		*Tubificoides benedii*	*Tubificoides benedii*
Polychaeta			Arenicola agg.	Arenicola agg.
			Capitella capitata	*Capitella capitata*
			Flabelligera affinis	
			Janua pagenstecheri	*Janua pagenstecheri*
			Platynereis dumerili	*Platynereis dumerili*
			Polyopthalmus pictus	*Polyopthalmus pictus*
			Pomatoceros triqueter	*Pomatoceros triqueter*
			Spirorbidae indet.	Spirorbidae indet.
Crustacea			*Semibalanus balanoides*	*Semibalanus balanoides*
			Tanais dulongi	*Tanais dulongi*
	Neomysis integer	*N. integer*	*Praunus flexuosus*	*Praunus flexuosus*
	Jaera nordmanni	*J. nordmanni*	*Jaera forsmani*	*Jaera spp.*
	Lekanesphaera hookeri	*J. ischiosetosa*	*Lekanesphaera hookeri*	
	Gammarus zaddachi	*Gammarus duebeni*	*Idotea chelipes*	
	Gammarus finmarchicus	*Melita palmata*	*Ampithoe rubricata*	*Atylus guttatus*
		Palaemonetes varians	*Calliopius laevisculus*	*Gammarus zaddachi*
		Carcinus maenas	*Caprella acanthifera*	*Phtysica marina*
			Sunampithoe pelagica	*Microdeutopus gryllotalpa*
			Carcinus maenas	*Carcinus maenas*
			Palaemon serratus	*Palaemon serratus*
Insecta	*Ischnura elegans*	*I. elegans*		
	Nepa cinerea			
	Gerris thoracicus			
	Gerris odontogaster			
	Hydrometra stagnorum			
	Corixa panzeri			
	Sigara dorsalis	*Sigara stagnalis*		
	Gyrinus caspius	*Enochrus bicolor*		
	Hygrotus inaequalis			
	Laccobius colon			
	Laccophilus minutus	*Ephydra riparia*		
Mollusca	*Potamopyrgus antipodarum*	*P. antipodarum*	*Lepidochitona cinerea*	*Lepidochitona cinerea*
	Lymnaea peregra	*Hydrobia ventrosa*	*Hydrobia ulvae*	*Hydrobia ulvae*
	Segmentina complanata	*Littorina saxatilis*	*Littorina obtusata*	*Bittium reticulatum*
			Littorina "tenbrosa"	
			Onoba aculeus	*Onoba aculeus*
			Patella vulgata	*Patella vulgata*
			Rissoa membranacea	*Rissoa membranacea*
			Skeneopsis planorbis	*Skeneopsis planorbis*
			Runcina coronata	*Gibbula umbilicalis*
			Cerastoderma glaucum	*Cerastoderma glaucum*
			Musculus discors	*Paphia aurita*
			Mytilus edulis	*Mytilus edulis*
Bryozoa	*Plumatella repens*		*Alcyonidium hirsuta*	*Aetea truncata*
			Bowerbankia gracilis	*Bowerbankia gracilis*
			Callopora lineata	*Scrupocellaria reptans*
			Conopeum seurati	*Conopeum seurati*
Echinoderms			*Amphipholis squamata*	*Amphipholis squamata*
			Leptosynapta inhaerens	*Asterina gibbosa*
Ascidians			*Ascidiella aspersa*	*Ascidiella aspersa*
			Ciona intestinalis	*Ciona intestinalis*
			Clavelina lepadiformis	*Clavelina lepadiformis*
			Dendrodoa grossularia	

Lough Murree is practically isolated from the sea as well as from any permanent running freshwater, and the community is species-poor, especially in terms of fauna, with only 16 taxa recorded. Five of these taxa are insects, two of which are lagoonal specialists (the water-beetle *Enochrus bicolor* and the water-boatman *Sigara stagnalis*), but generally insect taxa are less common at this slightly higher salinity and crustaceans such as isopods (*Jaera nordmanni, J. Ischiosetosa*), gammarids (*Gammarus duebeni, Melita palmata*) and decapods (*Palaemonetes varians, Carcinus maenas*) are more common. The floral community is dominated by lagoonal specialist plants (*Chara canescens, Lamprothamnion papulosum, Ruppia, Chaetomorpha linum*) and the only common freshwater species is *Potamogeton pectinatus*.

Loch an Aibhnín has permanent inlets for both freshwater and seawater, with a much higher species richness, more lagoonal specialists including the cnidarian, *Gonothyraea loveni,* crustaceans, (*Lekanesphaera hookeri, Idotea chelipes, Palaemonetes varians*), molluscs (*Littorina* “tenebrosa", *Onoba aculeus, Cerastoderma glaucum*) and the Bryozoan, *Conopeum seurati,* only Chironomids representing the insect taxa and many more marine molluscs, crustaceans, tunicates and cnidarians. The plant community is dominated *Zostera marina* and marine algae, but with an important lagoonal element represented by *Ruppia maritime, Lamprothamnion papulosum* and *Chaetomorpha linum.*

Loch Athola, where tides enter the lagoon on almost every day but freshwater enters only in small quantities, has the highest species list, dominated by marine fauna and flora, with no freshwater species, only sparse amounts of *Ruppia* and *Chaetomorpha* and only three lagoonal specialist fauna (*Onoba aculeus, Cerastoderma glaucum, Idotea chelipes*).

It was necessary to combine count data with a scale of abundance, (see methods) and Table 2.4.3 explains the justification for this combination and the use of a standardised abundance scale of 0-1000 for all faunal data. Most noticeable about this comparison is that using the 0-5 abundance scale exaggerates any seasonal differences in all cases, so that for taxon abundance in L. Murree, for example, using a Log-transformation of count data, none of the pairs of seasons out of ten seasons (0%) shows any significant difference and only one pair out of 10 (10%) shows any difference using the 0-1000 scale, whereas using the 0-5 scale, all of the seasons (100%) are significantly different to all other seasons. All of the taxa recorded in visual searches in L. Murree are also recorded in the counts (100%) resulting from the combination of sweep net, sediment core and light trap data (see methods). The slight difference between the true count and 0-1000 abundance scale in L. Murree is due to the difference in numbers of cryptic crustacean species such as *Jaera*, *Gammarus* and *Melita*. These are recorded in the counts but are more abundant or more frequently found during searches.

Table 2.4.3. Comparison of percentage differences in pair-wise comparisons of seasons using true count data and abundance scales from visual estimates. (n = number of taxa. Figures in bold indicate major differences to be discussed)

	Abundance of taxa			Presence/absence of taxa		% of taxa recorded in both true count and visual search data
Transformation	True count Log 10 (x + 1)	0 – 5 scale None	0 – 1000 scale Log 10 (x + 1)	True count Pres/Abs	Abundance scales Pres/Abs	
L. Murree	0 (n=17)	**100** (n=17)	10 (n=17)	0 (n=17)	**10** (n=17)	**100**
L. Gill	50 (n=38)	**100** (n=52)	**60** (n=52)	20 (n=38)	20 (n=52)	**73**
L. an Aibhnin	33 (n=65)	**73** (n=120)	6.6 (n=120)	13 (n=65)	6.6 (n=120)	**54**
L. Athola	**33** (n=73)	**80** (n=138)	**0** (n=138)	33 (n=73)	0 (n=138)	**54**

The difference in using the 0-1000 scale and the count data is much more noticeable in the other three lagoons as only 73% of the total taxa recorded in L. Gill are recorded in true counts, and only 54% in both L. an Aibhnin and L. Athola, due to the large number of sessile species such as molluscs, tunicates and bryozoans and also highly mobile fish species that are only recorded by visual estimates. The fact that up to half of the taxa present in the lagoon may not be represented as true counts necessitates the combining of true count with visual abundance data. Table 2.4.3 shows the 0-1000 scale to be more appropriate for statistical analysis than the 0-5 scale commonly used for field surveys. Henceforth all statistical analyses of faunal data will therefore use the standardised 0-1000 scale for all taxa.

Non-parametric analysis of variance (NPManova) reveals that all four lagoons show very different seasonal patterns with respect to changes in their floral and faunal communities (Table 2.4.4).

Table 2.4.4 Percentage of pair-wise comparisons of seasons that are significantly different from each other at four coastal lagoons in Ireland, 2002-3.
Results are shown (a) for 1) fauna alone (Log-transformed), 2) Flora alone (square-root-transformed), 3) Fauna and Flora combined, and b) presence and absence.

	Abundance			Presence/Absence		
	Fauna	Flora	F & F	Fauna	Flora	F & F
(transformation)	Log 10	Sq. rt.	Log 10	pres/abs	pres/abs	pres/abs
Lough Gill	**60**	**30**	60	**20**	0	20
Lough Murree	10	0	0	**10**	0	0
Loch Aibhnín	6.6	0	6.6	6.6	0	6.6
Loch Athola	0	**13.3**	0	0	**13.3**	6.6

Pair-wise differences in seasons are most noticeable in terms of abundance of faunal taxa (60%) in Lough Gill, the lowest salinity lagoon, and also, to a lesser extent, in floral abundance (30%) at the same lagoon (Table 2.4.4). Both faunal and floral abundance are much more variable at this low salinity lagoon than at any of the other more saline lagoons. Faunal presence/absence also is more variable in L. Gill (20%) than vegetation (0%), whereas it is the abundance of floral taxa (13.3%) and presence/absence (13.3%) which is most variable in L. Athola. In the mid-salinity lagoons (L. Murree and L. an Aibhnín), there is very little difference between seasons, with only slight changes in the abundance and presence/absence of faunal taxa and no statistical differences in vegetation. In Loch Athola, the most marine lagoon, there are no statistical differences in fauna between any of the seasons and the greatest seasonal differences are accounted for by the changes in both abundance and presence/absence of algal taxa.

Table 2.4.4 summaries 24 statistical analyses and it would be cumbersome to present the details of all these analyses individually. Thus, I have chosen to illustrate the seasonal changes in abundance (Log 10) and presence/absence of fauna across all lagoons based on the primary importance of this specific data set in showing seasonal changes across most lagoons. This will be supplemented by additional comparisons of the differences in floral abundance in Lough Gill, and floral abundance and presence/absence in L. Athola, followed finally by a comparison of stations within individual lagoons.

Faunal comparisons in L. Gill

Seasonal differences in faunal abundance in Lough Gill are statistically significant (NPManova; $F=3.1730$; $p <0.001$) and multidimensional scaling (MDS, Primer) shows these differences quite clearly (Fig. 2.4.1). Six of 10 seasonal pair-wise comparisons (Table 2.4.5) differ significantly from each other: Feb 03 is significantly different from Sept 02 and Aug 03 and June 02 is significantly different from all other seasons. This not only suggests a seasonal difference in faunal abundance between the coldest month of February and the late summer months of August and September, but also an inter-annual difference with June 02 significantly different from both May and August 03 (Table 2.4.5). Based on presence and absence, differences between seasons are also apparent but to a much lesser extent, suggesting that the major seasonal differences are due to the changes in abundance of the dominant fauna.

Table 2.4.5 Pair-wise comparisons of faunal abundance by season in L. Gill (* = significant, $p < 0.05$)

Groups	t	p	No.perm.
June 02 – September 02	1.7309	0.0288*	35
June 02 – February 03	1.8579	0.0286*	35
June 02 – May 03	2.1305	0.0293*	35
June 02 – August 03	2.5334	0.0289*	35
September 02 – February 03	1.5537	0.0289*	35
September 02 – May 03	1.6335	0.0608	35
September 02 – August 03	1.3104	0.1445	35
February 03 – May 03	1.2782	0.1187	35
February 03 – August 03	2.1357	0.0289*	35
May 03 – August 03	1.6106	0.0877	35

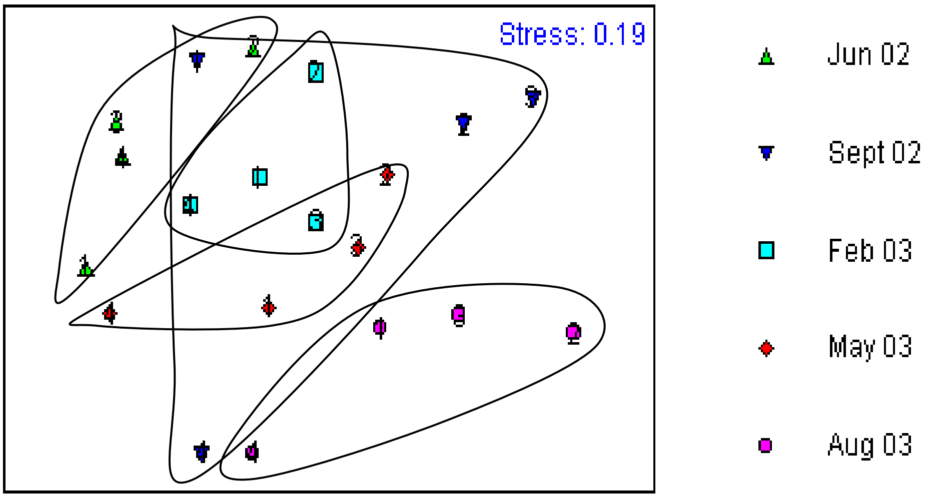

Figure 2.4.1 MDS Plot of seasonal variations in faunal abundance at 4 stations in Lough Gill. 2002-3.

SIMPER analysis attributes these differences in abundance largely to changes in abundance of the eight taxa listed in Table 2.4.6, which together account for 76.5% of the dissimilarity between seasons for combined stations. *Neomysis integer* was most abundant in Jun 02 and then May 03 (Fig2.4.2 a), appearing to have a spring peak in abundance, but with lower numbers recorded in 2003 than 2002. *Potamopyrgus antipodarum* is most abundant in Jun 02 and less so for the rest of that year and the following one (Fig2.4.2 b), *Lymnaea peregra* is most abundant in Feb 03 (Fig 2.4.2 c), appearing to have a winter peak, and *Sigara dorsalis* (Fig 2.4.2 d) shows an increase in abundance through the summer of 2002 with an Autumn peak, but considerably lower numbers are recorded in 2003. Chironomids are more numerous in Feb 03, whereas *Gasterosteus* and Hydracarina are only numerous in August 03 and September 02. Clearly there are differences between seasons, but some of these differences appear to be due to differences between years more than between seasons within a year.

Table 2.4.6 Average abundance of dominant faunal taxa at all stations combined in 5 seasons in Lough Gill. 2002-3 (SIMPER analysis).

	Jun 02	Sept 02	Feb 03	May 03	Aug 03	Average % contribution
Potamopyrgus antipodarum	387.5	20.00	50.00	50.00	30.00	21.60
Neomysis integer	277.50	3.75	77.50	100.00	7.75	16.34
Sigara dorsalis	37.75	38.75	27.50	2.75	2.75	10.91
Chironomidae	5.00	18.75	32.50	16.25	3.75	9.69
Lymnaea peregra	4.00	5.00	25.00	10.00	10.00	4.10
Hydracarina	0.25	5.75	1.25	12.50	20.00	5.26
Gasterosteus aculeatus	0.25	4.00	2.50	15.00	26.50	4.40
Corixa panzeri	3.75	26.50	2.50	1.25	2.75	4.24
						Total = 76.54%

Based on presence and absence (Fig 2.4.3) only 2 of the pairs of seasons are significantly different. Aug 03 differs from Feb 03 ($t = 1.8855$, $p < 0.05$) and Jun 02 ($t = 2.0703$: $p < 0.05$). August differs to February due largely to the presence of *Lymnephilus* and *Ischnura* in the winter, compared with greater frequency of *Plumatella, Hydracarina*, Hirudinea, amphipods, beetles and juvenile flounder in August. Ten faunal taxa explain 45.95 % of the dissimilarity, with the remainder comprising several beetle species which were only recorded in the summer, but not at all stations. August 03 differs from June 02 due largely to the presence of species which differentiate it from February, and in this respect, June 02 is much more similar to the winter seasons than the summer.

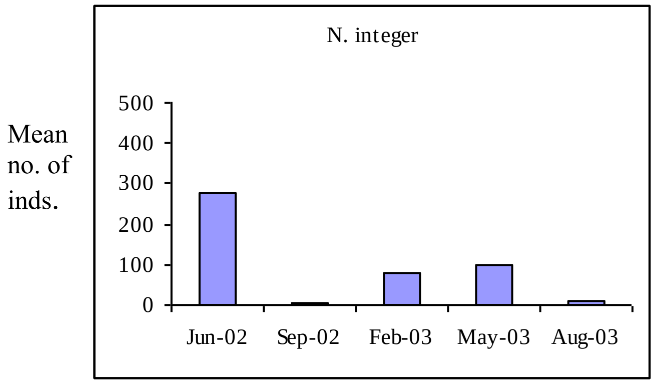

Fig 2.4.2 (a) *N. integer* in L. Gill

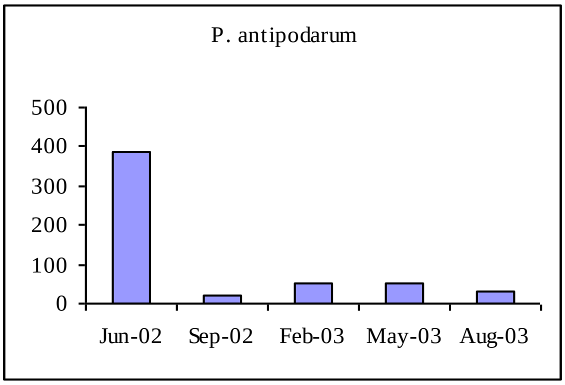

Fig 2.4.2 (b) *P. antipodarum* in L. Gill

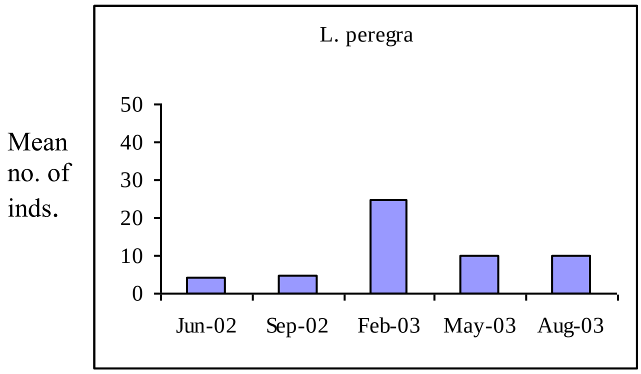

Fig 2.4.2 (c) *L. peregra* in L. Gill

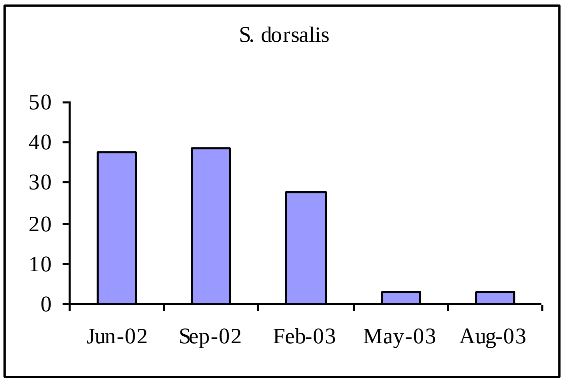

Fig 2.4.2 (d) *S. dorsalis* in Lough Gill

Figure 2.4.2. Seasonal changes of 4 of the dominant faunal taxa in Lough Gill. 2002-3

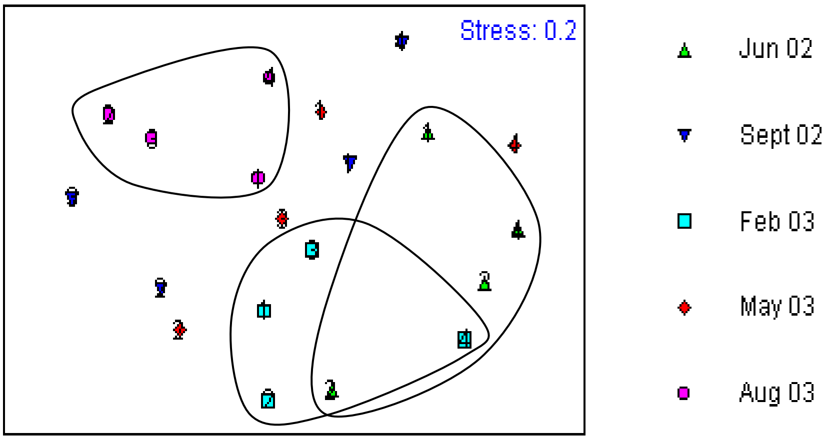

Figure 2.4.3 Plot resulting from multidimensional scaling of seasonal differences in faunal presence and absence at four stations in Lough Gill 2002-3.

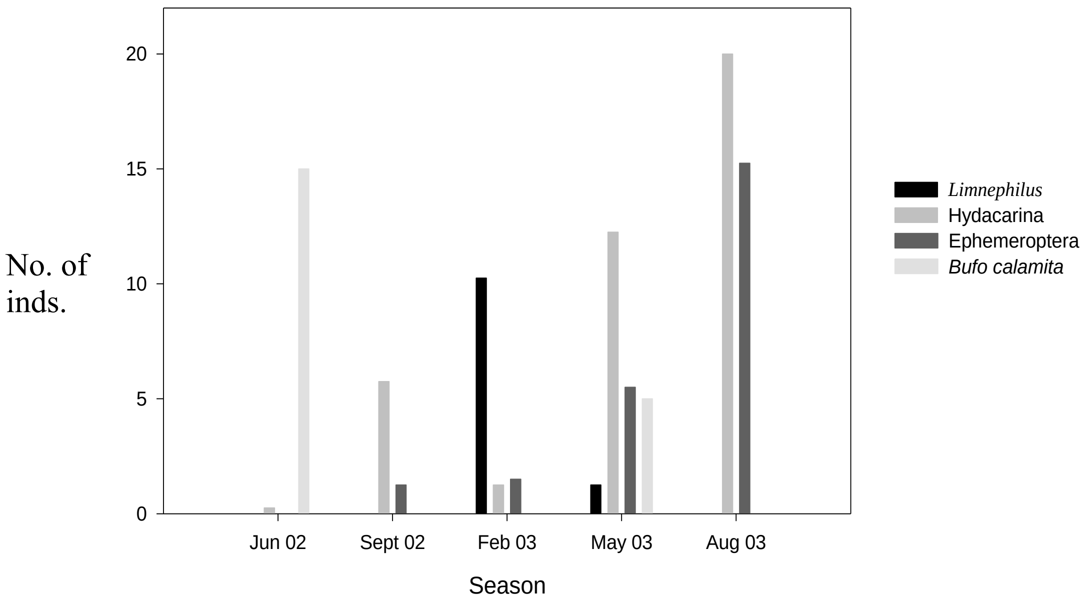

Figure 2.4.4 Seasonal changes based on presence/absence of Limnephilus, Hydracarina, Ephemeroptera and *Bufo calamita* in Lough Gill, 2002-3

Certain species show an obvious seasonal variation in presence and absence such as *Limnephilus* only being present in Feb and May 03 and *Bufo calamita* in May and June, whereas the increasing presence of Ephemeroptera and Hydracarina in 2003 appears to be an inter-annual difference (Fig 2.4.4). The much increased frequency of *Gasterosteus* and Ephemeroptera species in 2003 also suggests a difference between years

Floral comparisons in L. Gill

A total of 21 floral taxa were recorded in Lough Gill during the sample period, of which 16 were identified to species. After deleting taxa with only single occurrences, 17 were used for statistical analysis plus the categories of “bare ground” and “rotting vegetation”.

Using pair-wise comparisons in NPManova, February 03 is floral abundance is significantly different from all other seasons except May 03 (MDS, Fig. 2.4.5). Using presence and absence data there are no significant differences between any of the seasons. Except for three, rarely recorded species, the floral species in Lough Gill can be found throughout the year but relative abundance changes considerably. Percentage cover of all species, with the occasional exception of *Cladophora*, declines in winter and is replaced by an increase in “bare ground” and “rotting vegetation” (Fig. 2.4.6).

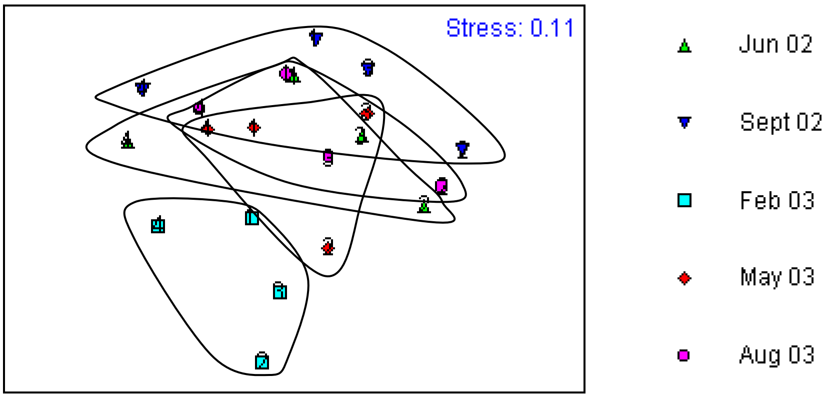

Figure 2.4.5 MDS Plot resulting from multidimensional scaling of floral presence and absence at 4 stations in Lough Gill.

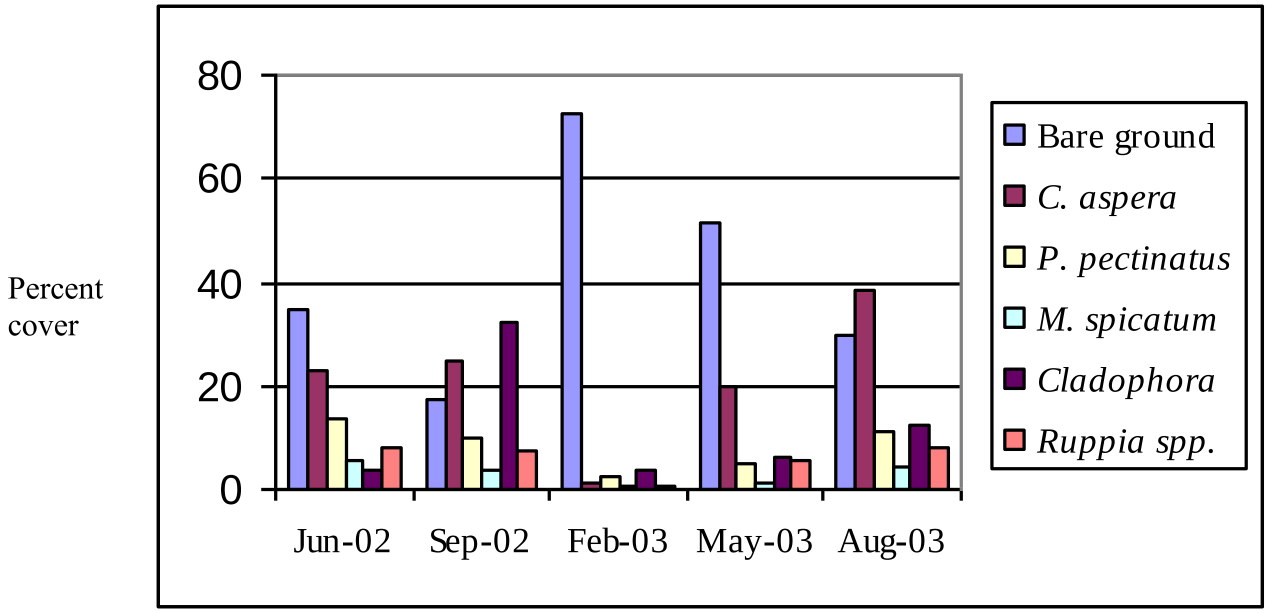

Figure 2.4.6 Seasonal variation in abundance of dominant ground cover at 4 stations in L. Gill. 2002-3.

Seasonal changes in L. Murree

Salinity in Lough Murree ranged from 1.7 at the surface of the water in Jun 02 to a maximum of 24.3 at Station 1 during a time of seawater inflow in May 03, but for most of the period was much less variable, ranging from 10.2 to 12.7.

Fauna

Faunistically, the lagoon is very species-poor, with a total of 25 taxa recorded during the sampling period 2002-3 (Appendix IV). By far the most numerous taxa in Lough Murree are *Potamopyrgus antipodarum, Gammarus duebeni, Gasterosteus aculeatus* and Chironomidae, but despite slight changes in abundance of these dominant taxa, the only seasons that are significantly different in the pair-wise comparison (Tables 2.4.4, 2.4.7; Fig. 2.4.7) are September 02 and May 03. June 02 is quite different but not significantly so, from all other seasons, as seen in L. Gill, again suggesting an inter-annual difference.

Table 2.4.7 Pair-wise comparisons of faunal abundance by season in L. Murree (* = significant, $p < 0.05$).

Season	**t**	**p**
Jun 02 – Sept 02	1.1053	0.3913
Jun 02 – Feb 03	1.8452	0.0587
Jun 02 – May 03	1.9537	0.0590
Jun 02 – Aug 03	1.6868	0.0583
Sept 02 – Feb 03	1.1306	0.2799
Sept 02 – May 03	1.5850	0.0294*
Sept 02 – Aug 03	1.1057	0.3118
Feb 03 – May 03	1.3316	0.1359
Feb 03 – Aug 03	1.2173	0.2832
May 03 – Aug 03	1.4437	0.1147

Simper analysis attributes the difference between these two seasons largely to the greater abundance of *Neomysis integer*, *Jaera nordmanni*, *Palaemonetes varians,* Chironomidae and *Potamopyrgus antipodarum* in May 03, in comparison to greater abundance of *Gasterosteus aculeatus*, *Melita palmata* and *Ephydra riparia* in September 02. It is interesting to note that maximum numbers of *Neomysis integer* occur in June 02 and those of Gasterosteus occur in Aug 03, as they do in L. Gill. When data is transformed to presence and absence (Table 2.4.4) again only one pair-wise comparison is significantly different, but in this case, the difference is between June 02 and Feb 03 (Table 2.4.8).

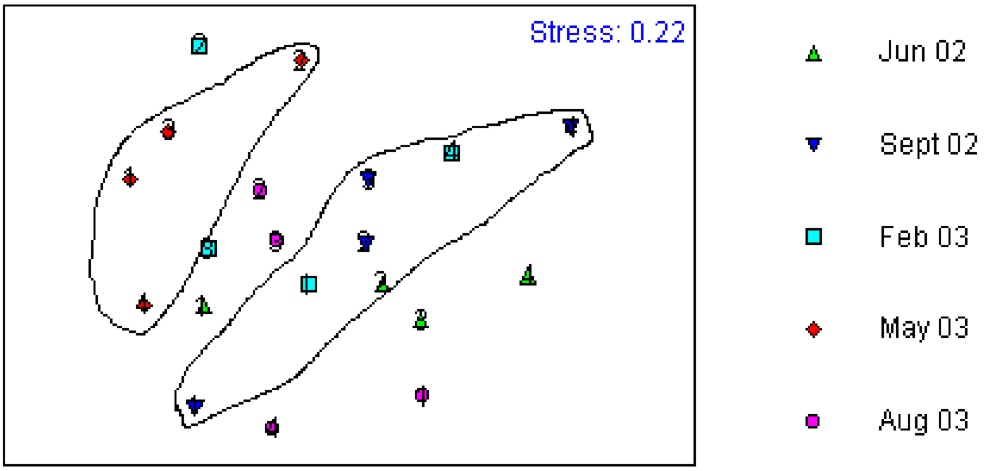

Figure 2.4.7 MDS plot of seasonal differences in abundance of faunal taxa in L. Murree, 2002-3.

Table 2.4.8 Pair-wise comparisons of seasonal differences in presence and absence of faunal taxa in L. Murree 2002-3 (NPManova, * = significant, p <0.05).

Season	**t**	**p**
Jun 02 – Sept 02	0.9707	0.4528
Jun 02 – Feb 03	1.8603	0.0275*
Jun 02 – May 03	1.6565	0.1133
Jun 02 – Aug 03	1.5190	0.1431
Sept 02 – Feb 03	1.2542	0.1704
Sept 02 – May 03	1.4291	0.1130
Sept 02 – Aug 03	1.0282	0.4580
Feb 03 – May 03	1.4005	0.1686
Feb 03 – Aug 03	1.5987	0.0878
May 03 – Aug 03	1.9266	0.0590

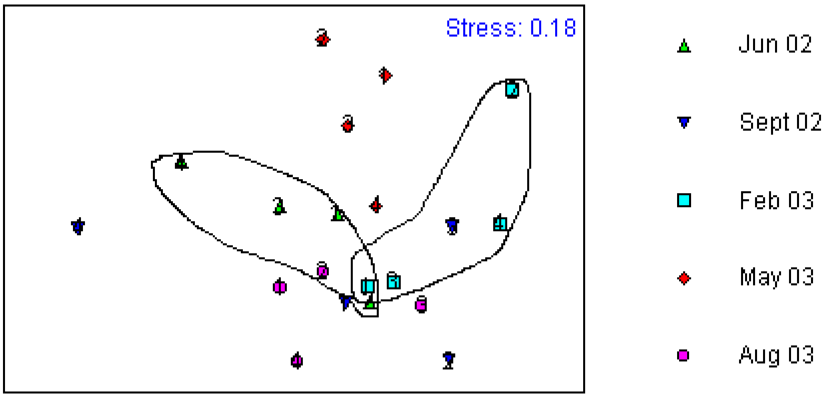

Figure 2.4.8 MDS plot of seasonal differences in presence and absence of faunal taxa in L. Murree, 2002-3.

Using SIMPER analysis, these results are explained largely by the presence of *Lymnephilus* in February 03 but absence in June, in contrast to the presence *Enochrus* and higher frequency of *Ischnura,* Chironomidae and *Neomysis* in June 02. The caddis *Lymnephilus* is only present in February, and to a lesser extent in May, whereas the beetle *Enochrus* was not recorded in September 02 or February 03, but these seasonal differences in presence and absence are not as significant in L. Murree as they are in the more insect-rich L. Gill.

Vegetation in L. Murree

Floristically, Lough Murree is also species-poor, with only 12 taxa recorded during the sampling period 2002-3 (Appendix VI), but 5 of these are lagoonal specialists and 2 are very rare charophytes (*Chara canescens*, *Lamprothamnion papulosum*).

Unlike in Lough Gill, where charophytes were recorded in all seasons, neither *C. canescens* or *L. papulosum* were recorded in Lough Murree in Feb 03 or May 03. Despite the fact that charophytes are not recorded in the winter months and there are apparent changes in abundance of other species, no statistically significant differences were found between seasons when using either floral abundance or presence/absence data (Table 2.4.4).

Seasonal changes in Loch an Aibhnín

Fauna

Faunistically, this site is much richer than the previous two and more similar to that of a rocky shore, but the main body of the lagoon is dominated by dense beds of *Zostera* and *Ruppia*. A total of 120 faunal taxa were recorded during the sampling period 2002-3 (Appendix VII).

NPManova results (Table 2.4.4) show that using faunal abundance, only one pair-wise comparison (6.6%) is significantly different. June 02 is significantly different to Mar 03 using both abundance and presence and absence of faunal taxa. An MDS plot (Primer, Fig. 2.4.9) shows this difference quite clearly, and while it might be expected that fauna recorded in March, following the coldest months of the year, might differ from other sampling periods, it is surprising that June 02 should be so different.

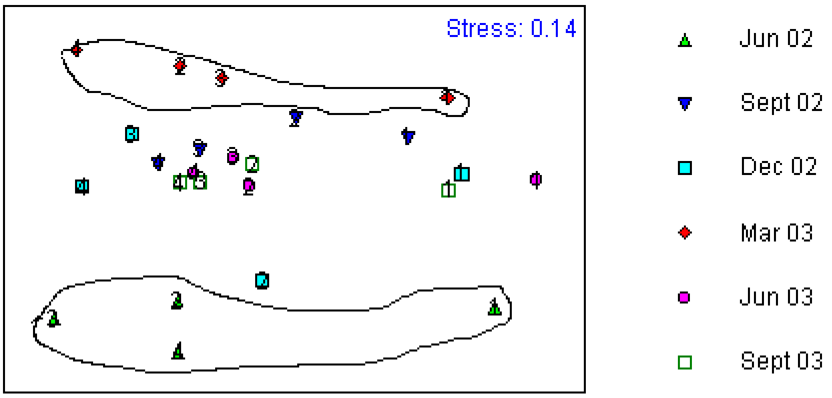

Figure 2.4.9 MDS plot of seasonal differences in abundance of faunal taxa in L. an Aibhnin, 2002-3.

Of the highest contributing taxa, SIMPER analysis (Table 2.4.9) attributes differences between these two months to higher numbers of, for example, molluscs (*Skeneopsis planorbis, Musculus discors, Runcina coronata,* and *Rissoa membranacea*) as well as *Ciona intestinalis* and *Sycon ciliatum* in March 03, compared with higher numbers of mostly crustaceans (*Praunus flexuosus, Palaemon serratus, Idotea chelipes,* *Caprella acanthifera*) in June 02. Of the species selected it appears generally that crustaceans are more abundant in the winter months (Figure 2.4.10) and molluscs more numerous in the summer (Figure 2.4.11). The eleven taxa listed in Table 2.4.9, however, only explain 22.35% of the difference between months. The rest of the statistical difference comprises a large number of very different taxa, present at lower abundance.

Table 2.4.9 Average abundance of dominant faunal taxa at 4 stations combined in June 02 and March 03 in L. an Aibhnin (SIMPER analysis).

	June 02	March 03	% Contribution
Skeneopsis planorbis	0.00	54.00	4.20
Ciona intestinalis	15.00	221.00	3.63
Musculus discors	0.00	7.00	2.48
Gonothyraea loveni	2.50	16.00	2.21
Runcina coronata	0.25	8.00	2.17
Praunus flexuosus	155.00	28.00	1.89
Sycon ciliatum	0.00	14.00	1.86
Palaemon serratus	15.00	2.00	1.73
Idotea chelipes	10.00	4.40	1.40
Rissostomia membranacea	10.00	24.00	1.35
Caprella acanthifera	11.25	5.00	1.29
			Total = 22.35%

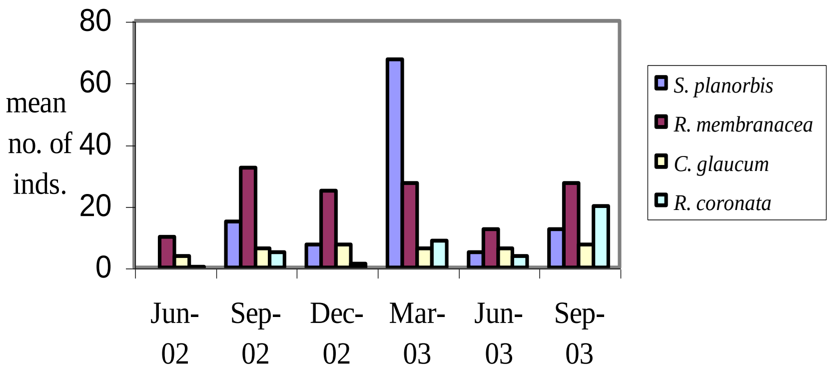

Figure 2.4.10 Seasonal changes in average abundance of dominant molluscan species in L. an Aibhnín, 2002-3.

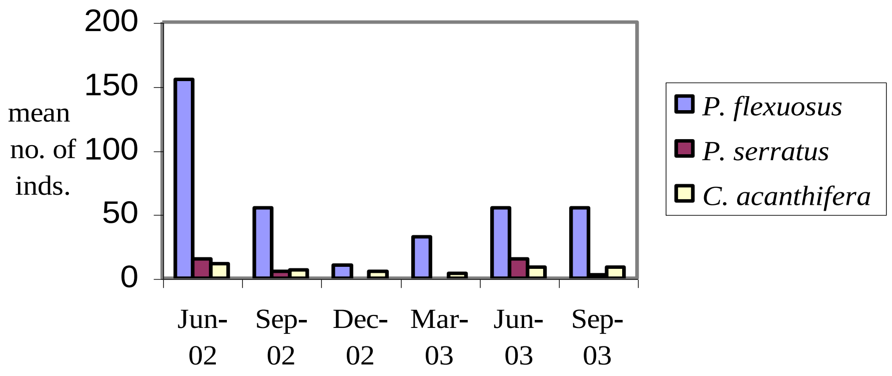

Figure 2.4.11 Seasonal changes in average abundance of dominant crustacean species in L. an Aibhnín, 2002-3.

Of the most numerous lagoonal specialist fauna present in Loch an Aibhnín (*Cerastoderma glaucum, Onoba aculeus, Rissoa membranacea, Idotea chelipes*), the mollusc *R. membranacea* is most abundant in September 02, but this does not appear to be a seasonal phenomena as numbers are relatively low in September 03. All four of these lagoonal specialist species are present throughout the year (Figure 2.4.12), and in general show no clear seasonal differences. Interestingly, the data for *C. glaucum* used in this analysis refers only to spat, which is present in all sampling periods, indicating that this species is reproducing throughout the year with no seasonal pattern.

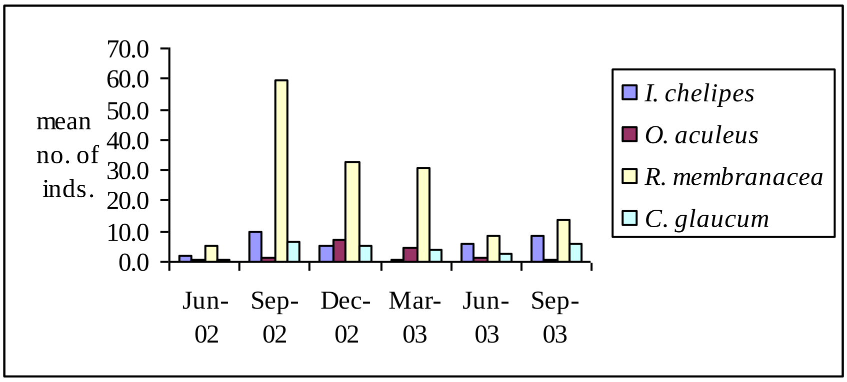

Figure 2.4.12 Seasonal changes in average abundance of lagoonal specialist species in L. an Aibhnin, 2002-3.

Flora in L. an Aibhnin

A total of 49 taxa, recorded during the sampling period 2002-3 (Appendix VIII), plus the categories “bare ground” and “rotting vegetation” were used for statistical analysis, but despite apparent changes and noticeable appearances of certain algal taxa, no significant differences in vegetation between seasons were found either for abundance or presence and absence (Table 2.4.4).

Seasonal changes in Loch Athola

Fauna

A total of 138 faunal species were recorded in L. Athola (App XI). Based on both faunal abundance and presence/absence data, no statistically significant differences were found among seasons. Certain changes are apparent, for example, in abundance and presence/absence of certain amphipod species, (Figure 2.4.13), as eight of the total 22 amphipod species are recorded in only one of the six seasons. Of the six species illustrated in Figure 2.4.13, *Ampithoe rubricata* is present throughout the sampling period in low numbers, *Atylus guttatus* is the most abundant species, but is absent in June 02 and December 02, whereas *Gammarus locusta* is recorded in these two months but not in any others. As with total fauna, there is a clear difference in both abundance and presence/absence of the dominant amphipod species between June 02 and March 03. However, based on a community analysis, these changes are not great enough to be statistically significant.

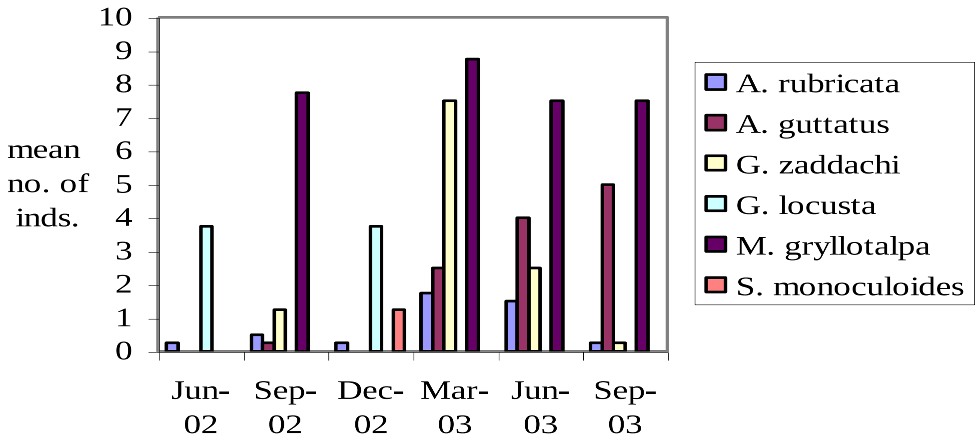

Figure 2.4.13 Changes in average abundance of selected Amphipod species in Loch Athola, 2002-3.

Vegetation in L. Athola

In contrast to Loch an Aibhnín, where there are no significant differences between seasons, the vegetation of L. Athola shows more seasonal differentiation (Table 2.4.4). Using abundance data, Sept 03 is significantly different to both Jun 02 (t = 2.0074) and Jun 03 (t = 1.5239). SIMPER analysis attributes differences between September 03 and June 02 (Table 2.4.10) to higher abundance of C*haetomorpha linum*, *Enteromorpha* and *Mastocarpus/Chondrus* in June 02 and greater abundance of "BARE" rock and rotting vegetation, *Cladophora* and *Polysiphonia* species, *Ruppia* and *Cystoseira tamariscifolia* in September 03. The difference between September 03 and June 03 (Table 2.4.11) is also due to higher abundance of "BARE" rock and rotting vegetation, *Polysiphonia* species, *Ruppia* and *Cystoseira tamariscifolia* in September compared with June suggesting a true seasonal difference, but another major contributing factor is the greater, rather than lower, abundance of *Cladophora battersii* in 2003, the lower rather than greater abundance of *C. linum* and the greater abundance of *Sporochnys/Spermatochnus* and *Cystoseira baccata* in June 03 compared to June 02.

Table 2.4.10 Average abundance of dominant ground cover at 4 stations combined in Sept 03 and Jun 02 in L. Athola (SIMPER analysis).

	Sept 03	Jun 02	%Contribution
Chaetomorpha linum	7.75	28.75	9.18
BARE - rock	35.00	13.75	8.12
Cladophora battersii	32.50	28.75	7.83
Polysiphonia spp.	12.50	1.25	7.26
Cladophora rupestris	6.75	0.00	6.24
BARE – rotting veg.	8.75	1.25	5.88
Enteromorpha sp.	0.50	5.50	4.51
Mastocarpus/Chondrus	1.00	5.50	3.96
Ruppia cirrhosa	5.25	1.25	3.87
Cystoseira tamariscifolia	4.25	1.75	3.56
			Total = 60.42

Table 2.4.11 Average abundance of dominant ground cover at 4 stations combined in Sept 03 and Jun 03 in L. Athola (SIMPER analysis).

	Sept 03	Jun 03	%Contribution
Cladophora battersii	32.50	37.50	9.04
Sporochnys/Spermatochnus	0.75	18.00	8.33
BARE - rock	35.00	12.50	7.23
Cystoseira baccata	1.00	8.75	5.50
Chaetomorpha linum	7.75	2.50	5.05
Polysiphonia spp.	12.50	4.25	4.94
Sphacelaria	0.00	7.50	4.94
BARE – rotting veg.	8.75	3.75	4.47
Ruppia cirrhosa	5.25	2.75	4.44
Cystoseira tamariscifolia	4.25	1.50	3.65
			Total = 57.60

Using presence and absence data there are also two significantly different pair-wise comparisons, but in this case, Sept 03 again differs from Jun 03 but also with March 03, rather than June 02. SIMPER analysis again attributes differences between September 03 and June 03 to the more frequent presence at some stations of *Sporochnys/Spermatochnus*, *Cystoseira baccata*, *Mastocarpus/Chondrus* and *Enteromorpha* in June 03 and the greater frequency of *Cystoseira tamariscifolia* and

Rupiia cirrhosa in September 03, but also to the presence of *Asperococcus fistulosus, Colpomenia peregrina* and *Jania rubens* in June 03, which are not recorded in September 03.

The difference between September 03 and March 03 based on presence/absence is again due to the presence of C. *peregrina*, but also *Sphacelaria* and the absence of *Hildenbrandia* in March 03, together with the greater frequency of "BARE" rotting vegetation, *Cystoseira baccata, C. foeniculaceus, Lithothamnion* and *Ruppia* in September, compared with higher frequency of *Enteromorpha,* and the red algae, *Ceramium rubrum* and *Furcellaria/Polyides*, in March.

The combined results of vegetational changes in L. Athola not only demonstrate some clear differences in terms of percentage cover of taxa found throughout the year and also presence/absence at certain times, of other species, but also that these seasonal differences are more noticeable and significant in one year than other.

Differences among stations within lagoons

Differences among stations within the four sites chosen for study reflect the differences in lagoon type, substrates and relative importance of fresh and seawater inflows. Lough Gill shows a clear gradient among all stations, L. Murree shows a difference between two extreme sediment types, while L. Athola and L. an Aibhnín show clear differences between the tidal inlet station and all 3 of the other stations.

Differences among stations in Lough Gill

Lough Gill has fairly uniform substratum of clean, firm sand but shows significant differences between all stations except between stations 2 and 3, based on both floral presence and absence data (NPManova; $F = 6.3911$, $p < 0.001$; Fig 2.4.14), and abundance ($F = 6.904$, $p < 0.001$), which reflect the salinity gradient (0 - 4psu). Stations 2 and 3 near the freshwater inlet shows a higher relative abundance of

Phragmites, Potamogeton spp. and *Chara aspera* plus other occasional freshwater species. Station 4 shows higher relative abundance of *Ruppia* species and *Scirpus maritimus*, and is located closest to the occasional tidal inlet.

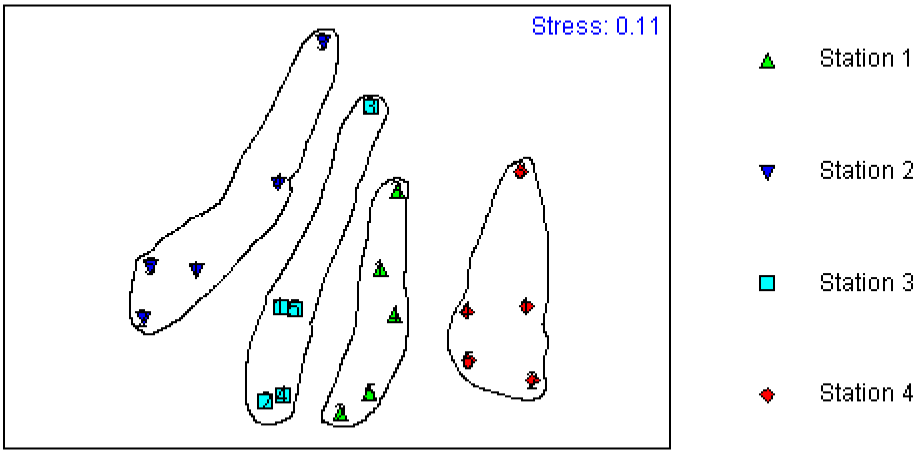

Figure 2.4.14 Multi-dimensional scaling of presence and abundance of floral species by station in Lough Gill. 2002-2003.

Based on fauna, the differences are similar but less clear, with Station 4 significantly different to Stations 2 and 3. At these latter stations, freshwater molluscs, corixids and beetles dominate, whereas *Pomatoschistus microps* and *Lekanesphaera hookeri* are more abundant at Station 4. Station 1 lies midway between these stations and its faunal composition broadly overlaps with that at the other three sites and is not significantly different to any other station.

Differences among stations in Lough Murree

In L. Murree, using floral abundance, all stations are significantly different to all others ($F=6.6087$, $p<0.0001$, Fig. 2.4.15), but using floral presence/absence only Station 2 is significantly different to all others ($F = 4.7410$, $p<0.0001$). On the other hand, using faunal presence/absence, there are no significant differences between stations, but using abundance station 4 is significantly different to all others ($F = 2.2586$, $p<0.0001$). In terms of vegetation, Station 2 is different to all others in having a permanent community of *Cladophora pellucida* covering 20% of the hard limestone substratum. SIMPER analysis reveals that all stations differ in floral abundance with dense beds of *Potamogeton* and *Ruppia* only at stations 1 and 3, and large areas of station 4 having a very soft, muddy substrate devoid of vegetation ("BARE ground"). Station 1 differs from 3 in having greater abundance of *Lamprothamnion papulosum* and *Enteromorpha*. The faunal taxa recorded in L. Murree are likely to be found at all stations, but Station 4 differs in having a greater average abundance of *Neomysis integer,* Chironomids, *Ishnura elegans* and *Ephydra riparia* and lower abundance of *Jaera ischiosetosa, Gammarus duebeni* and *Melita palmata* than all other stations.

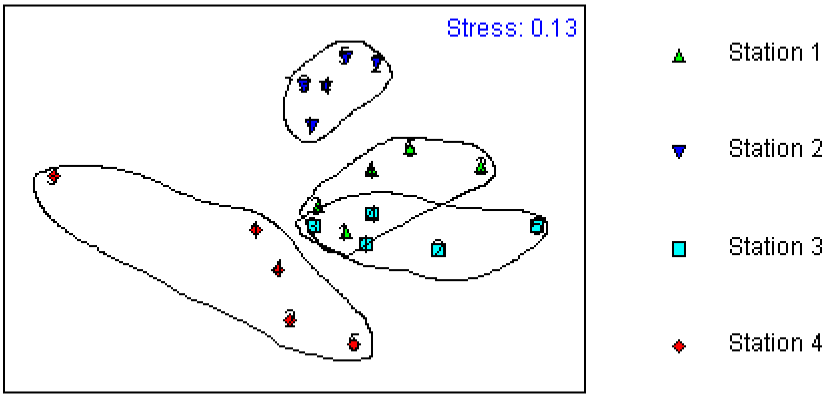

Fig 2.4.15 Multi-dimensional scaling of floral abundance by station in Lough Murree. 2002-2003.

Differences among stations in Lough anAibhnín

Lough an Aibhnín shows significant differences, particularly in terms of presence and absence of fauna (NPManova; F = 4.8530, p=<0.0002) between Station 1, near the tidal inlet, and the other 3 stations. Species such as *Patella vulgata, L.ittorina obtusata,* and many of the amphipod species were recorded only at Station 1, whereas *Cerastoderma glaucum, Conopeum seurati* and *Onoba aculeus* are absent from 1, but found at all of the other 3 stations. Using floral presence and absence, Station 1 is again significantly different to all others (NPManova; F = 9.8004, p=<0.0002), which show no significant differences among themselves. Stations 2, 3 and 4 are all characterised by dense growths of *Ruppia, Zostera* and *Chaetomorpha*, which are all present at station 1, but not in all seasons and never in abundance. Station 1, on the other hand, has certain marine species, such as *Porphyra, Dichtyota,* and *Saccharina,* which are not found at the other stations. As Station 1 was distinct both in terms of fauna and flora, an MDS plot using the combined data sets of flora and fauna revealed just how distinct this station was as compared to the variation among the other sites (Fig. 2.4.16).

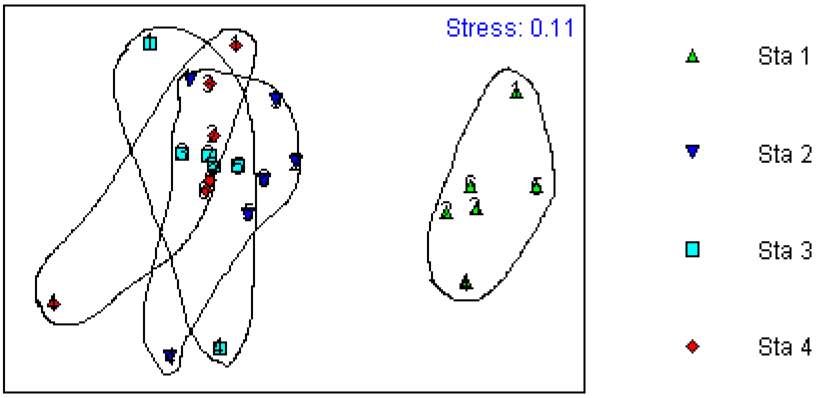

Fig 2.4.16 MDS plot of presence and absence of the combined faunal and floral taxa at 4 stations in Lough an Aibhnín. 2002-2003.

Differences among stations in Lough Athola

Finally, in Lough Athola, an MDS plot for abundance of vegetation (Fig 2.4.17) reveals that station 4 (nearest the tidal inlet) is the most distinct from the other sites, having more "BARE" rock, and marine algal species such as the three *Cystoseira* species*, F. vesiculosus, Ceramium rubrum* and *Mastocarpus/Chondrus,* and less *C. battersii, Chaetomorpha* and *Corallina* than other stations. However, NPmanova shows significant differences among all stations (F = 7.6016, p=<0.0002). Based on both faunal abundance and presence/absence, there are also significant differences (F= 4.2102, 4.0394, respectively, p = <0.0001), with Station 4 significantly different to all other stations due to the presence and abundance of "open-coast, intertidal, rocky shore" species, such as *Asterina gibbosa, Patella vulgata, Calliostoma zizyphinum, Gibbula cineraria, Littorina littorea, Pomatoceros triqueter, Semibalanus balanoides* and many other species. Station 2 differs significantly from station 3, due to the presence and greater abundance of annelids (*Tubificoides benedii, Capitella capitata, Platynereis dumerili*) and species tolerant of lower salinities (*Gammarus aculeatus, Musculus discors, Palaemonetes varians*, *Jaera ischiosetosa* and *Laomedia angulata*) at the former.

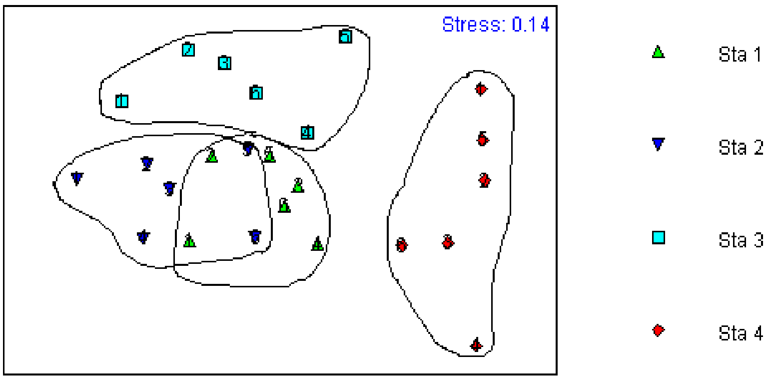

Fig 2.4.17 MDS plot of abundance of floral taxa at 4 stations in Lough Athola. 2002-2003

Summary

1. Comparison of statistical analyses indicates the need for standardisation of data handling as well as of that of sampling procedures. The use of a standardised abundance scale of 0 –1000 appears to be the most appropriate scale to use.
2. Clear statistical differences are seen between many of the sampling periods and the type and degree of change varies according to lagoon type.
3. Seasonal changes in both abundance and presence/absence of the insect-dominated faunal and also of floral abundance, though not presence/absence, are greatest in the low salinity lagoon (Lough Gill)

4. In the highest salinity site (L. Athola), faunal changes occur, but are not statistically significant, whereas differences in abundance and presence/absence of algal taxa in are significant within the year 2003, but not in the year 2002.
5. In the mesohaline lagoons (L. Murree and L. an Aibhnin), seasonal changes are only slight, with most of the characteristic species present throughout the year. In L. Murree, with mean salinity 13 psu, this difference is partly due to changes in certain insect species, whereas in L. an Aibhnin, the difference appears to be related to differences in abundance and presence/absence of crustacean species compared with molluscs.
6. Sampling stations within lagoons also vary considerably, indicating the need for careful selection of stations for monitoring purposes and the need for consistency in sampling the same areas on return visits.

2.5. Discussion

Sampling and data handling

There is an obligation under the Habitats Directive to select representative sites of the habitats listed in Annex I of the Directive and to monitor these sites for maintenance of conservation value. The main objective of investigating seasonal changes in fauna and flora of Irish lagoons was to identify changes and their implications for monitoring strategies. In the U.K. a great deal of effort has been put into formalising sampling procedures to conform to Common Standards (JNCC 1998) in order to make sampling of different sites, ideally throughout Europe, more comparable. These common standards, are aextended in The Marine Monitoring Handbook (Davies *et al.* 2001) have been applied to monitoring coastal lagoons in the U.K. (e.g. Bamber 1998, Bamber *et al.* 2001b, Bamber 2004). The use of the SACFOR scale of abundance from 1 –6 (Crapp 1973, Hiscock 1996, Appendix I), representing "Superabundant", "Abundant", "Common", "Frequent", "Occasional" and "Rare" has been used extensively for marine sites and modified for lagoons in the U.K..

As seen in this study, this scale does not lend itself well to statistical analyses and a translated scale of 0-1000, similar to that used by Sconfietti *et al*. (2003) and Marchini *et al*. (2004) in Adriatic lagoons, gave results closer to those using counts. In one lagoon (L. Murree) all of the faunal data was in the form of counts, resulting from a combined figure of counts from sweep nets, sediment cores and light traps, and this data could be used without translation into a 0-1000 scale. However, in the more marine sites with more species strongly attached to a substrate, over 50 % of the fauna present were recorded only from visual searches, and it was necessary to combine the counts with an abundance score in order to combine all species. In this situation, the 0-1000 scale appears to be a better representation of the data. Sophisticated statistical analyses may not be necessary for monitoring purposes, in which case the SACFOR scale is very simple and useful, but if statistical tests are to be performed, the manipulation of the data needs to be standardised, as well as that of the sampling procedure.

Temporal changes in fauna and flora

The low salinity lagoon, Lough Gill, shows the greatest differences throughout the year especially in abundance of faunal taxa but also in faunal presence/absence and in abundance of floral species. Lough Murree and Lough Aibhnín show relatively little difference between sampling periods for faunal abundance and no statistical differences in faunal presence/absence or either floral abundance or presence/absence, whereas Lough Athola shows no statistical differences in fauna but much greater differences in both presence/absence and abundance of algal species. Seasonal differences are apparent therefore in the four sites studied, especially in the lowest and highest salinity sites, but in some situations, inter-annual differences are also apparent and may be greater than any seasonal difference.

In Lough Gill, over 50% of the faunal taxa are insects. Many insect species decline in abundance or are dormant in the cold winter months and seasonal changes in abundance and presence of these taxa in freshwater systems is well documented. For example, most caddis species (e.g. *Lymnephilus* spp.) overwinter as larvae, pupate in the spring and emerge from the water as adults in early summer (Wallace *et al.* 1990), so they are generally only recorded in aquatic environments during the winter months. Coleoptera exhibit many types of life history. Some are aquatic during the larval or adult phase only and many are only found in the water during the summer months (Balfour-Browne 1940,1950, 1958; Friday 1988). Differences in abundance of permanently resident species are also well documented. Only adult females of the dominant corixid in Lough Gill, *S. dorsalis*, survive through the winter and numbers of these in the winter months are very low. In Britain, eggs are laid in early spring and the first generation matures in July and can produce a second brood so that highest abundance of this species occurs in late summer, September or even October (Southwood and Leston 1959, Savage 1989). Most insect species increase in abundance through the summer and decline or are absent in the winter. Therefore, the profound changes in faunal abundance through the seasons in Lough Gill is primarily due to changes in the insects present, meaning that this low salinity lagoon has a community which varies seasonally in a similar way to that which one is likely to observe in a freshwater stream or lake.

Lough Gill also has a permanent freshwater inlet and some of the seasonal changes may be due to inflow of certain other species such as freshwater molluscs from the stream, especially at times of heavy rainfall and during the winter months. Even freshwater snails, such as *Potamopyrgus jenkinsi*, which are not highly mobile species, have been shown to colonise new areas up to 2 km away within a few months (Lassen 1978). Certain marine species, such as gobies (*Pomatoschistus microps*), flounder (*Platychthys flesus*) and mysids (*Neomysis integer*) also appear to enter the lagoon at certain times of the year through the occasional tidal inlet.

Lough Murree has very few faunal species (n = 17), and of those few, the presence of *Lymnephilus* during the winter (January and May) and *Enochrus bicolor* in the summer months (June, August, September) result in slight differences between seasons. However, based on this community analysis, the differences are not as great as in the insect-dominated Lough Gill. Lough Murree is an isolated lagoon with no permanent connection to the sea or to running fresh water. Seawater enters occasionally by overtopping the barrier, by percolation and possibly through underground fissures, but chances of any seasonal colonisations by water-borne fauna are very restricted. For those faunal species that gain access to the lagoon, chances of survival may also be low. The salinity regime (12-14 psu) is also relatively close to the theoretical critical range of 5-8psu for fauna (Remane 1971, Sheader 1986, Barnes 1989), where both freshwater and marine species find it difficult to survive Botanically, L. Murree is very interesting as it is dominated by lagoonal specialist plants, two of which are very rare and protected by European law (*Lamprothamnion, C. canescens*). The lagoon is generally regarded as eutrophic and algal blooms have been frequent for many years (Pybus and Pybus 1980, C. Roden pers. comm.). Although, statistically, the flora did not vary significantly in terms of percent cover through the year, it was visually apparent that the aquatic plants underwent periods of rapid growth and dominance. Most aquatic plants, whether through germination, or increased vegetative growth of perennials, gain in biomass during the summer and die back in winter. Verhoeven (1980b) describes a curious development of *Ruppia maritima* in Holland, in which plants grow rapidly in the spring, then reach a point in late summer when the plants decay at the base and become detached, then grow vigorously again from the base in autumn before senescing through the winter. As the *Ruppia* decays in late summer, it is replaced by *Potamogeton pectinatus.* In Lough Murree it may be partly due to this decay in late summer that the two charophyte species are able to develop dramatically in monocultural patches of very large plants (50cm length). This process may be enhanced by wildfowl feeding on the *Ruppia*, as witnessed in L. Murree, which supports a wintering flock of Wigeon (*Anas penelope*) and Mute swan (*Cygnus olor*) that arrive in late summer.

Lough Murree appears to go through cycles of algal blooms followed rapidly by intense growth of macrophytes, filamentous algae or charophytes. Such high growth of plants would be expected to lead to anoxic periods later in the year as the plants decayed, which may further restrict the number of faunal taxa which can survive. The combined pressures of restricted recolonisation opportunities, the critical salinity range and fluctuations in salinity, and the possibility of seasonal anoxia presumably restrict the number of faunal taxa present in the lagoon, and those that do occur are able to tolerate the changes and are present throughout the year.

In general, insects dominate freshwaters and crustaceans dominate marine waters. Of the few crustacean species found in freshwaters, *Neomysis integer* was shown to have a bi-modal pattern of seasonal abundance in Lady's Island Lake (Healy 1997) and in Lough Furnace (Parker and West 1979), but in both of these Irish studies there are also dramatic differences between some years. The bi-modal pattern of *Neomysis* appears not to be supported in Lough Gill, with only a spring peak in June 02 and a lower peak in May 03. Differences between "seasons" may therefore be partly due to differences between the two years, although statistically there is no significant difference between September 02 and August 03, or June 02 and May 03.

It is interesting to note that charophytes are recorded in all seasons in L. Gill, but are not recorded in winter in L. Murree. In Ireland, these species generally decrease in winter, but according to Moore (1986) the Characeae (mainly species of *Chara*) may form perennial dense carpets in stable habitats. In The Fleet (U.K.), Johnston & Gilliland (2000) describe *Lamprothamnion* as an annual, but in a letter dated 1987, published in that report, Moore describes it as "probably present throughout the year", and in the even milder winter climate of western Ireland the same is likely to be true. Charophytes were found on the strandline at L. Murree in January, and *Chara canescens* was recorded in February 03 and May 03 in L. Gill but not in L. Murree. Lough Gill is shallower than L. Murree and the substrate is clean firm sand, more sparsely vegetated than L. Murree. In the deeper, often more turbid water, and often with dense growths of the filamentous algae (*Chaetomorpha, Enteromorpha* and *Cladophora*) in Lough Murree, it may be that the charophytes were present, but were much rarer or more difficult to find and therefore were not encountered when in very low abundance following this sampling regime.

Some stations in the two more marine lagoons (Aibhnín and Athola) are more like intertidal or subtidal marine systems. Seasonal variation on rocky shores is well documented, such as by Lewis (1964) and by Stephenson and Stephenson (1972) among many such studies. On marine rocky shores, Lewis (1964) describes how the delicate and short-lived algae tend to grow in the winter or spring, and die away or "migrate" downshore as the summer advances. Algae with thin membranous parts may lose these parts in the autumn and winter storms, leaving only the tougher midrib or stipe (e.g. *Membranoptera, Delesseria*) (Hiscock 1986). These seasonal variations are often related to the reproductive cycle of marine fauna which move inshore or offshore to spawn and to marine algae adapted to different light intensities. For example, most of the population of the prawn, *Palaemon serratus,* moves offshore in winter and return in spring (Fish & Fish, 1989). According to Barnes (1974) similar seasonal migrations of shallow-water decapod crustaceans are particularly characteristic of estuarine and other brackish habitats. But many other less mobile species such as the echinoderms *Echinus esculentus, Psammechinus miliaris, Asterias rubens* and *Henricia sanguinolenta* may also extend further up the shore in their summer seasonal migrations (Lewis 1964).

In both of the more marine lagoons, the number of faunal taxa is high, but the two lagoons differ slightly in salinity with the result that L. an Aibhnín contains a much higher proportion of mesohaline lagoonal specialists than L. Athola, which is dominated by euhaline marine species. Both have permanent tidal inlets and seawater can enter at least twice every month, so in both sites marine species can enter and leave the lagoon frequently. This was actually witnessed on one occasion when shoals of sprat (*Sprattus sprattus*) entered L. an Aibhnín. There are many examples of these changes, and when individual taxa are concerned, there are noticeable differences between seasons and years such as for certain molluscs and crustaceans in L. an Aibhnín (Figures 2.4.10, 2.4.11) and amphipods in Loch Athola (Figure 2.4.13) but because the number of species is so high, slight changes in presence or abundance of some of the taxa do not result overall in significant differences. This is likely to be the case in all lagoons with a frequent tidal inflow.

In terms of vegetation, the lower salinity Loch an Aibhnín is dominated by a large percentage cover of permanent species (*Zostera, Ruppia, Chaetomorpha*) in the more "lagoonal" environment, whereas in L. Athola, various species of marine algae alternate in relative abundance.

There is a certain amount of information available concerning year-to-year variations in abundance and population dynamics of selected species (Healy 1997), but very little on changes in communities between seasons in lagoons of the temperate/oceanic region. Of the studies conducted in European lagoonal habitats, most are concerned with lagoons in the micro-tidal Mediterranean and Baltic Seas, but these two areas are in many ways climatic extremes. In the Baltic, breeding seasons are very short and much of the coastal area freezes over in winter and day length is extremely short. This situation causes widespread mortalities or migration (Redeke 1933, Segerstråle 1957, Muus 1967, Verhoeven 1980). At the other extreme, many lagoons in the Mediterranean (Amanieu *et al.* 1977, Sacchi 1979, Marchini *et al.* 2004), and on the Atlantic coast of Portugal (Fonseca *et al.* 1989, Costa *et al.* 2003) and southwest France (Amanieu 1967, Labourg 1978) may undergo dystrophic crises in the summer resulting from high nutrient, temperature and salinity levels that also cause declines or mortalities and/or migration of the biota followed by regrowth or colonisation in the autumn through to the following summer. Similar conditions to the Baltic extend to a decreasing degree to the SW Netherlands (Verdonschot *et al.* 1982) and even to parts of Britain, but such conditions are far less extreme on the west coast of Ireland.

Information from other Irish lagoons

Population density of *Neomysis* varied seasonally in Lough Furnace (Parker and West 1979) and Mauchline (1971) related such fluctuations to seasonal variation in breeding activity. Others have associated these changes with migrations to deeper and more saline waters in response to falling temperatures (Kinne 1954, Muus 1967a, Barnes *et al.* 1971), but Parker and West (1979) suggest that in the relatively milder and stable conditions of L. Furnace there is no evidence of a migratory response to falling temperature since over-wintering populations were present in three out of four years.

In Lady's Island Lake species such as *Lekanesphaera hookeri* and *Idotea chelipes* produced two or even three broods a year (Healy *et al*. 1982, Norton and Healy 1984, Healy 1997) so that populations tended to peak in late summer, but any seasonal pattern is partly obscured by deliberate breaching of the barrier and most studies of this lagoon have concentrated on inter-annual rather than seasonal changes.

Pybus and Pybus (1980) recorded two peaks of phytoplankton in L. Murree, one pre-winter and the other post-winter. Diatom populations collected from mud samples showed no pronounced seasonal alterations in generic composition. Euglenoid flagellates, while being common in all but the winter months never dominated the flora as they would in a nutrient rich alkaline fresh-water lake (Round 1965) and perhaps surprising was the lack of any well-developed zooplankton, similar to that reported for Swanpool (Crawley *et al*. 1979) and Salts Hole in England (Hunt 1971).

Information from British lagoons

Of the few seasonal studies carried out in lagoons in the U.K., are those of Swanpool in Cornwall carried out over several years (Barnes *et al.* 1971, Dorey *et al.* 1973, Barnes *et al*. 1979, Crawley *et al.* 1979, Little 1984, 1986), a brackish pond in Hampshire (Bamber *et al.* 1991a) and a four year study of invertebrates in Essex by Mason (1986).

In the Swanpool, over four years, the naidid oligochaete *Nais elinguis* was found in high densities only from January to May, usually with a peak in March (Little 1984). However, in a preliminary study in 1978 this species was common in November and the apparent regularity during the study period may have been to some extent coincidental. The decline in *N. elinguis* was followed by a rise in populations of chironomid larvae (Little 1986), which were most often recorded in the summer months, but peak densities at the two stations sampled did not coincide. Ostracods were present only from January to May. Most meiofaunal species, including *N. elinguis*, reached peak densities in the spring, dependent upon the growth of the Aufwuchs. Other meiofaunal populations peaked in summer, possibly controlled more by limiting values of salinity and temperature but two of the species showed irregular bursts in numbers (Little 1986).

Crawley *et al*. (1979) found that many of the algae were more or less present throughout the period and that marked changes occurred in the phytoplankton but the changes did not conform to any clear seasonal pattern such as that typical of many temperate freshwater lakes. Of the macrofauna, Barnes *et al* (1979) found that populations of *P. varians* and *N. integer* showed regular seasonal cycles, with large numbers present in the summer but few or none present in the winter, due to migration from the lagoon in winter. Most of the fish species (*A. anguilla, P. microps, G. aculeatus, P. flesus*) also appeared to make seasonal migrations into the pool resulting in summer maxima, but the amphipod,*Gammarus chevreuxi,* was present throughout the year (including ovigerous females) but showed irregular fluctuations in numbers apparently unrelated to season.

Generally, these results from Swanpool show changes through the year that are in some cases seasonal, such as the macrofaunal migrations, but it is not known how typical this phenomenon is for other temperate lagoons. Other changes appear to be seasonal but are not always repeated in subsequent years, while others are completely irregular. It is interesting to note that the lagoonal specialist, *G. chevreuxi,* is present throughout the year but shows irregular fluctuations, apparently unrelated to season.

In the brackish pond at Calshot, Bamber *et al*. (1991a) found that seasonal trends in the benthos were dominated by recruitment of small annelids in spring-summer and chironomids were densest in spring 1988 but decreased after February in the following year. Of the natant fauna, mysids (*Praunus flexuosus*) were only common from May to September and none were caught between October and April, presumably due to migration as in Swanpool. Prawns were present throughout the year but migrations along the pond system were evident. The plankton of the pond was considered negligible, but occasional summer blooms of flagellate phytoplankters were observed. In a study of invertebrate populations in relation to breeding success of Avocets in lagoons on Havergate Island, Essex, Mason (1986) found that high summer salinities in the shallow lagoons caused poor invertebrate productivity or mortalities. In some ways these small, shallow lagoons are subject to dystrophic crises similar to those found in some Mediterranean lagoons.

Summary of seasonal changes

Seasonal changes in the four Irish lagoons vary according to their degree of isolation and the frequency of freshwater and/or tidal inflow. Lower salinity lagoons, dominated by insects, behave more like freshwater lakes, whereas higher salinity lagoons behave more like coastal marine systems, and the changes expected between sampling periods may be more apparent in the insect dominated lagoons. In the two mid-salinity lagoons (L. Murree and L. an Aibhnin) seasonal changes occur but are less significant. Despite these changes in abundance, lagoonal specialists are remarkably resilient to changes in environmental conditions and it is suggested by Bamber *et al*. (1992b) that it is for this reason that the lagoonal specialists are more capable of survival than their freshwater or marine competitors. Most lagoonal species are present throughout the year and this is supported by the example of the four most abundant lagoonal specialists in Loch an Aibhnín (Figure 2.4.12). In this example the mollusc, *Rissostomia,* appears to be more abundant in 2002 than 2003, but the other three species show no great differences between any of the sampling periods. Most noticeable about these results is that *Cerastoderma glaucum* spat is present throughout the year in both years. Many of the other changes recorded in the four Irish lagoons are however more related to inter-annual changes as to any seasonal changes.

Community changes between years.

In this study there are only two years to compare, yet there are several apparent differences in community composition between these years. Any such change may be due to a change in climatic conditions between years, to some form of change caused by management or an irregular population explosion or decline. For example, in Lough Gill there appear to be differences between the two years, with higher numbers of *Neomysis, Potamopyrgus* and corixids recorded in 2002, but higher numbers of Ephemeroptera, Hydracarina and certain beetle species in 2003. This pattern is reflected to some extent by the vegetation, in that *Cladophora* is more abundant in 2002, whereas the charophytes *Chara canescens* and *Chara aspera*, as well as the *Ruppia* spp. were much more abundant in 2003. According to local anglers, in 2003 Lough Gill was "the best they had seen it for many years" (M.J.O'Shea pers comm.). This change was believed locally to be due to the fact that the north-eastern part of the lagoon had been dredged in order to remove an accumulation of sand. The dredging may have allowed slightly more saline water to enter the lagoon and an accumulation of nutrients to be flushed from the lagoon.

Differences between years were also found, for example in presence/absence and abundance of algal species in L. Athola, and although not statistically significant changes are also apparent in molluscan and amphipod species in both L. Athola and L. an Aibhnín. Long term studies of rocky shores, such as on Sherkin (Bishop 2003), have shown similar variations for a wide range of species. These variations may be due to natural cycles or non-cyclical extreme events. Fucoid species are generally regarded as perennial, long-living species, but monitoring on Sherkin Island over 20 years has shown that 4 species were common in the 1980s, declined around 1990, and from 1996 to the present, some species (e.g. *Laminaria digitata*) are totally absent from certain long-term monitoring sites (Bishop, 2003). The author of this report suggests that these changes may be related to recorded changes in sea temperature during the period. Such changes may also be related to global warming, or to changes in the North Atlantic Oscillation.

Information from other Irish lagoons

Of the few studies carried out in Ireland, Healy (1997) found wide fluctuations in salinity and water level in Lady's Island Lake due to more or less regular breaching of the barrier. Observations over seventeen years revealed changes in the salinity regime every two to four years, with poly-euhaline phases alternating with oligo-mesohaline phases. Vegetation either grew luxuriantly or was nearly absent, and when present was dominated by *Ruppia cirrhosa* or *Potamogeton pectinatus*, depending on salinity. Faunal species also replaced each other following changes in the salinity regime. For example, *Neomysis integer* replaced *Praunus flexuosus* following a fall in salinity from 24psu in September 1976 to 9psu in March 1977. Hydrobids replaced each other more gradually as *Hydrobia ventrosa* (=*Ventrosia ventrosa*) persisted throughout 1977-8 and coexisted with the more abundant *Potamopyrgus antipodarum* into the 1980s, but following the catastrophic mortalities of the mid-1980s, *H. ventrosa* was slow to return and numbers remained low until 1991. Periods of gradual change were, however, punctuated by sudden changes and widespread mortalities, as for example, in 1985, when the breach in the barrier remained open for longer than usual, water levels dropped considerably, exposing benthic fauna and allowing relatively greater volumes of seawater to enter. Much of the pelagic lagoon biota was flushed from the lagoon and the rise in salinity caused by the inflow of seawater, subsequently concentrated by evaporation, caused mortalities of lower salinity species. The brackish component of the fauna appeared to be persistent over the seventeen years but population density fluctuated widely. Clearly there are dramatic changes in the biota of Lady's Island Lake between years, but this lagoon is somewhat exceptional in that many of these changes are unusually large because management attempts caused by the deliberate breaching of the barrier produce far-reaching changes in environmental conditions (Healy 1997), beyond what might be expected for natural variations occurring in an un-perturbed system.

Neomysis integer was shown to have a bi-modal pattern of annual abundance in Lady's Island Lake (Healy 1997) and in Lough Furnace (Parker and West 1979), but in both studies there are also "dramatic" differences between some years. In Lady's Island Lake, these fluctuations are at least partly related to changes in salinity regime breaching of the barrier and consequent competition with *Praunus flexuosus*, but in L. Furnace, *Neomysis* was said to be absent from the lough in one out of the four years of study and appears to be subject to occasional violent population crashes with slow recovery over several generations.

Some interesting comparisons can be made between the biological community of Lough Murree in 1973 and 1974 described by Pybus and Pybus (1980) and that found on a number of visits between 1996 and 2003. For example, Pybus and Pybus refer to the charophytes *Chara canescens* and *Lamprothamnion papulosum* "in the shallow waters at the south end" and the corixid *Sigara stagnalis* common in the same area where one specimen of the water beetle *Enochrus halophilus* was also found. Salinity does not appear to be any different between the two periods but from 1996 to 2003 the substrate in this area consisted largely of unvegetated, very soft mud and charophytes were never recorded here. The corixid was extremely rare between 1996 and 2003 and only found in the northern part of the lagoon but *Enochrus bicolor* was relatively common. Obviously there are differences between the two periods but it is not known which is the more typical condition.

Inter-annual differences in British lagoons

In Britain, Gilliland & Sanderson (2000) studied *Alkmaria romijni* and found numbers per square metre ranging from 5000 in one year, down to 20 or zero in most years with no evident pattern, and Bamber (2004) showed fluctuations in the populations of *Cerastoderma glaucum* and *Idotea chelipes* between years in Hampshire, "often without a consistent pattern between adjacent lagoons". Other taxa such as the amphipod *Gammarus chevreuxi* (Barnes *et al.* 1979), and hydrobiid species (e.g. Cherrill and James 1985, Barnes 1988) have been shown to exhibit fluctuations in abundance with no clear pattern.

In the Swanpool a 'bloom' of *Cyclops agilis* appeared in 1979 (Crawley *et al.* 1979) but this appears to have been an isolated incident (Little 1986). In the summer of 1968 the water-boatmen, *Sigara stagnalis,* and to a lesser extent *S. dorsalis* were extremely abundant, whilst *Palaemonetes* was scarce. During the autumn the numbers of *Sigara* declined and remained low throughout the whole of 1969. In the summer of 1969 there was an 'explosion' in the numbers of *Palaemonetes*. In 1970 *Neomysis integer*, previously unrecorded 'appeared from nowhere' and became co-dominant with *Palaemonetes.*

Apparently, Swanpool is characterised by the sporadic abundance of individuals of one or more of the species and during the periods of study, some species were present in fairly consistent numbers while others became enormously abundant (during summer months) in one year but not in others (Dorey *et al.* 1973).

Summary of changes in biota of the four Irish lagoons

Results of this study of four Irish lagoons suggest that both seasonal and inter-annual variations in the mesohaline lagoons (L. Murree and L. an Aibhnin) are far less significant than in the low salinity L. Gill, and in terms of flora, in the higher salinity L. Athola. As Healy (2003) points out, "most of the brackishwater inhabitants of the few Irish lagoons which have received frequent visits, and also differences between similar sites, appear to be persistent, with the same species being found when sites were sampled a decade or more later". For example, of the lagoonal specialists, *Gammarus chevreuxi* in Kinsale (Galvin 1992, Oliver Chapter 3), *Cerastoderma glaucum* in Lady's Island Lake (Healy *et al*. 1982, Healy 1997, Oliver 1999) and *Littorina "tenebrosa"* in the North Slob (Healy 2003). It is also interesting to note that in L. an Aibhnín, although 30 % of the species recorded in 2002 and in 2003 were only single occurrences, not found in both years, the total number of faunal taxa in each year was 106 and 108 in 2002 and 2003 respectively. This number is remarkably similar to the 105 recorded in 1998. Of the characteristic faunal and floral lagoonal specialists, the 14 species recorded in 1998 were present in both 2002 and 2003.

Although populations may fluctuate, this persistence has also been found in the U.K. by Barnes & Heath (1980) and Barnes (1987). This implies that for monitoring purposes, one may expect inter-annual changes in the faunal and floral community of a lagoon to occur, which are of an equal or greater magnitude than that related to seasonality.

Among stations comparisons

Significant differences were found in the fauna and flora in different parts of the same lagoon in every lagoon examined. Those parts of the lagoon nearest to freshwater or marine inlets often have the most distinct fauna and flora from the rest of the lagoon, but differences caused by substrate, depth, type of shoreline and adjacent land use may be equally significant. In particular, lagoons with a salinity gradient, as seen in L. Gill, may be very different at the two extremes of the lagoon. Such variability is well documented for example in Lady's Island Lake (Healy *et al*. 1982, Healy 1997) and the largest lagoon in the U.K., the Fleet (Johnston and Gilliland, 2000). Differences between stations may also be very temporary, however. Fish shoals and *Neomysis* "swarms", for example, are highly mobile and, by definition, extremely patchy in distribution. Several of the algal species are unattached (*Enteromorpha intestinalis, Cladophora vagabunda, Cladophora battersii, Chaetomorpha linum*) and can form large floating rafts, which often move about the lagoon depending on wind strength and direction. Large floating masses of decaying vegetation, with or without living algae may behave in a similar way, and react very quickly to a change in wind direction.

Weather conditions may also affect abundance estimates for different species. For example, in January 03, Lough Murree was frozen on one day, and such cold weather undoubtedly would affect animal activity. The cold spell at the beginning of the year was followed by strong winds, and certain animals (corixids, beetles) are likely to cling tightly to vegetation at times of increased water movement.

Sampling implications for lagoon monitoring.

Sampling protocol for marine sites is described in Davies et al., (2001) and for lagoon monitoring in the U.K. (Bamber *et al.* 2001b, Bamber 2004, Symes and Robinson 2004). Results of this study have shown that the timing of visits will depend to some extent on the salinity regime of the lagoon, and therefore monitoring protocol will vary with the particular species of conservation interest. Low salinity lagoons are dominated by insect taxa, which vary considerably with season, both in presence and abundance, and if these are the species of interest, then monitoring should be concentrated in late summer and early autumn.

Of particular importance in Ireland is the importance of coinciding the monitoring of the more marine lagoons with neap tides, as opposed to monitoring rocky shores on spring tides. On the open coast lowest water levels occur at Extreme Low Water Spring tide, whereas in coastal lagoons, the time lags of tidal water entering and leaving the lagoon caused by frictional drag (Hill 1994) result in lowest water levels occurring immediately after the lowest Low Water Neap tide. The difference in water depth between these tidal heights makes a considerable difference to sampling efficiency and in these lagoons, tidal state is more important than season when planning to monitor faunal and floral assemblages. This is not always possible, given the small window of opportunity of the right tide and weather conditions, and the number of lagoons that may need to be visited, but is extremely important and may affect survey results considerably.

Many of the characteristic lagoonal specialist fauna and flora and the fauna of more marine sites can be found throughout the year and could be surveyed in colder months of the year. Abundance may vary, but mere presence and absence may be as useful a figure as one of abundance. It is even suggested that for some species, for example *Neomysis*, that due to their patchy distribution, quantitative estimates are almost impossible (Mauchline 1971), but at least relative abundance in the form of a modified SACFOR scale should be recorded. It is normal to monitor vegetation in the summer months, but all floral species recorded in L. Murree, including the two red data charophytes, were found on the strand line of the lagoon in January, at a time when any other sort of sampling was impossible. On the other hand, *Ruppia* can only be identified to species with certainty, by flowering heads, which in the lagoons sampled were only present for a very short period in late summer.

Monitoring protocol for coastal lagoons will therefore depend on the lagoon type and the faunal and floral species of particular conservation concern. Other physical attributes, required under the Habitats Directive, for monitoring conservation status of lagoons such as size and depth are straight forward, but it will be very hard to attain a meaningful figure for target values such as numbers of rare plants or animals, as suggested for terrestrial sites.

2.6 Conclusions

1. Significance of statistical tests vary according to data transformation and there is therefore a need to standardise the handling of data as well as sampling methods if statistical tests are to be performed. The standard method of using the SACFOR scale of abundance for marine fauna does not lend itself well to statistical analyses and a translated scale of 0-1000 appears to be more satisfactory. However, perhaps sophisticated statistical analyses are not necessary for monitoring purposes. This decision will depend a great deal on financial and manpower resources available.
2. Seasonal variations appear to be much greater in low salinity lagoons and it is more critical for monitoring purposes to sample these lagoons in similar seasons each year. Most species are scarce in the spring and increase in abundance towards late summer. Sampling should therefore concentrate on the period between July and September.
3. Marine algal species appear to vary in both presence/absence and abundance to a much greater temporal degree than fauna, and this should be expected when monitoring the more marine sites.
4. The fauna and flora of mesohaline lagoons and the fauna of the more marine sites show apparent changes between visits but these variations are not statistically significant in relation to season. The seasonal timing of visits to these sites is therefore not as critical, but weather conditions and day-length are disadvantages in winter months. In lagoons with a strong tidal influence, monitoring should be carried out following neap tides, to coincide with lowest and more similar tidal heights.
5. The fauna and flora of sampling stations within the same lagoon may vary considerably, and great care should be taken in selection of sample areas and in revisiting precisely the same areas for monitoring purposes.

CHAPTER 3

3.Biological classification of Irish coastal lagoons

3. Biological classification of Irish coastal lagoons

3.1 Introduction

Coastal lagoons are one of only seven marine habitats listed in Annex I of the European Habitats Directive (92/43/EEC) compared with almost two hundred terrestrial habitats. They are also the only one of the seven habitats listed as a "priority habitat" in "special need of protection". The terrestrial habitats listed in Annex I are well studied and defined but the marine habitats are far less well known. The original definition of a coastal lagoon, according to the interpretation manual of the Habitats Directive (CEC 1996) was: "expanses of shallow coastal salt water, of varying salinity or water volume, wholly or partially separated from the sea by sand banks or shingle, or, less frequently, by rocks. Salinity may vary from brackish water to hypersalinity depending on rainfall, evaporation and through the addition of fresh seawater from storms, temporary flooding by the sea in winter or tidal exchange. With or without vegetation from *Ruppietea maritimae, Potametea, Zosteretea* or *Charetea* (CORINE 91:23.21 or 23.22)." A later version of the manual revised the definition to include unusual types of coastal lagoon such as the Baltic "flads and gloes" and the Scottish "obs", and also artificial lagoons such as "salt basins and salt ponds…providing that they had their origin on a transformed old natural lagoon or on a salt marsh, and are characterised by a minor impact from exploitation." Member States may interpret the definition as they think best in the interests of nature conservation, but along with the problems of defining coastal lagoons are problems of classification of the various lagoon types.

Historically, the emphasis in the classification of brackish waters was in relation to salinity and attempts to relate the distributions of species to the various salinity zones (e.g. Redeke 1922, 1935; Välikangas 1926, Aguesse 1957, D'Ancona 1959, Den Hartog 1964a, Heerebout 1970, Remane and Schlieper 1971, Parma and Krebs 1977, de Kroon *et al*. 1985). Salinity zones were standardised by the Venice system (Anonymous 1959), and most researchers in brackish waters have continued to use this system. Salinity is generally regarded as a "master factor" (Heerebout 1970, Den Hartog 1974) in determining species distributions and typology of brackish waters, or at least a powerful surrogate for covariables of salinity. However, it is difficult to decide which measure of salinity is the most appropriate measure to use (mean, minimum, maximum, range, variability, occasional extreme values) and to collect sufficient data to show precisely how salinity affects the inhabitants of the system.

The definition according to the Habitats Directive is based largely on geomorphology and when describing a lagoon and they are most often classified according to morphological types (e.g. Barnes 1980, Covey *et al*. 1998, Healy and Oliver 1998, Bamber *et al*. 2001b, Healy 2003). While this is a convenient way to describe many of the sites, there is a certain amount of difficulty involved in describing lagoons which have a combination of geomorphological features, or are unusual lagoon types not covered by the definition. Besides, the Directive was intended to give protection to the biological community which the habitat contains, and it would be very useful to have a biological classification of the sites, regardless of the morphological type, which often bears no relationship to the biological community they contain.

A biological classification of "*Ruppia* based communities" in several parts of Europe was given by Verhoeven (1980a) based on flora and fauna, and many of the areas he studied are lagoons. Lagoons are listed in the marine biotope classification of Britain and Ireland (Connor *et al.* 1997a, 1997b) and Scotland (Covey and Thorpe 1994) and the biotopes within lagoons are described, but the classification of the lagoon itself still relies heavily on salinity or geomorphology, rather than on the biological community, which the Habitats Directive is intended to protect.

Surveys were carried out in Ireland of 20 lagoons in 1996 (Good and Butler 1998, Hatch and Healy 1998, Healy and Oliver 1998, Oliver and Healy 1998) and of 16 lagoons in 1998 (Good and Butler 1999, Healy 1999a,b; Oliver 1999, Roden 1999). An additional 24 lagoons were sampled in 2002 and 2003 as part of the present study.

At present, information is lacking for a small number of lagoons in Northern Ireland, but 58 lagoons of the total number of 102 lagoons and “lagoon-like” habitats in the Republic of Ireland have now been surveyed, representing 87% of the total habitat in the country (Chapter 4). Having gathered data from a large percentage of the lagoons within the country it would be very useful to have a system which helps to describe and classify them based on their biological community using species or communities as indicators of complex conditions. The objective of this study therefore is to analyse faunal and floral data collected in these surveys, attempt a biological classification of these lagoons, and discuss implications for management and monitoring.

3.2 Methods

Experimental design

Twenty-four lagoons were surveyed in 2002-2003 and taxon abundance data were recorded. Four other lagoons surveyed previously to this study were surveyed seasonally during 2002-3 (Chapter 2) and data from these four lagoons in the autumn season (August/September) of 2003 was combined with the 24 lagoons to give a total of 28 lagoons (with 113 stations in total) for analysis using taxa abundance data (Appendices XII, XIII). Taxa abundance data from the stations within these 28 lagoons were then converted to presence/absence data for the lagoon as a whole, and combined with presence/absence data from previous surveys in 1996 and 1998 of 32 other lagoons (Hatch and Healy 1998, Oliver and Healy 1998, Oliver 1999, Roden 1999) to provide presence/absence data from 60 lagoons for analysis (Appendices XV, XVI).

The number of stations sampled within each lagoon varied according to the size and environmental diversity of the lagoon, from a minimum of three in some small lagoons to a maximum of six in the largest. Positions of stations were determined using a GPS Personal Navigator (Global Positioning Satellite, Garmin GPS 45). Each sampling station measured 25m x 20m, to give an area of 0.05ha. At each sampling station, the depth of water and substrate type was recorded. Salinity (psu) and temperature were measured using a conductivity meter (WTW LF330) and tidal exchange estimated, based on visual estimates of the increased height of water at high tide (ranging from 0 to 1m), using local predicted tide tables. Notes were made concerning lagoon type, type of barrier, surrounding land use and apparent threats to the lagoon.

Aquatic fauna

All species recorded are listed with authorities in Appendix I. Faunal sampling at each station was mostly confined to depths of less than 1m, but additional samples were also collected by snorkelling to depths of up to 2m. Faunal samples were collected by a combination of sweep-netting, sediment cores, light-traps and timed searches. Sweep nets (1mm. mesh, 25 x 25cm diam., Alana Ecology) were used for a timed period of one minute and were replicated three times per station. Three sediment cores (8cm diam.= $0.005m^2$) were taken at each of 3 random positions at each station, and sieved (1 mm. mesh) *in situ*. The 3 cores from each position were then combined into one, resulting in 3 sediment samples from each station. Timed searches were carried out by close inspection of stones and vegetation for a maximum duration of one hour at each station. As additional species became harder to find the "5-minute rule" was applied, such that if, in a timed period of 5 minutes, no additional species were recorded the search was terminated. Light-traps were left overnight at each station: These consisted of a perspex box (25x25x25cm) containing a chemical light (Starlight). The boxes were constructed according to the model described by Holmes and O'Connor (1988). Fyke nets were used in all lagoons unless water depth was too great or water levels too low (lagoons surveyed in 2002/3 tended to be smaller than those sampled previously in 1996 and 1998, and nets were not used in 8 of the 28 lagoons). The nets used are referred to as summer fyke nets (Moriarty 1975, Poole 1994) and consist of two 3m traps, facing each other, joined by a 6m leader net, mesh size 16mm. The trap at each end consists of two chambers and a cod end, with knot-to-knot mesh sizes of 16, 12 and 10mm, respectively. Nets were generally placed at right angles to freshwater inflows or tidal inlets in order to trap fish swimming from either direction. Nets were set in the evening, left overnight and retrieved in the morning. A small number of fish were retained for identification purposes, but all other individuals were returned alive immediately following retrieval of the nets.

Faunal samples were preserved in 70% alcohol and stored for subsequent identification. Nomenclature used in results for most of the marine fauna are those according to Costello *et al*. (2001) and Hayward and Ryland (1995) when not listed in the former. Other nomenclature used is according to Ashe *et al*. 1998 (aquatic insects) and Kerney 1999 (freshwater molluscs). Certain groups were identified or certain species verified by relevant specialists: Amphipoda (D. McGrath, S. de Grave), Hemiptera (B. Nelson), Ephemeroptera (M. Kelly-Quinn), Coleoptera (G. Foster, Balfour Brown Club) Bryozoa, Oligochaeta (B. Healy).

Faunal abundance data used for statistical analysis of the 28 lagoons are a combined abundance for all sampling methods. This was calculated as the sum of the mean of 3 sweep-net samples, plus the mean of 3 sediment core samples, plus the total number from the light-trap samples, plus the estimated abundance from the timed searches. Fish recorded in fyke nets were given an abundance estimate and added to the search data. The first three methods (sweep nets, cores, and light-traps) resulted in counts for each species, whereas the timed searches resulted in relative abundance data. Estimated abundance in the field was on a scale of 1 – 5, based on the SACFOR (1-6) scale (Crapp 1973, Hiscock 1996) for marine surveys, and suggested guidelines for lagoonal habitats by Bamber (1998) and Bamber *et al*. (2001b). In this study, 1 = rare, 2 = occasional, 3 = common, 4 = abundant and 5 = super-abundant. The category of “frequent” was not used in these surveys, due to the low number of samples at each station, and taxa in this category are assigned to the “occasional” or “common” category. Counts for many taxa resulted in much higher values than the relative abundance scale of 1-5, and some taxa are considerably more numerous than others. Therefore, for statistical comparability, the data were treated as follows:

1. Abundance of taxa recorded during the timed searches were recorded on a scale from 0 – 5, which was then translated into a relative abundance scale of 0 – 1000 for each taxon, as shown in Appendix II.

2. The combined count data from sweep nets, sediment cores and light traps were converted to an abundance scale of 0 – 5, and translated as in (1), into a relative abundance scale of 0 –1000 for each taxon, again using the same table shown in Appendix II.
3. The data from the timed searches were then combined with the converted counts, so that all taxa were analysed using an abundance scale of 0 –1000.

Aquatic Vegetation

All species recorded are listed with authorities in Appendix I. Vegetation was surveyed by a combination of wading and snorkelling. A species list was compiled at each station and an estimate of percent cover was recorded for each taxon. Species not readily identifiable in the field were collected for subsequent examination in the laboratory. Most species identifications were easily made using standard floral keys (Hiscock 1979, 1986; Moore 1986, Stewart and Church 1992, Webb *et al.* 1996). Some taxa, however, are difficult to identify and considerable help was supplied by Dr. C. Roden. Using the protocol of Roden (1999), “Following Preston (1995), no attempt was made to identify non-flowering *Ruppia* to species.” Samples of *Cladophora* spp. were collected and preserved in 70% alcohol whenever encountered for later identification in the laboratory. Nomenclature follows Stace (1997) for vascular plants, Hardy and Guiry (2003) for marine algae and Bryant *et al*. (2002) for charophytes.

Statistical Analysis

Species data were analysed for the 28 lagoons using abundance data in 3 discrete groupings. First data for fauna was analysed followed by that for flora. Secondly, flora and faunal data was combined and analysed. Then, species considered to be lagoonal specialists encompassing both floral and faunal species was analysed. Lagoonal specialist taxa are those listed for Ireland (Oliver and Healy 1998, Roden 1999, Healy 2003) with some later additions (Chapter 4), based on species previously listed for the

UK (e.g. Barnes 1988, 1989a; Sheader and Sheader 1989b, Bamber *et al.*, 1992b) and used in UK lagoon surveys. For each discrete grouping analysed, four statistical steps were used. Due to high numbers of certain taxa, abundance data for fauna were log transformed and floral abundance data (% cover) were square root transformed before analysis. Data were first analysed using Principal Components Analysis (Canoco v4.0). Abundance data for the 32 sites previously surveyed for presence and absence of species were not initially comparable to that obtained for the 28 sites, so data for the additional 28 sites were transformed to presence and absence for analysis with the other lagoons. Data for total fauna and then total flora were analysed together with environmental data using Redundancy Analysis (RDA in Canoco v4.0.) due to the expected linear increase or decrease in abundance of most species with salinity. Data for lagoonal specialists with environmental data were analysed using Canonical Correspondence Analysis (CCA Canoco 4.0.) because the maximum abundance peak for these specialist species was expected to be in intermediate ranges of salinity.

Environmental data

Environmental data used in the analyses (Appendices XI, XIV) comprises substratum (where sub1 = rock, sub2 = abundant stones, sub3 = sand, sub4 = mud and sub5 = peat), depth of sampling station (Depth1, in metres), maximum depth of lagoon (Depth2, in metres), trophic status based on catchment area and apparent water quality (where tro1 = oligohaline/clean, tro2 = mesotrophic, tro3 = eutrophic, tro4 = highly eutrophic), size of lagoon (in hectares), position on coastline (where coast1 = North, Donegal-Down; coast2 = East, Louth-Wexford; coast3 = South, Cork-Wexford; coast4 = West, Cork-Sligo), mean salinity (Salmean, being the mean of all salinity measurements available) and salinity range (Salran, being the maximum range of all salinity measurements available).

3.3 Study Sites

Data from a total of 60 Irish coastal lagoons were analysed in an attempt to classify these lagoons biologically (Table 3.3.1; Figure 3.3.1). Species lists and details of size, salinity, depth, substrate and trophic status for each lagoon are included in Appendices XI-XVI.

Table 3.3.1. Location, code number, year of survey and size of the 60 sites used for classification of Irish coastal lagoons.
(* = 28 lagoons analysed using abundance data).

Code No.	Year of Survey	Site	County	Grid Ref	Size (ha)
1	2003	Castle Espie *	Down	J 495 673	1
2	2003	Strand Lough *	Down	J 535 373	4
3	2003	Greenore Golf Course *	Louth	J 215 102	2.5
4	2003	Broadmeadow *	Dublin	O 215 473	280
5	2003	Kilcoole *	Wicklow	T 312 061	5
6	2002	North Slob channel *	Wexford	T 090 248	50
7	2002	South Slob channel *	Wexford	T 072 183	50
8	1996	Lady's Island Lake	Wexford	T 099 065	350
9	1996	Tacumshin	Wexford	T 050 065	450
10	1998	Ballyteige channels	Wexford	S 955 060	8
11	2002	Rostellan Lake *	Cork	W 871 660	50
12	2002	Cuskinny *	Cork	W 839 674	4
13	2003	Commoge Marsh, Kinsale *	Cork	W 630 498	12
14	2002	Oysterhaven Lake, Clashroe *	Cork	W 699 501	3
15	2002	Inchydoney *	Cork	W 384 393	2
16	2003	Clogheen/White's Marsh *	Cork	W 398 394	3
17	1996	Kilkeran	Cork	W 338 344	20
18	2002	Roscarberry *	Cork	W 290 367	20
19	1996	Lissagriffin	Cork	V 775 265	15
20	1996	Farranamanagh	Cork	V 830 378	6
21	1998	Kilmore L.	Cork	V 958 489	6.5
22	2002	Reenydonegan Lake *	Cork	V 000 514	25
23	1996	Drongawn	Kerry	V 731 640	20
24	1996	Lough Gill *	Kerry	Q 606 142	144
25	2003	Quayfield/Poulaweala *	Limerick	R 297 527	2.5
26	2002	Shannon Airport Lagoon *	Clare	R 350 620	2
27	2002	Scattery *	Clare	Q 974 527	10
28	1996	Cloonconeen Pool	Clare	Q 836 497	7

continued………

Table 3.3.1. cont.. Location, code number, year of survey and size of the 60 sites used for classification of Irish coastal lagoons. (* = 28 lagoons analysed using abundance data).

Code No.	Year of Survey	Site	County	Grid Ref	Size (ha)
29	1996	Lough Donnell	Clare	R 002 707	25
30	1996	Lough Murree *	Clare	M 255 119	13
31	1996	Aughinish	Clare	M 286 134	8
32	1998	Loch Mór, Inish Oírr	Galway	L 989 019	6
33	1998	L. Phort Chorruch, Arainn	Galway	L 857 112	4
34	1998	Loch an Chara, Arainn	Galway	L 887 009	5
36	1996	Lettermullen	Galway	L 827 213	1
37	1998	Loch Fhada	Galway	L 939 305	15
38	1996	L. Tanaí	Galway	L 950 305	11
39	1998	L. an Aibhnín *	Galway	L 947 315	55
40	1998	Loch Cara Fionnla	Galway	L 963 290	14
41	2002	L. Doire Bhanbh *	Galway	L 961 384	1.5
42	1998	Loch an tSaile (L. Ahalia)	Galway	L 954 390	90
43	1996	L. Conaorcha (Aconeera)	Galway	L 875 369	28
44	1996	L. an Mhuilinn (Mill L.)	Galway	L 754 331	5
45	2002	L. Ballyconneely *	Galway	L 620 437	20
46	1998	L. Athola *	Galway	L 626 484	11
47	2002	Lough Anillaun *	Galway	L 613 581	15
48	1996	L. Bofin	Galway	L 525 656	12
49	1996	Corragaun Lough	Mayo	L 748 698	10
50	1996	Roonah Lough	Mayo	L 755 765	55
51	1996	Furnace Lough	Mayo	L 965 975	125
52	2003	Tanrego *	Sligo	G 615 298	2.5
53	1996	Durnesh Lake	Donegal	G 878 695	83
54	1998	Maghery Lough	Donegal	B 723 094	19
55	1998	Sally's L.	Donegal	B 728 168	6
56	1998	Kincas L.	Donegal	B 752 197	6
57	1998	Moorlagh	Donegal	B 790 187	10
58	2003	Carrick Beg Lough *	Donegal	C 157 366	2
59	2003	Blanket Nook Lough *	Donegal	C 307 194	40
60	1998	Inch Lough	Donegal	C 352 230	160

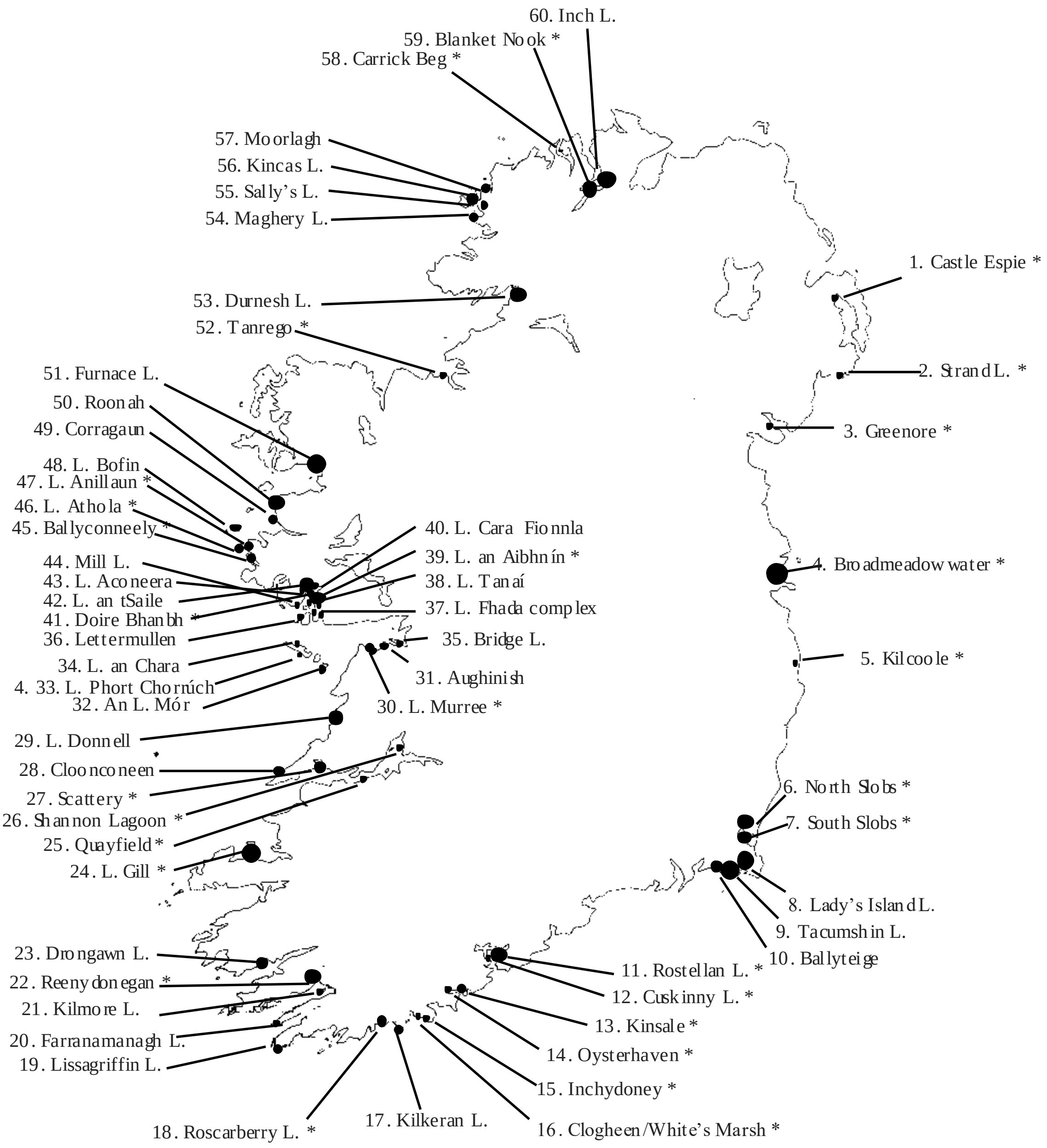

Figure 3.3.1 Location map of the 60 sites used for the classification of Irish coastal lagoons
(* = 28 lagoons analysed using abundance data).

3.4 Results

Table 3.4.1 summarises the statistical analyses (PCA, RDA, CCA) used to classify coastal lagoons along with the transformations used and the cumulative percent variance of the original data set retained following the statistical analysis.

Table 3.4.1 Analyses used for classification of Irish coastal lagoons, 2002-3.

Taxon	No. of lagoons	Form of data	Env. data	transformation	stats	Cum % Variance
Total fauna	28	abundance		log	PCA	41.7
Total fauna	28	abundance	yes	log	RDA	30.7
Total flora	28	abundance		Sq. root	PCA	49.3
Total flora	28	abundance	yes	Sq. root	RDA	29.1
Lagoonal sp. fauna	28	abundance		log	PCA	73.0
Lagoonal sp. fauna	28	abundance	yes	log	CCA	20.9
Lagoonal sp. flora	28	abundance		Sq root	PCA	81.5
Lagoonal sp. flora	28	abundance	yes	Sq root	CCA	33.1
Total fauna	60	Pres/abs		None	PCA	34.2
Total fauna	60	Pres/abs	yes	None	RDA	20.9
Total flora	60	Pres/abs		None	PCA	42.6
Total flora	60	Pres/abs	yes	None	RDA	22.7
Lagoonal sp. fauna	60	Pres/abs		None	PCA	57.0
Lagoonal sp. fauna	60	Pres/abs	yes	None	CCA	23.2
Lagoonal sp. flora	60	Pres/abs		None	PCA	65.9
Lagoonal sp. flora	60	Pres/abs	yes	None	CCA	25.8

Analysis of faunal abundance in 28 lagoons by station (n=113)

Results show quite a broad scatter of stations from within a lagoon, but with a group in the lower left of the plot which includes L. Gill, Kilcoole 1 and 2, N Slobs 2 and Ballyconneely (Figure. 3.4.1). The high salinity sites are clearly to the right of the plot on Axis 1 with Athola and Aibhnin in the lower right, separated from a group in the upper right which includes Broadmeadow, Inchydoney and Kinsale. Sites such as Rostellan 1, Cuskinny, and Strand Lough lie in the upper left of the plot. It is interesting to note how some of the stations within lagoons are clustered close together (Murree 1-

4, South Slobs 1-4), whereas others such as North Slobs (solid squares, 1-6) are widely scattered.

North Slob 2 is grouped with Gill in the lower left, stretching across to North Slob 6 in the upper right with Broadmeadow and Kinsale, reflecting the extreme heterogeneity of the species abundance at stations within some of the lagoons and homogeneity of the species abundance at stations in other lagoons.

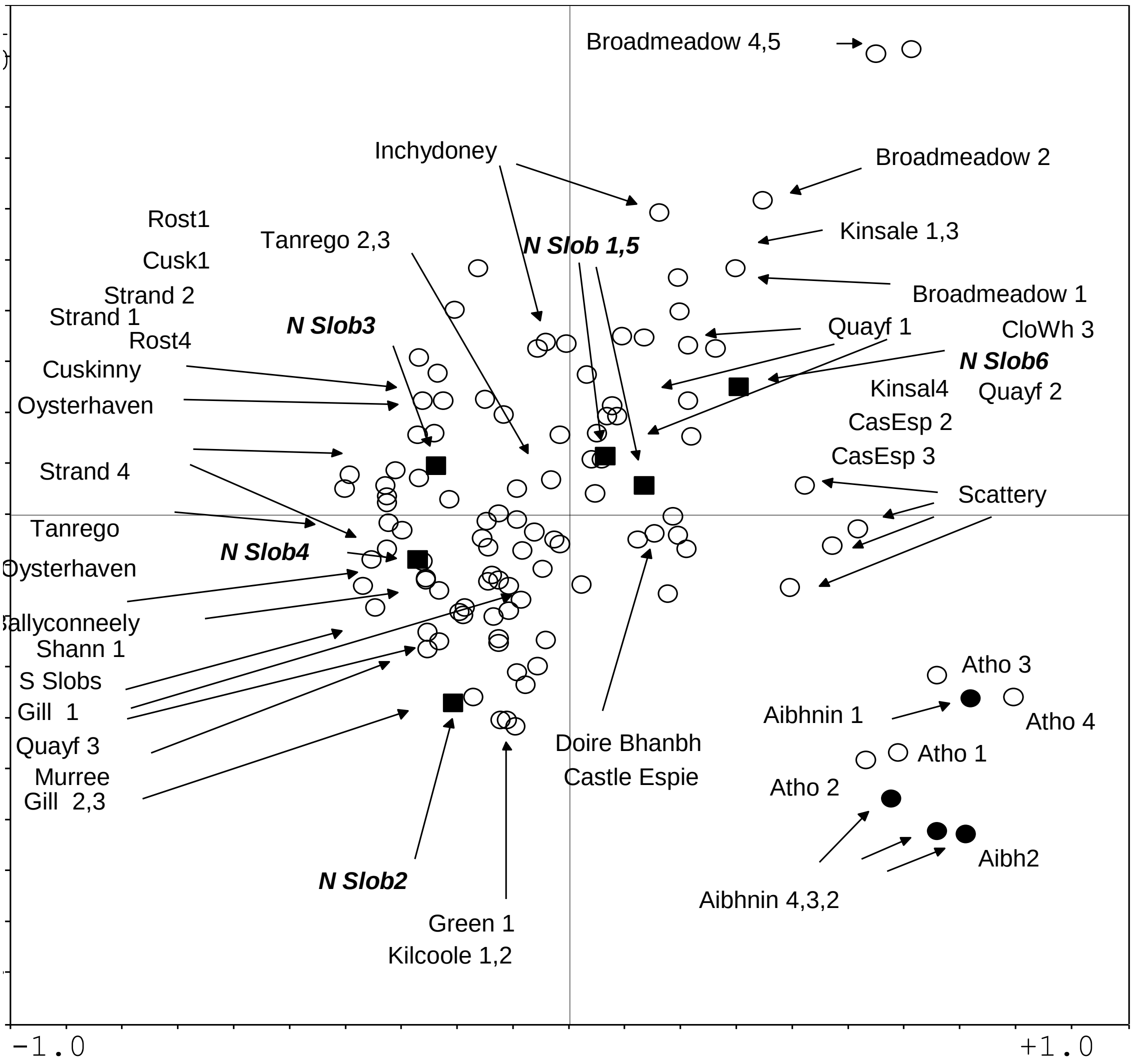

Figure 3.4.1 PCA of 113 stations in 28 lagoons based on abundance of faunal taxa. (solid circles = stations in L. an Aibhnin; solid squares = 6 stations in North Slobs)

Using Redundancy Analysis (RDA, Figure 3.4.2), 30.7 % of the species distribution is explained by the environmental factors used in the analysis, with mean salinity having the largest influence, complemented by lagoon size and depth 1 and depth 2 (depth at sampling station and maximum depth of lagoon, respectively). Particularly noticeable again in Figure 3.4.2 is the salinity gradient with high salinity sites to the right of the plot on Axis 1, and the splitting of this group into those above and below the axis. Athola and Aibhnín in lower right are strongly associated with trophic status 1 (oligotrophic), sub 1 (rock) and sub 5 (peat), and coast 4 (west) and these could be referred to as "clean, rock/peat West coast lagoons".

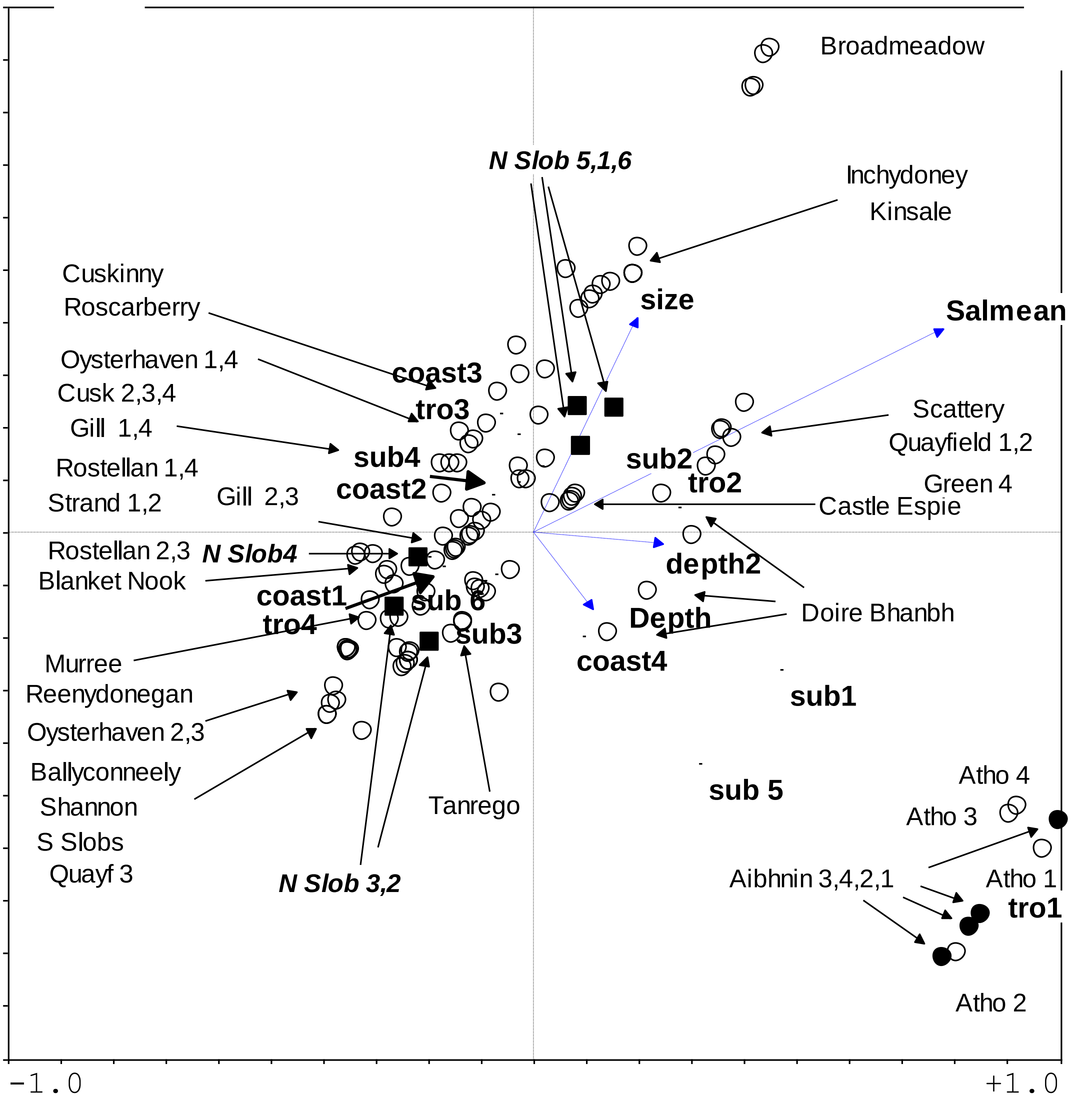

Figure 3.4.2 RDA of 113 stations in 28 lagoons based on abundance of faunal taxa. (solid circles = stations in L. an Aibhnín; solid squares = stations in North Slobs)

Those in the upper right of the plot (Broadmeadow, Inchydoney and Kinsale) are "estuarine" lagoons which are aligned in a diagonal towards the centre with sites such as

Roscarberry, Cuskinny and Rostellan. The latter sites are associated with sub 2 (stones), sub 4 (mud), coast 3 (South), coast 2 (East), and tro 3 (eutrophic). These are eutrophic sites on the south and east coasts, muddy with stones, and having characteristic brackish species (*C. insidiosum, G. chevreuxi)*. This group stretches in a scatter (Greenore, Scattery, Doire Bhanbh) towards the right of the plot, as these brackish stations become more similar to the higher salinity west coast stations. In the lower left of the plot is a distinct cluster of low salinity sites including Shannon, Reeydonegan, Ballyconneely and South Slobs associated with sub 3 (sand) and tro 4 (highly eutrophic).

Lough Murree is also close to this cluster, though more saline than other members of the group. The North Slobs stations (solid squares) are less scattered using RDA than PCA (Figure 3.4.1), but still reflect the salinity gradient with stations 1, 5 and 6 closer to Scattery and Kinsale, but also the south and east coast brackish stations, whereas stations 2, 3 and 4 are closer to the low salinity stations, associated with sand and high nutrients. Stations such as within Castle Espie are clustered very close together, whereas stations in Oysterhaven and Rostellan are quite separate. Aibhnín 1 (solid circles) is clearly more closely related to Athola 1, 3 and 4, whereas Athola 2 is more closely related to Aibhnín 2, 3 and 4.

These results clearly separate the low salinity sites dominated by insects (Coleoptera, Hemiptera) from the high salinity sites dominated by crustaceans and various marine species of Porifera, Cnidaria, Polychaeta, Bryozoa and Tunicata. Between these two extremes are the mid salinity sites dominated by species more tolerant of salinity fluctuations such as *Idotea chelipes, Lekanesphaera hookeri, Conopeum seurati* and *Cerastoderma glaucum.*

Analysis of floral abundance in 28 lagoons by station (n=113)

PCA of floral taxa using abundance data (Fig 3.4.3, taxa = 82) shows some similarities to that for fauna (Figure. 3.4.1) but with certain differences.

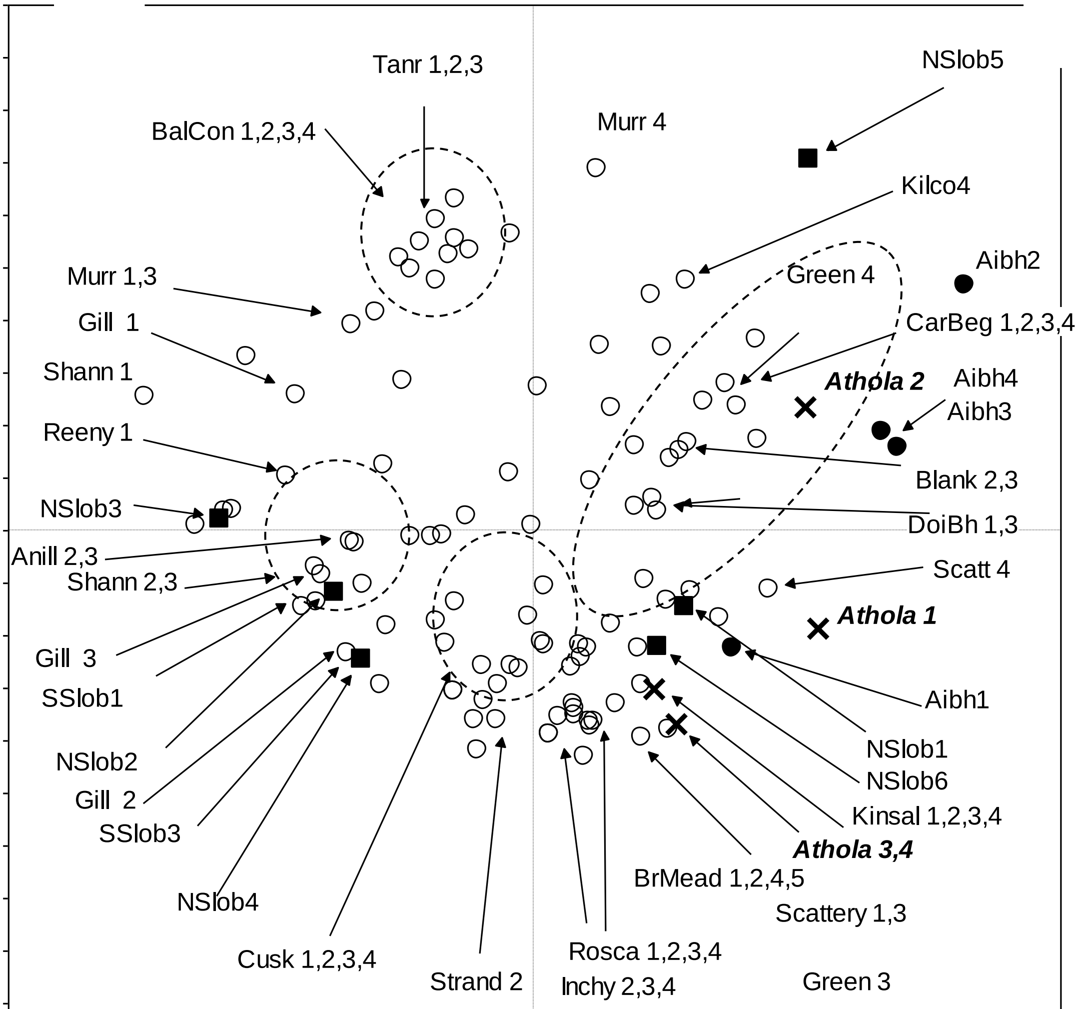

Figure 3.4.3 PCA of 113 stations in 28 lagoons based on abundance of floral taxa. (solid circles = L. an Aibhnín; cross = Athola; solid squares = North Slobs)

Athola and Aibhnín for example are again grouped to the right of the plot on Axis 1, but not as closely clustered together, or as separate from other stations as when using faunal abundance. Aibhnín (solid circles) 1 and Athola 1 (crosses) are now grouped more closely with the more estuarine sites such as Scattery and Kinsale. The North Slobs stations (solid squares) are even more widely spaced across the plot than when using fauna but show the same pattern with N Slobs 2, 3 and 4 close to the South Slobs, Shannon and Anillaun. North Slobs 1 and 6 are grouped with Scattery and

Kinsale, whereas 5 is closer to Aibhnín 2,3 and 4, which are now closer to sites such as Doire Bhanbh, Carrick Beg and Castle Espie. Such a separation of stations within a lagoon shows the heterogeneity of the lagoon, just as observed for fauna (Figure 3.4.1). Lagoons such as Shannon, Murree, Tanrego and Ballyconneely are still grouped in the upper left of the plot but there is much more of a cluster in the lower centre of the plot (Rosscarbery, Inchydoney, Strand Lough and Cuskinny).

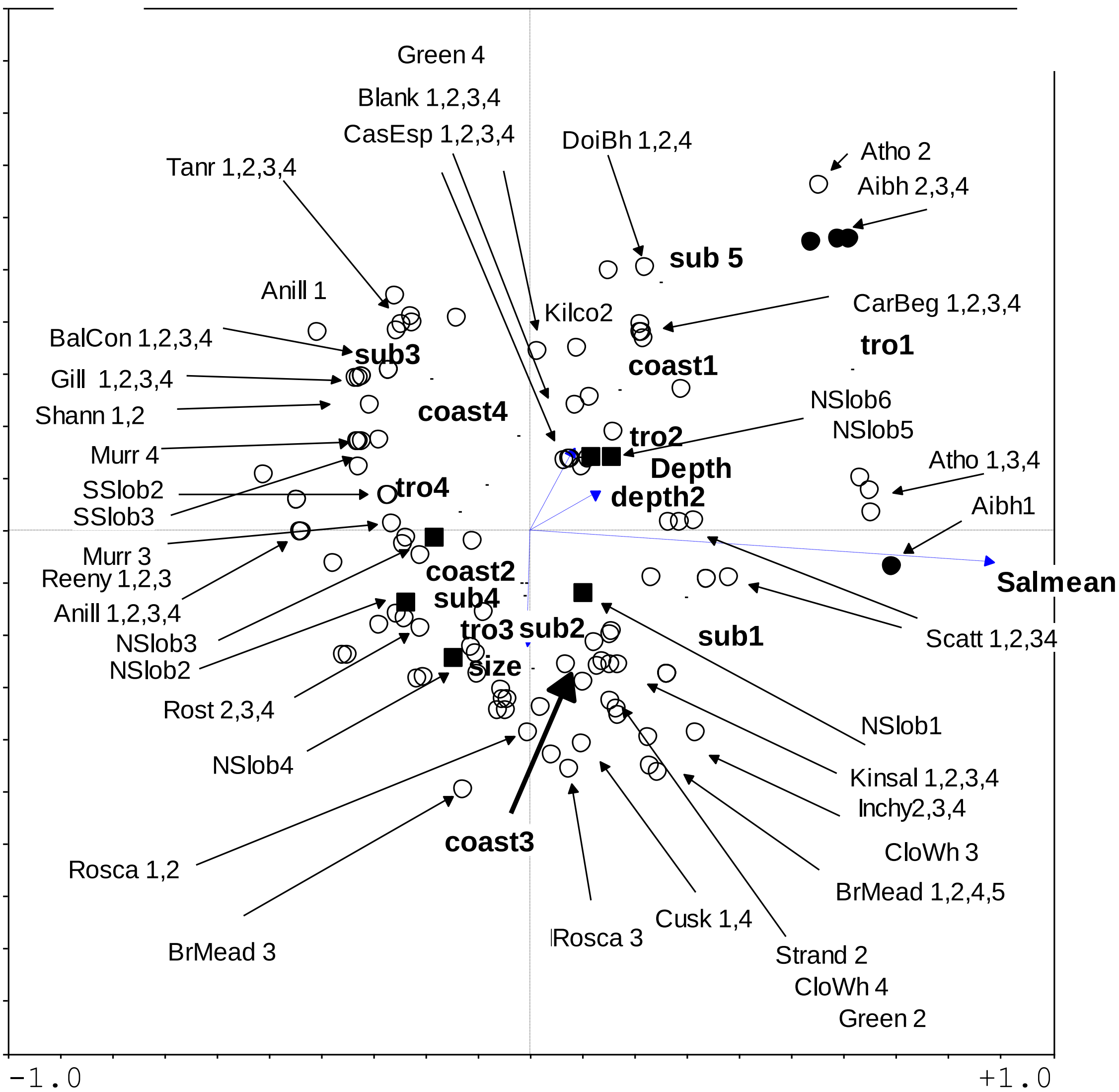

Figure 3.4.4 RDA of 113 stations in 28 lagoons based on abundance of floral taxa (solid circles = stations in L. an Aibhnin; solid squares = stations in North Slobs)

Using RDA (Figure 3.4.4), the pattern is similar to that for fauna (Figure 3.4.2) with Athola 2 grouped with Aibhnín 2,3 and 4, characterised by *Ruppia* and *Zostera* and associated with high salinity, sub5 (peat) and tro 1 (oligotrophic), but Aibhnín 1 and

Athola 1,3 and 4, are separated more clearly using flora than fauna and more closely associated with sub1 (rock) and with sites such as Scattery, which has *Ruppia* and *Chaetomorpha*, in addition to various marine algae. Environmental factors explain 29.1% of the species distribution, with salinity as the dominant environmental factor. The stations are less scattered than in the PCA, but those on the North Slobs, for example are still widely separated, with stations 2, 3 and 4 associated with the low salinity sites on the left of the plot, and stations 1, 5 and 6 with the higher salinity stations on the right. North Slob 1 is grouped with the sub2 (stoney), coast 3 (south) stations in the lower right, whereas stations 5 and 6 are closer to the “clean, west-coast” stations in the upper right. This indicates that not only are the species abundances variable in the North Slobs, but so are the environmental conditions which help to define the species composition. Many other stations within lagoons, for example L. Gill, Kinsale, Ballyconneely, Castle Espie and Blanket Nook also are generally grouped more closely together than when using fauna, suggesting that the vegetation within these lagoons is more similar among stations, than the abundance of faunal species. Vegetation data, in the form of relative abundance therefore appears to be more appropriate data to use in order to characterise the lagoon.

Analysis of faunal abundance using lagoonal specialists in 28 lagoons (113 stations)

Using only lagoonal specialist fauna (24 species, Figure 3.4.5), PCA shows major differences to previous analyses using total fauna or flora. The North Slob stations are still spread across the plot, but Aibhnín 1 is quite separate from other stations within that lagoon, and all are quite separate from Athola, which is now grouped with other lagoons, with wide ranging salinities such as L. Gill, Ballyconneely, L. Murree and Broadmeadow. All of these stations have very low numbers or a complete absence of lagoonal specialist fauna, and it appears that the PCA results in clusters of sites based on paucity of lagoonal specialist fauna in comparison to the other stations.

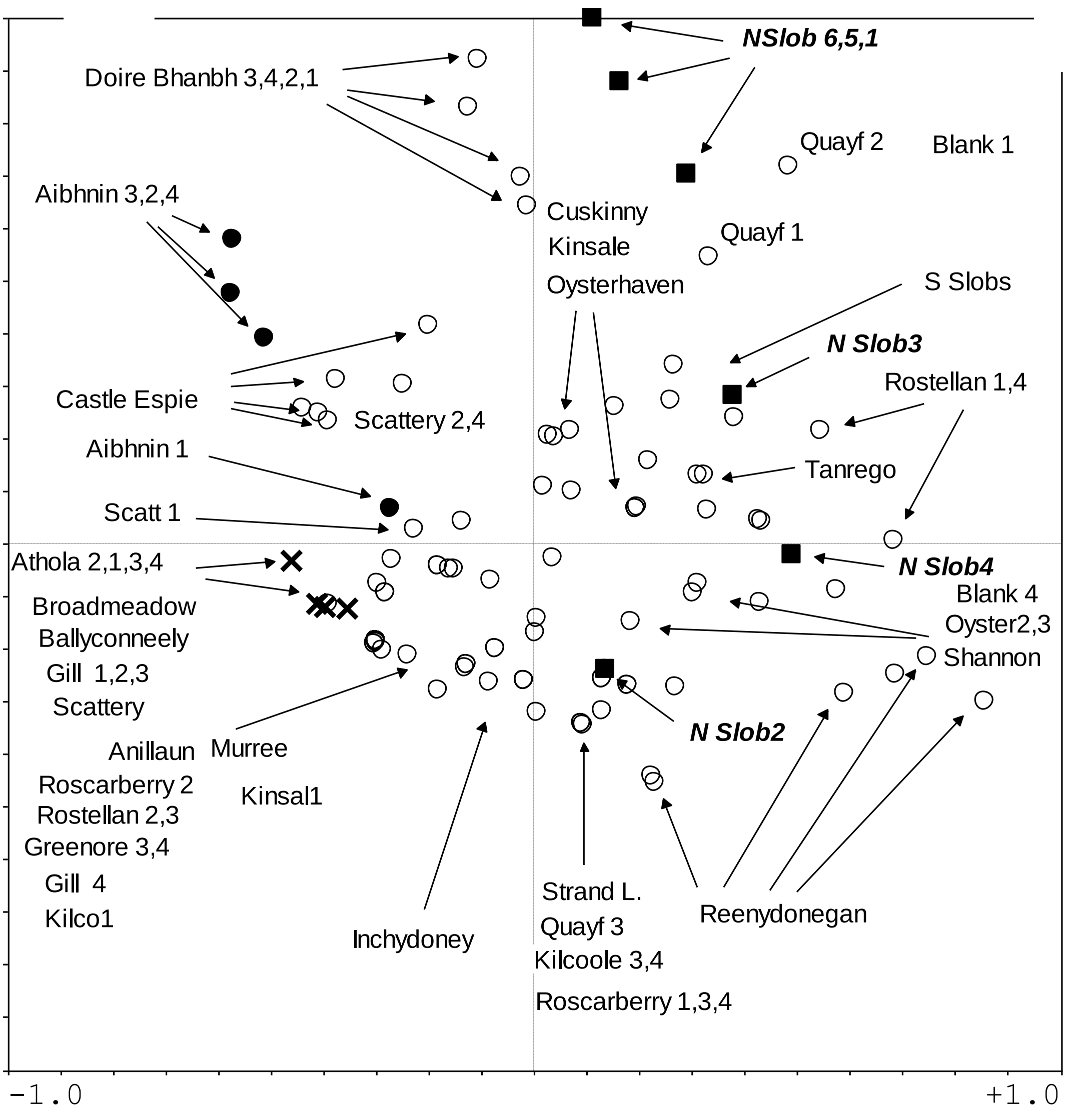

Figure 3.4.5 PCA of 113 stations in 28 lagoons based on abundance of lagoonal specialist faunal taxa.
(solid circles = Aibhnin; crosses = Athola; solid squares = North Slobs)

Using Canonical Correspondence Analysis (CCA, Figure 3.4.6), Athola and Aibhnín are again grouped together in the lower right of the plot, associated with "rock" and "oligotrophic", and with the more marine of the lagoonal specialists (*Gonothyraea loveni, Onoba aculeus Rissoa membranacea, Cerastoderma glaucum*).

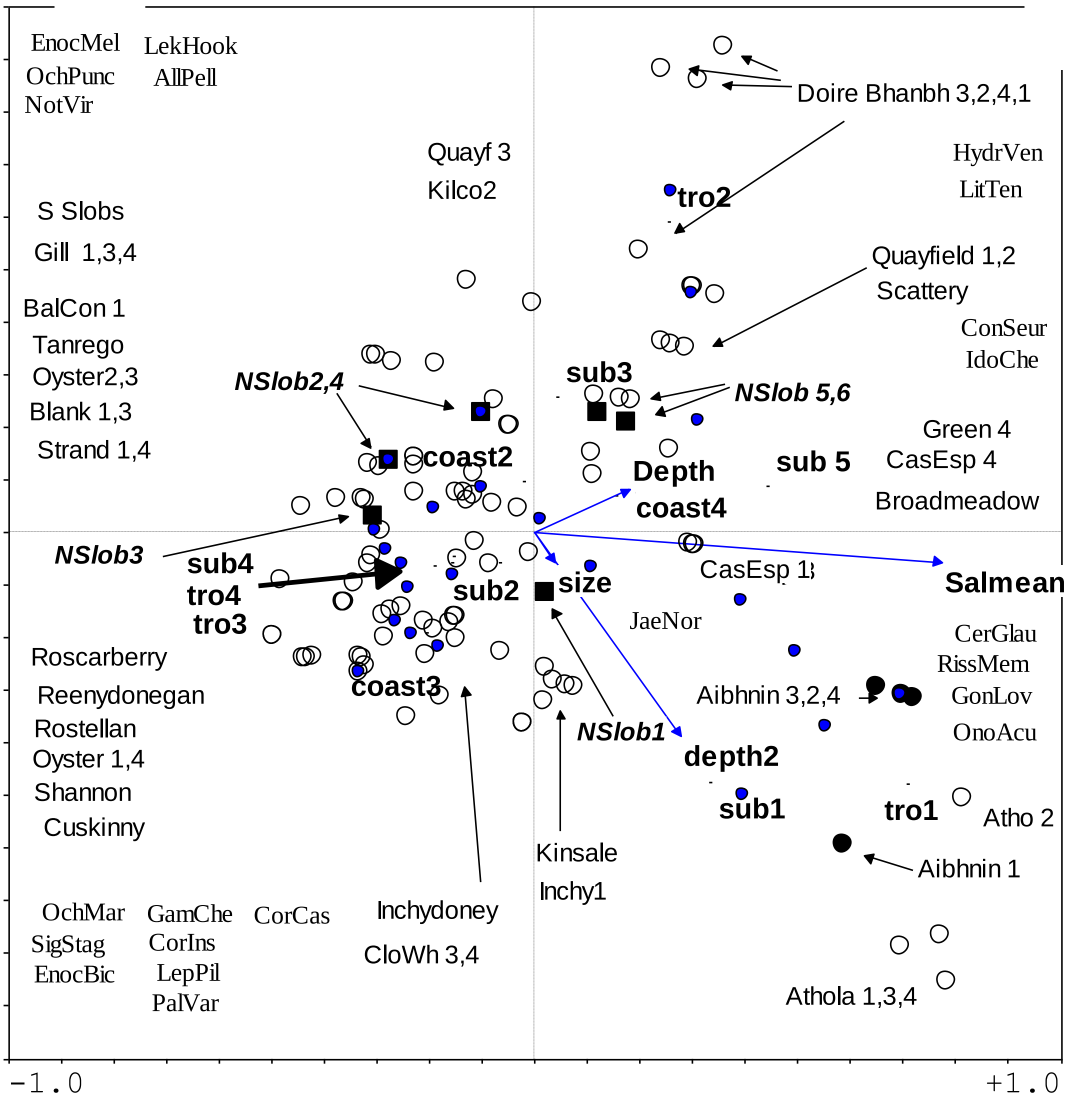

Figure 3.4.6 CCA of 113 stations in 28 lagoons based on abundance of lagoonal specialist faunal taxa.
(solid circles = Aibhnin; solid squares = North Slobs)

Mean salinity is again the dominant factor, but the Doire Bhanbh stations are much more separate from Aibhnin and Athola than in previous analyses, and are now grouped in the upper right, closer to Scattery and Quayfield 1 and 2, associated in particular with higher numbers of *Idotea chelipes, Hydrobia ventrosa* and *Conopeum seurati*. The remaining stations are all clustered much closer together in the centre of the plot, with the main cluster in the lower left, associated with lagoon sites chracterised as "eutrophic and highly eutrophic, mud, south coast" and the main concentration of lagoonal specialists, which includes both crustaceans (e.g. *Corophium insidiosum*, *Gammarus chevreuxi*) and insects (E.g. *Enochrus bicolor*, *Sigara stagnalis*).

Another smaller cluster lies on the left, very close to the centre of the plot, associated with “stony” substrate, but two of the associated specialists are very rare water-beetles and occur only at one station of the 113 in the analysis (*Enochrus melanocephalus, Ochthebius punctatus*). Lough Gill, an outlier of this group, has no lagoonal specialist fauna, other than the occasional *Lekanesphaera hookeri.* Likewise, Ballyconneely, another member of this group, contains very few species of specialist fauna, so again it appears that the clustering is based partly on the paucity of lagoonal specialist fauna.

Analysis of floral abundance using lagoonal specialists in 28 lagoons (113 stations).

PCA of lagoonal specialist flora (17 species) shows a very broad scatter and an unusual distribution (Figure 3.4.7). For example, Gill 1 (pyramids) is grouped in the upper left with Murree and Ballyconneely, Gill 2 & 3 with Athola 4 and Broadmeadow in the lower left and Gill 4 with Rostellan 1 and Doire Bhanbh in the upper right.

Stations in L. Gill are all low salinity sites, grouped with low, medium and high salinity sites, as shown in the distribution of lagoonal specialist fauna. This indicates that the distribution of floral as well as faunal lagoon specialists may not be as regular within a lagoon as the general community present.

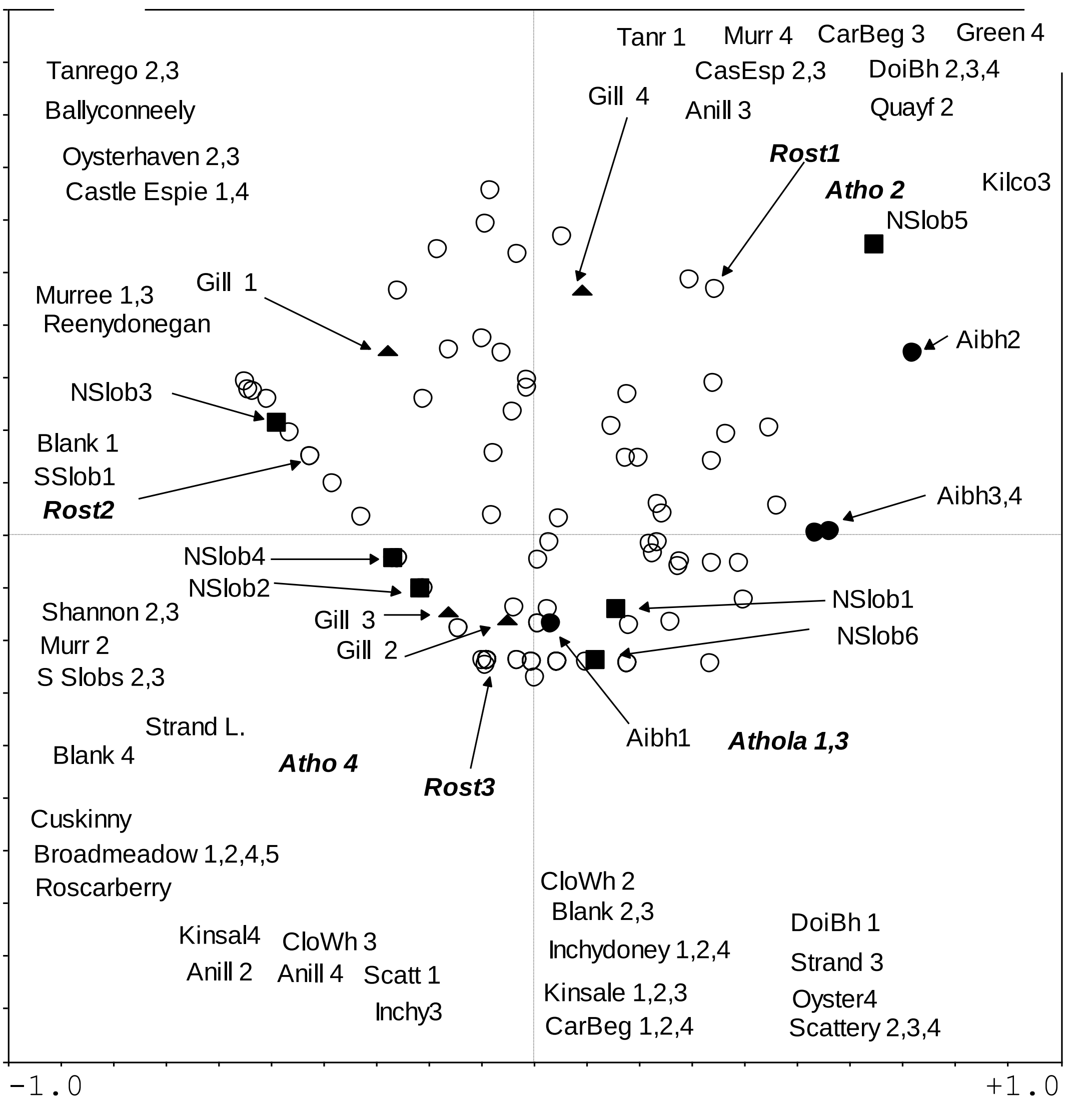

Figure 3.4.7 PCA of 113 stations in 28 lagoons based on abundance of lagoonal specialist floral taxa.
(solid circles = Aibhnin; pyramids = L. Gill; solid squares = North Slobs)

A CCA of lagoonal specialist flora (Figure 3.4.8) shows a much clearer distribution (not easily seen in the PCA). Salinity is again the dominant environmental factor, complemented by depth 2 (max. depth of lagoon) and, to a lesser extent, size (of the lagoon). The more saline stations are to the right of the plot with Aibhnin and Athola in the upper right associated with sub1 (rock) and “oligotrophic”, characterised by *Zostera*, and possibly *Ruppia cirrhosa*. Athola 1, 3, 4 and Aibhnin 1 are in the extreme upper right, characterised by *Cladophora battersii* and *Cystoseira* spp. In the lower right are the more “estuarine” stations, largely devoid of vegetation, other than occasional marine algae (Broadmeadow, Inchydoney, Kinsale).

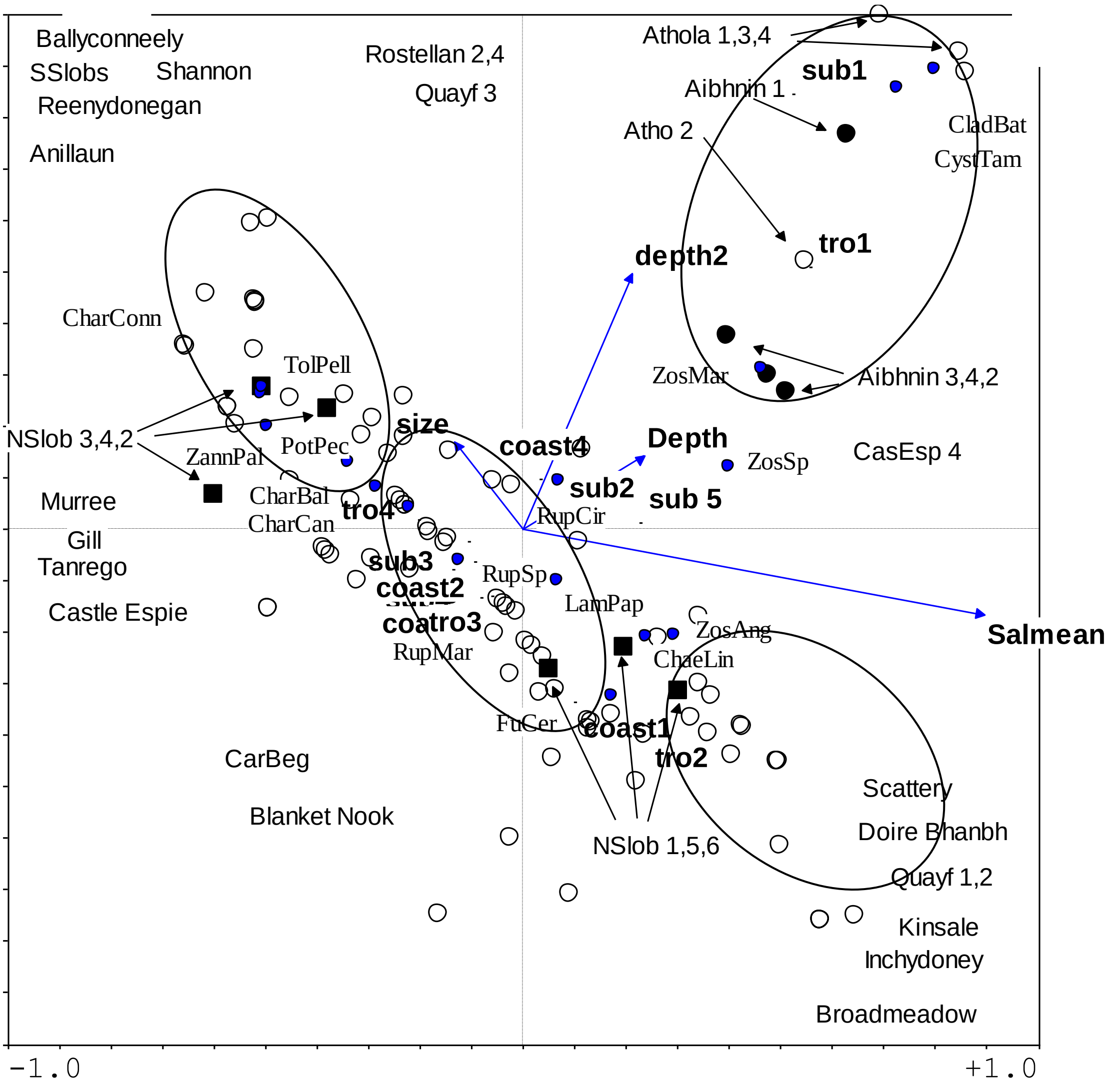

Figure 3.4.8 CCA of 113 stations in 28 lagoons based on abundance of lagoonal specialist floral taxa.
(solid circles = Aibhnin; solid squares = North Slobs)

In the upper left are the low salinity, eutrophic sites (Ballyconneely, Reenydonegan, Shannon, North Slobs 3,4,2), with abundant *Potamogeton* and often with charophytes (*C. canescens* and the rare spp., *C. connivens, C. baltica, T. nidificans*). Between these last two, lying in the centre, are the mid-salinity stations (Scattery, Doire Bhanbh, North Slobs 1,5,6) dominated by *Ruppia* and *Chaetomorpha* and associated with “sand and mud”. Both *Ruppia* and *Lamprothamnion* occupy a wide range of salinities and overlap with *Potamogeton* at one end of this gradient, and *Zostera* at the other. In this analysis, the North Slobs stations are split into just two separate groupings with 2, 3, and 4 in the *Potamogeton/Ruppia* group, and the other in the *Ruppia/Chaetomorpha* group (although N.Slobs 5 also has *Zostera angustifolia* and *Lamprothamnion)*. This CCA with lagoonal flora shows a better clustering of lagoon sites than that using lagoonal fauna.

Analysis of faunal presence and absence in 60 lagoons (n= 440)

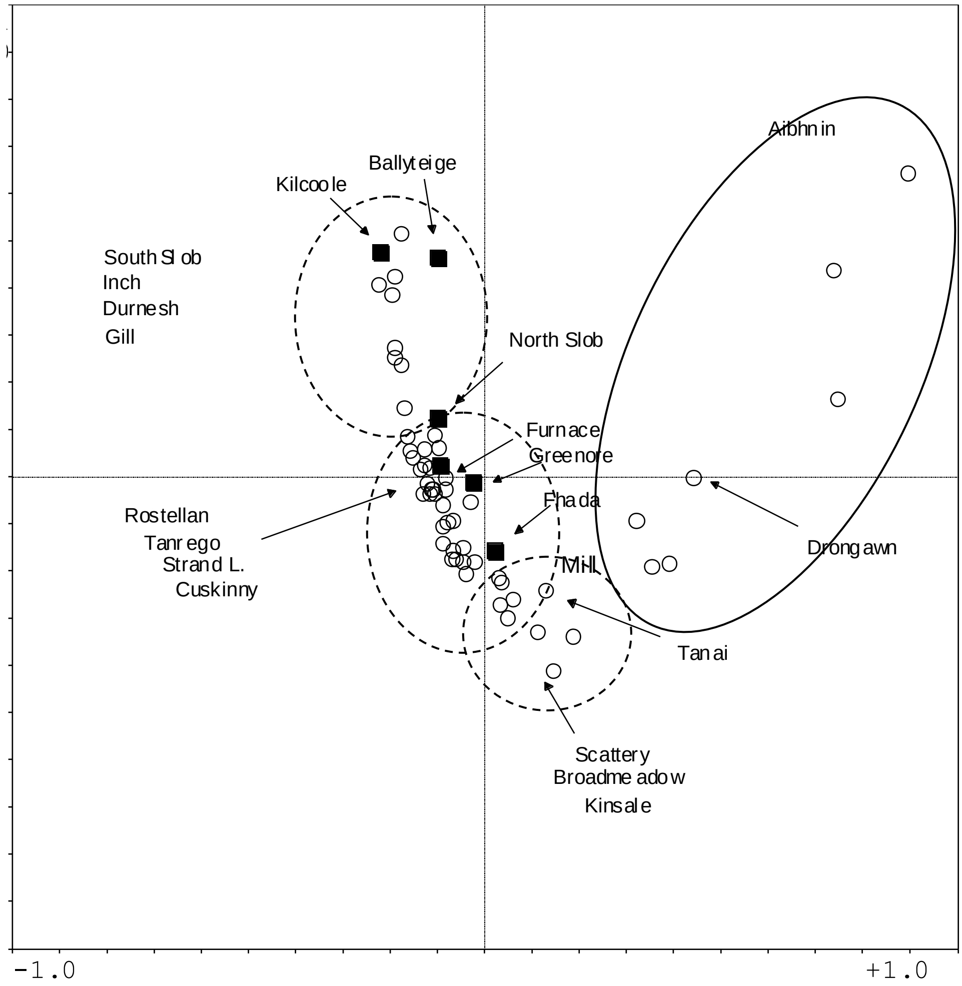

Fig 3.4.9 PCA of faunal presenc/absence in 60 lagoons.
(solid squares = "mixed community" lagoons

PCA using presence/absence of fauna in 60 lagoons shows a very simple pattern (Fig. 3.4.9), with one scattered group to the right of the plot with Athola and Aibhnín, joined by Kilmore, Drongawn, Tanaí, Lettermulen and Aughinish, then another linear scatter of sites running from the lower centre of the plot to the upper left.

Within this scatter are the “estuarine” lagoons in the lower part (Kinsale, Broadmeadow, Scattery, Lissagriffin), then mid salinity lagoons (e.g. Rostellan, Tanrego, Strand, Cuskinny). In the upper left of the plot are the large low salinity lagoons (Gill, Durnesh, Inch).

Whereas, when using faunal abundance data of stations within the lagoon, the North Slobs stations are spread across the plot (Figures 3.4.1 & 3.4.2), this site, together with other “mixed community” lagoons (Kilcoole, Ballyteige, Greenore, Fhada) lie either in the centre of the plot or mixed with large low salinity lagoons.

RDA (Figure 3.4.10) reveals that of the environmental variables, mean salinity is again the dominant environmental factor, complemented by depth, size and salinity range. The high salinity lagoons are to the right on axis 1, split into “clean, rock, west coast” lagoons in the lower half of the plot comprising Aibhnín and Athola, joined by Tanai, Drongawn, Maghery, Ahalia and Aconeera. The “estuarine” lagoons lie in the upper right (Broadmeadow, Kinsale, Scattery) joined by Bridge L. and Sally’s L.and Aughinish. On the left of the plot are the low salinity sites in the lower half (L. Gill, Reenydonegan, Shannon, Mór) then the brackish sites (Cuskinny, Tanrego, Chara), and again, but more clearly grouped, in the upper left the “mixed community” sites (Kilcoole, Clogheen , North Slobs, Ballyteige, Greenore, Quayfield). These sites are associated with salinity range, indicating a wide range of salinity regimes and a fauna comprised of species with a range of preferred salinities. The “estuarine” lagoons are associated with both high salinity and salinity range. The largest of the low salinity lagoons lie in the middle left of the plot associated with the factor “SIZE”. Three lagoons in particular (Murree, Bofin, Farranamanagh), marked with crosses, lie in the centre of the plot, and are lagoons with very low species number.

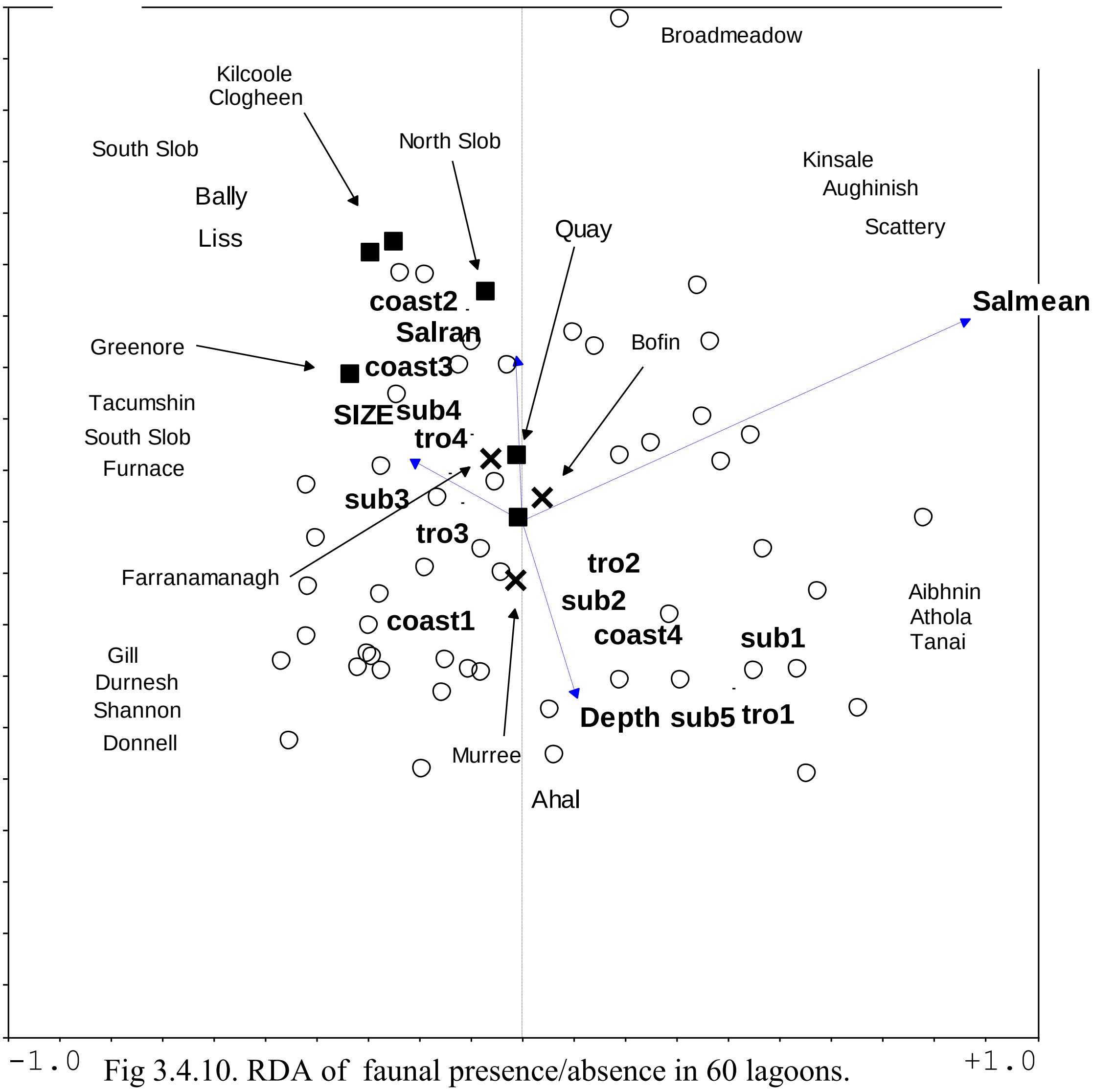

Fig 3.4.10. RDA of faunal presence/absence in 60 lagoons. (solid squares = "mixed community", crosses = low spp. number)

Analysis of floral presence and absence in 60 lagoons

PCA of presence/absence of floral taxa (n=147, Figure 3.4.11) shows a similar pattern to that of fauna (Figure 3.4.9) with marine sites to the right of the plot and a linear scatter across the plot from the lower part with "estuarine" sites (Broadmeadow, Kinsale, Inchydoney) to the upper left comprising low salinity lagoons (e.g. Gill, Inch, Durnesh), dominated by *Potamogeton pectinatus* with or without charophytes.

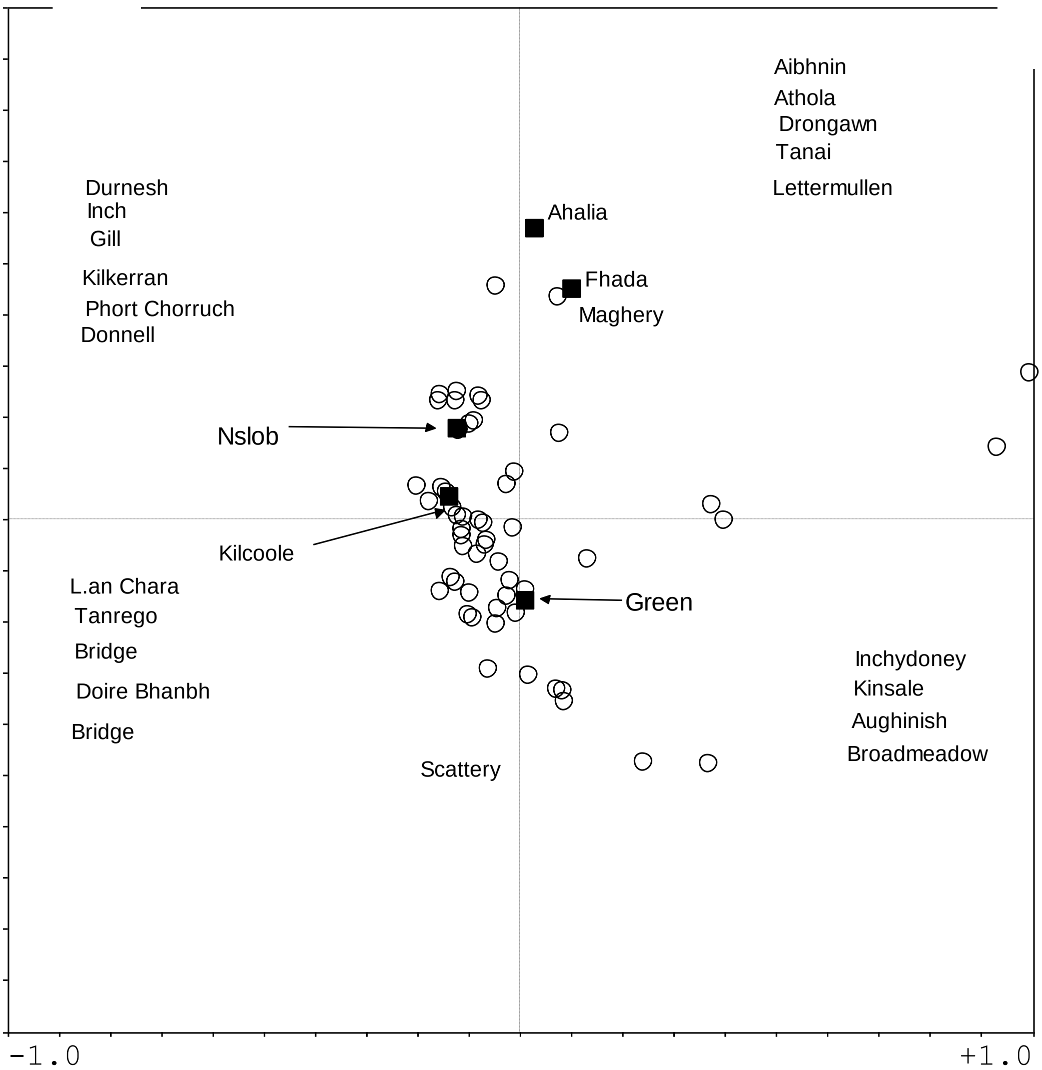

Figure 3.4.11 PCA Floral presence/absence in 60 lagoons (solid squares = "mixed community" lagoons)

In the centre are the mid salinity sites (L. an Chara, Tanrego, Bridge, Doire Bhanbh) dominated by *Ruppia* and *Chaetomorpha*. The "mixed community" sites (N Slob, Kilcoole, Greenore) are spread across these groups, extended to an outlying group of Carafinla, Ahalia, Fhada and Maghery, which are also "mixed community" lagoons, but with closer affinities to the higher salinity rock/peat lagoons in the upper right. The pattern is very similar, but simpler than using floral abundance data from stations as in Figure 3.4.3.

RDA of flora (Figure 3.4.12) shows better grouping than that of fauna (Figure 3.4.10), but otherwise the same general pattern is apparent, with salinity being the dominant environmental factor, complemented by size and depth. Marine sites lie to the right of the plot with "clean, rock and peat, west coast" lagoons in the lower right and "estuarine" sites in the upper right. Large, low salinity lagoons with *Potamogeton pectinatus* lie in the lower left, and mid-salinity sites with *Ruppia* and *Chaetomorpha* lie in the upper left.

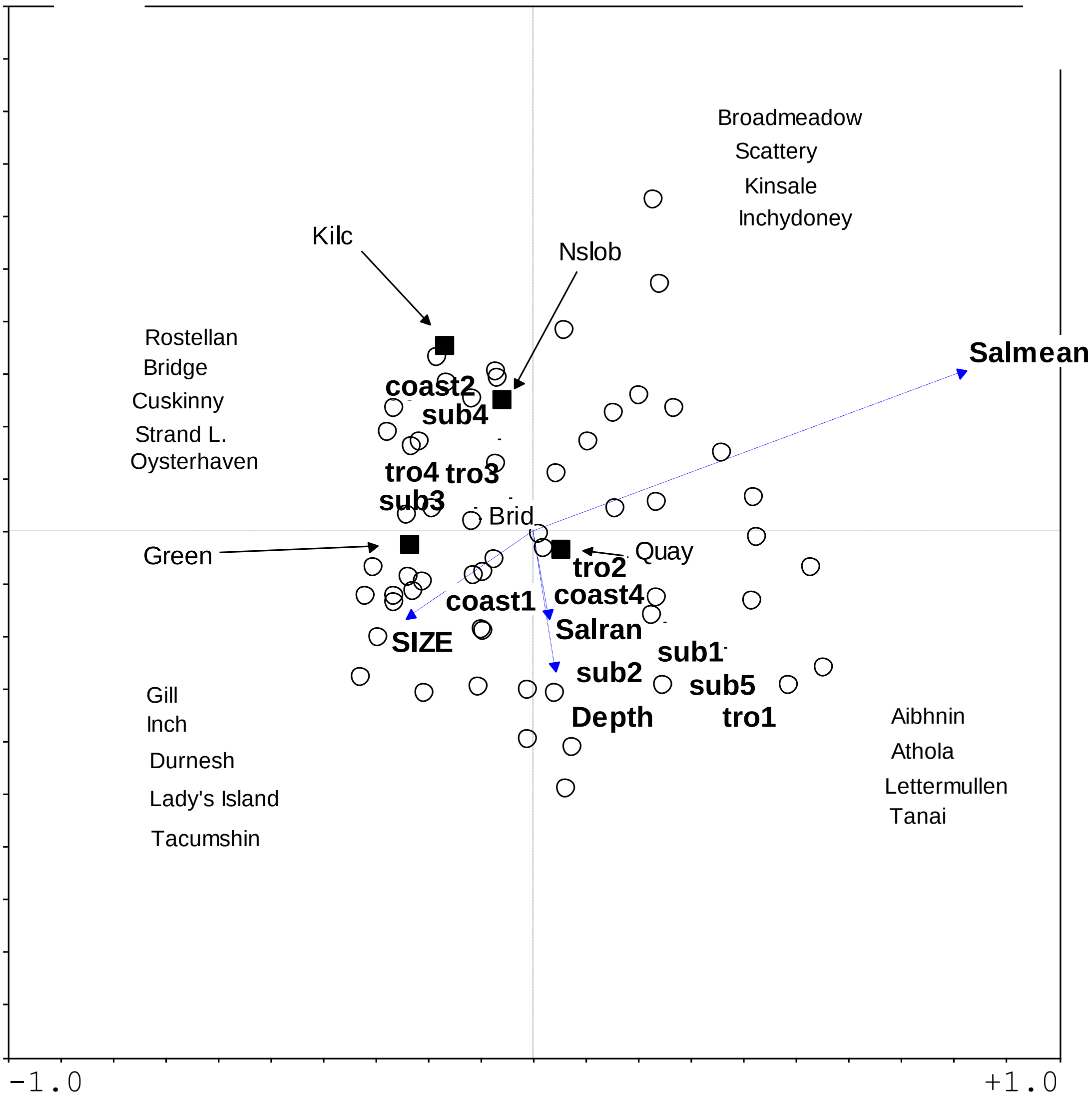

Figure 3.4.12 RDA Floral presence/absence in 60 lagoons

Analysis of lagoonal specialist fauna (n=24) presence and absence in 60 lagoons

A PCA (not shown) of lagoonal specialist fauna showed a generally broad scatter of sites with the higher salinity sites separated from all others. There is also a loose grouping of mixed community sites separate from a mixture of low salinity and brackish sites, but no obvious clusters were apparent.

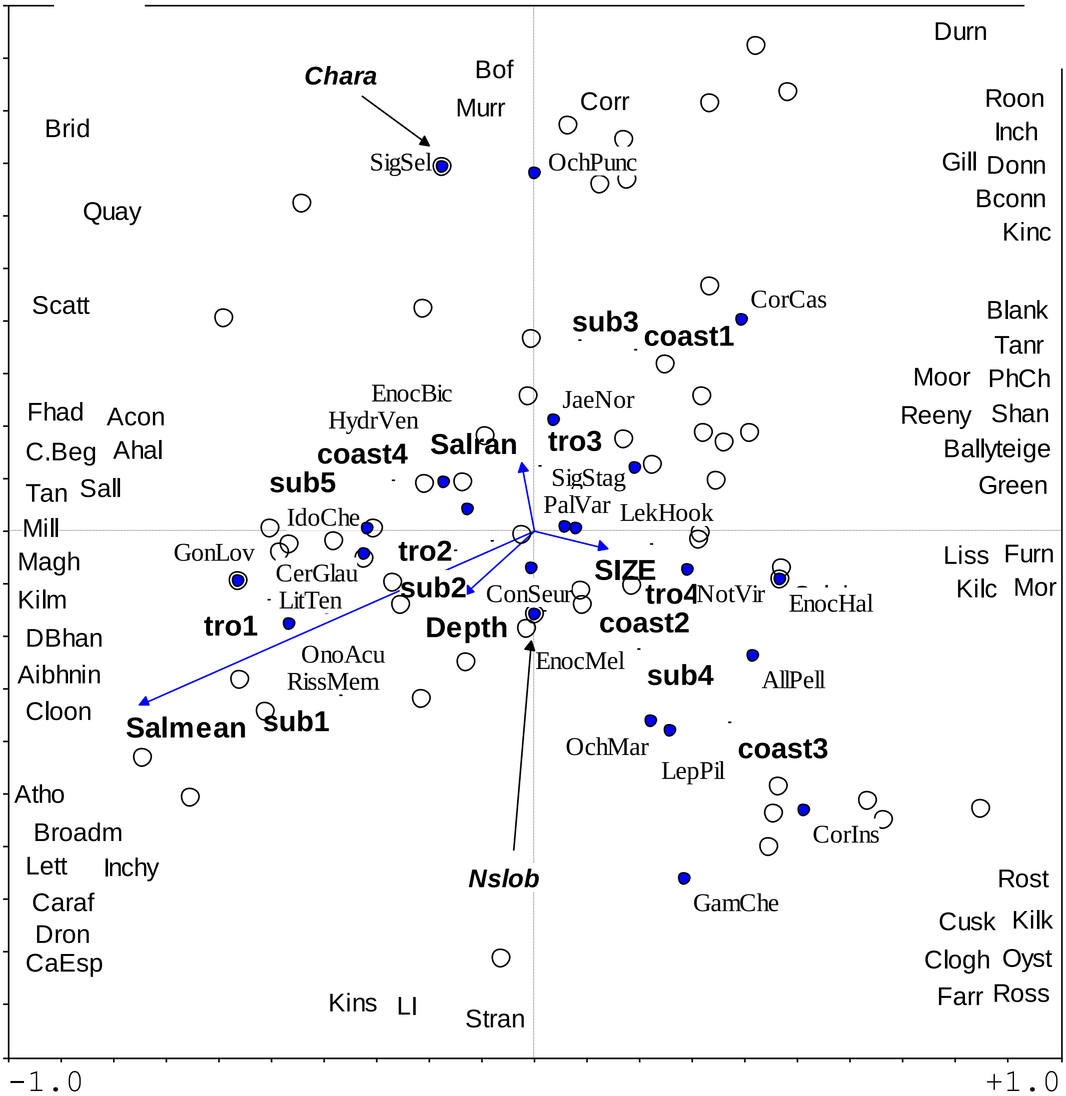

Figure 3.4.13. CCA of presence/absence of lagoonal specialist fauna in 60 lagoons

CCA (Figure 3.4.13) of lagoonal specialist fauna shows the dominant environmental factor to be salinity, but again the broad scatter of sites with no obvious clusters but some unusual groupings of sites. For example, Lady's Island is positioned close to the very different faunal community of Kinsale, and Athola is to the very different Broadmeadow and Carafinla. This pattern must be explained by the power that rare species have in the analysis; it appears that based on presence and absence, as well as abundance data, the rare species of lagoonal specialists are highly emphasised. For example, the position of the N Slobs (bold italics, Figure. 3.4.13) is determined primarily by the fact that one individual specimen of *Enochrus melanocephalus* was found at that site. Also, the position of L. an Chara (bold italics, Figure. 3.4.13) is determined by the record of a colony of *Sigara selecta* at that site, and at no other lagoon surveyed. Otherwise there is a broad scatter of sites with no obvious pattern.

Analysis of lagoonal specialist flora presence and absence in 60 lagoons (n=16)

Both PCA (not shown) and CCA (cum % variance =25.8, Figure. 3.4.14) show broad scatters of sites with no obvious clustering. It can still be seen that mean salinity is the dominant environmental factor, complemented by salinity range and size (of the lagoon). The low salinity sites lie on the right of the plot, characterised by *Potamogeton pectinatus*. The lagoons characterised by *P. pectinatus* often with charophytes lie in the lower right and those characterised by *P. pectinatus* and *Ruppia maritima* lie in the upper right. The *Ruppia* species and *Lamprothamnion* generally lie in the mid-line of the plot, suggesting a wide salinity range, whereas the high salinity "clean, west coast, rock" lagoons lie in the lower left, characterised by *Zostera, Lamprothamnion* and possibly *Ruppia cirrhosa,* with the highest salinity sites with *Cladophora battersii* and *Cystoseira* spp. in the extreme lower left. However, as with the fauna, it appears that based on both presence and absence as well as on abundance data, the rare species of lagoonal specialists are highly emphasised in the clustering of points, especially when the total species number is low.

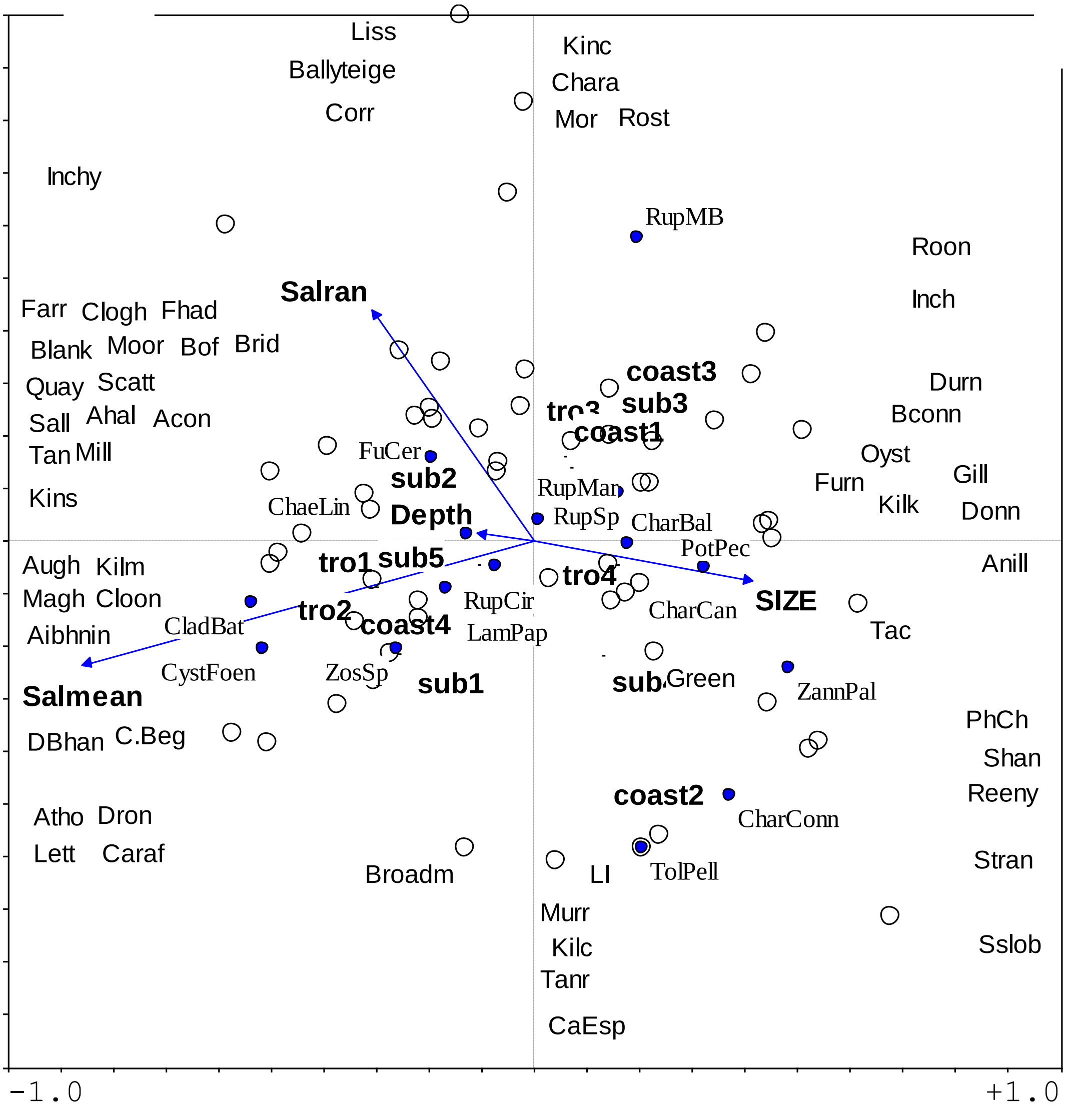

Figure 3.4.14. CCA of presence/absence of lagoonal specialist flora in 60 lagoons

Synthesis of Results

Statistical analyses were carried out using abundance data and presence/absence data for flora, fauna, lagoonal specialist fauna and flora, and a combination of lagoonal specialist fauna and flora and in nearly all analyses there is a consistently recurrent pattern. Certain lagoon types clearly group together, although more clearly in some analyses than others. The abundance data identifies four main groups, of which the "high salinity west coast rock and peat" lagoons are generally quite separate from all other sites. In addition to this type is a low salinity type, a "semi-isolated mid-salinity" and an "estuarine" type. Generally, these four types can be recognised using both faunal and floral species but grouping is somewhat clearer using floral abundance (Figures. 3.4.3 and 4). Using lagoonal specialist flora and fauna (Figures. 3.4.5-8) tends to confuse the pattern by overemphasizing rare species and to group lagoons based on paucity of faunal specialist species. Analysis of 60 lagoons using presence and absence data identifies the same four types described above, plus a fifth type of lagoon, which is a "mixed community" found either in large lagoons, or a mosaic of small lagoons with a range of environmental habitats (primarily a range of salinities, based on the environmental factors used in this analysis).

As a result of the analyses therefore, the following classification of five lagoon types is proposed, as in the model presented in Figure 3.4.15:

1. *Ruppia/Potamogeton* lagoons (low salinity)
2. *Ruppia/Chaetomorpha* lagoons (mid-salinity, semi-isolated)
3. "Estuarine" lagoons (high salinity mean and range, high tidal and FW flow)
4. *Ruppia/Zostera* lagoons (high salinity, "clean, rock, west coast")
5. "Mixed community" lagoons (combination of the above – large sites, or mosaics)

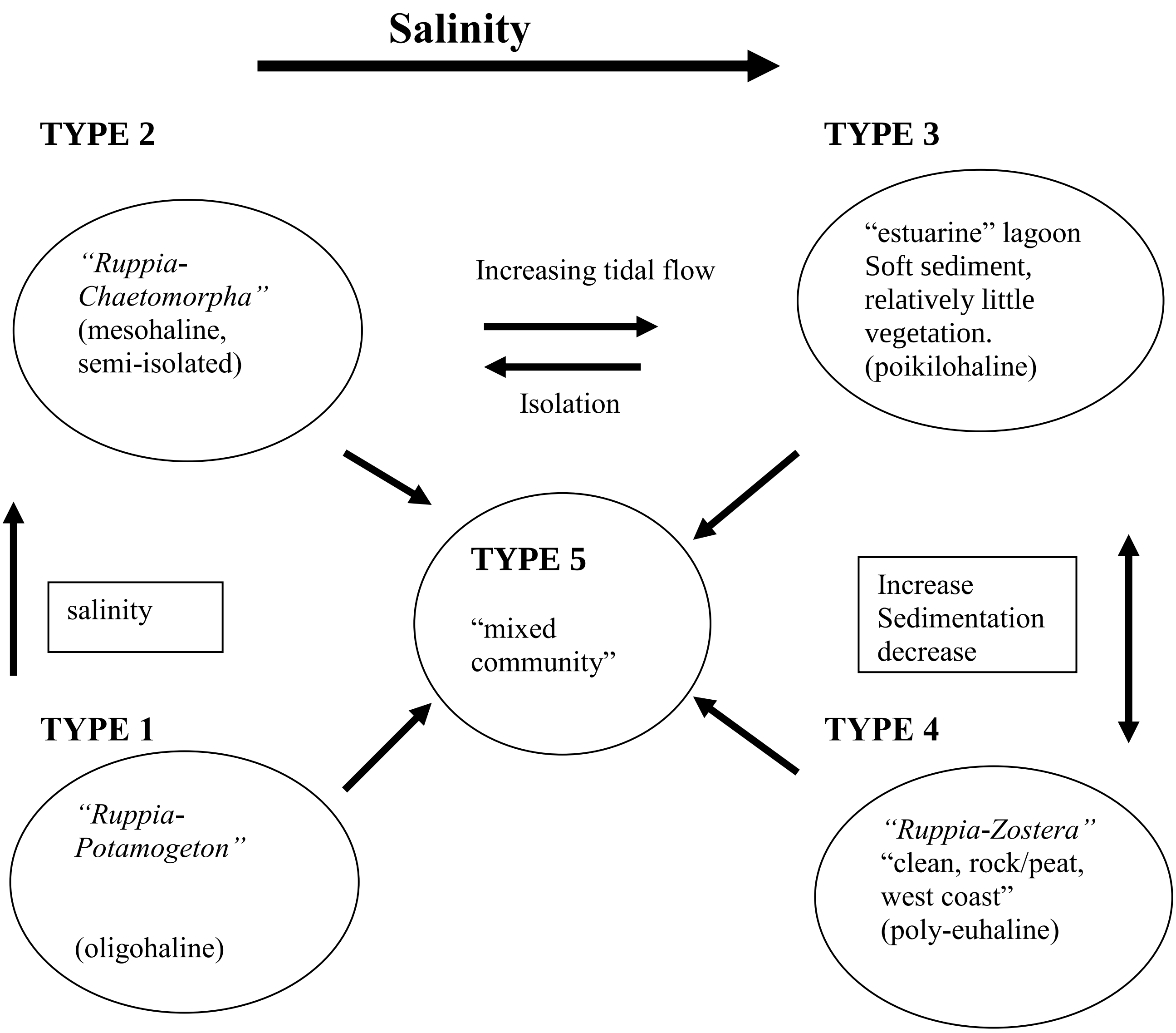

Figure. 3.4.15 Irish coastal lagoon model.

3.5 Discussion

The lagoons surveyed for this study, which represent the majority of lagoons in Ireland, represent a continuum of types in terms of size, salinity, substrate, degree of connection with freshwater and marine waters and other factors. However, in most analyses, the abundance data revealed a loose grouping of four main lagoon types. For both total fauna and flora, RDA indicates salinity as the most important determinant of community composition from among the environmental factors included in the analyses. When using only lagoonal specialists, rather than the whole community, the pattern is far less clear. In many cases the rare species are over-emphasised in the ordination, especially when the total species number is low. In other cases, especially using faunal specialists, the PCA groups several lagoons of varying salinities together based on general paucity of lagoonal specialists. Whereas the whole community in general is sensitive in particular to different salinities, lagoonal specialists are characteristically tolerant of wide ranges in environmental conditions and there are likely to be fewer organising factors. For example, *Lamprothamnion papulosum* has been recorded in salinities ranging from four to thirty psu., and although *Sigara stagnalis* is generally associated with low to medium salinity, it was recorded on one occasion in water of 30 psu..

The main lagoon types can best be described using vegetation, as the plants are generally sessile and more likely to reflect longer term environmental conditions, whereas the fauna is often more mobile and likely to react quickly to any short term fluctuation. At one extreme are the low salinity lagoons characterised generally by abundant *P. pectinatus* with only sparse amounts of *Ruppia* but often with abundant charophytes, especially in the sandier substrates (e.g. Gill, Durnesh). At the other extreme are the high salinity lagoons in which *P. pectinatus* is absent, but marine algae are common. The high salinity lagoons can be split into two types with abundant marine algae with *Ruppia*, and often with *Zostera* and in the "clean, rock/peat, West Coast" lagoons and the "estuarine, muddy, mostly east and south coast, eutrophic lagoons". In these "estuarine" lagoons marine algae may be common along the narrow intertidal shorelines, or some species, such as *Gracilaria verrucosa,* may be sparsely scattered on the bed of the lagoon (e.g. Rosscarbery, Cuskinny, Rostellan, Scattery), but generally the main body of the lagoon is largely devoid of vegetation. The "estuarine" lagoons are characterised by a combination of a daily tidal cycle plus frequent inputs of silt-laden riverine freshwater which results in soft muddy, mobile sediments, which are difficult for plants to colonise, plus frequent extremes in salinity which are equally deterrant to plant survival. At the extreme of this continuum are the species- poor "shock lagoons", similar to the "schock-biotopen" described by den Hartog (1974) as being characterized by a sudden transition between seawater and fresh water from minimum to maximum salinity and vice versa, twice during each tidal cycle. The fourth lagoon type is the mesohaline, semi-isolated lagoon dominated by the lagoonal form of *Chaetomorpha linum*, most commonly with *Ruppia*. These lagoons receive relatively little tidal water on a daily basis but may vary considerably on an annual or seasonal basis.

A fifth type of type lagoon which is a "mixed community" is noticeable by the wide separation of stations within a lagoon (e.g. North Slob, Quayfield, Kilcoole) in the plots using abundance data from stations and a loose grouping of these lagoons using presence/absence data for the lagoon as a whole (especially in the RDA using total fauna, Fig 3.4.10). This "mixed community" is found in large lagoons with a salinity gradient and a large freshwater component to the biota, or are mosaics of small lagoons of different salinities, resulting in a high species number with representatives of many salinity ranges.

Classifications based on salinity

Historically, efforts have been made to classify brackish waters and explain species distributions using for example, mean, median, maximum, or minimum salinity or chlorinity, or extreme values or changes during the year (e.g. Redeke 1922, Aguesse 1957, Amanieu 1967, Heerebout 1970, Kinne 1971, Remane and Schlieper 1971, Den Hartog 1974). Based on salinity regimes, authors have attempted to explain faunal and floral distributions, with the result that, for example, descriptions of the distributions of estuarine species have yielded more than a dozen salinity classification schemes (Bulger *et al.* 1993). However, it is difficult to decide on the most useful form of measurement and to take enough measurements for results to be meaningful. Heerebout (1970) stated that salinity data of one year are usually not sufficient, and used data collected over eight years for his classification. The Venice system (Anonymous 1959) defined salinity zones (Limnetic, Oligohaline, Mesohaline, Polyhaline, Euhaline) and most brackish water scientists now refer to this classification. However, this classification was used primarily in estuaries, and according to Den Hartog (1970), classification of marine waters, according to the "Venice system" is not well applicable to inland waters of marine origin (i.e. lagoonal habitats). Other factors affecting lagoons may be equally important. Temperature, for example, can have a significant influence on the limiting effect of salinity, as it has long been known that in warmer regions marine and brackish-water animals penetrate farther into fresh water than in the North Sea or the Baltic (Remane and Schlieper 1971). Bulger *et al.* (1993) recently described the Venice system as largely descriptive and not based on empirical data, and classified estuaries, based on known salinity ranges of faunal species, into ecologically-relevant estuarine salinity zonations. Again, this classification is for estuaries which are usually quite different from lagoonal habitats, in that they are "open" systems with a daily tidal influence, compared with the more isolated lagoons, which have smaller daily fluctuations or none, but may have greater fluctuations in salinity on a longer timescale, and are affected by many other influences.

Undoubtedly, salinity is a major factor governing composition of lagoonal communities. In lagoons in East Anglia, Barnes (1987) calculated that 58% of the dominant macrofauna also inhabit the sea, 13% are essentially freshwater in nature, and 28 % are more typically associated with lagoons. Salinity is one of the "master factors" in lagoon ecology, as shown in this study, but in combination with many other factors. The advantage of the "proposed model" is that it is a lagoon classification based on a large data set of faunal and floral information, and the five main lagoon types are based on "ecologically-relevant" groups of species, and not on assumed salinity regimes, about which there is very little information.

Classifications based on geomorphology

Until recently, lagoons were mostly studied by coastal geomorphologists and engineers and the definitions and classifications were based largely on mode of formation or degree of seawater exchange (e.g. Zenkovitch 1969, Lankford 1977, Lasserre 1979, Phleger 1981), although Por (1971) used a multidisciplinary approach and based his classification on the types of biological communities present, the salinity regime and the degree of isolation from the sea. Barnes (1980) divided lagoons into three ecotypes according to their degree of exchange with seawater and resulting implications for species recruitment. Following the Habitats Directive in 1992, surveys of coastal lagoons in the U.K. used a classification based on physiography in which five main lagoon types were identified i.e. isolated lagoons, percolation lagoons, silled lagoons, sluiced lagoons and lagoonal inlets (e.g. Sheader and Sheader, 1989b; Brown *et al.*, 1997; Bamber *et al.*, 2001b). A similar approach was adopted in Ireland, where four lagoon types were recognised (Healy and Oliver 1998, Healy 2003) as sedimentary lagoons, rock lagoons, natural saline lakes or artificial saline lakes. Verhoeven (1979a) referred to semi-isolated “blocked” lagoons with significant salinity fluctuations on an annual basis, but relative stability on a daily basis, and estuarine “open” lagoons with daily tidal fluctuations. Meanwhile, in the Mediterranean, Guélorget & Perthuisot (1992) refer to lagoons as part of the “Paralic systems”. But these paralic systems are more like estuaries with large open connections to the sea. According to Barnes (1993), such lagoons with open connections to the adjacent sea are uncommon in Atlantic France, the British Isles and the low countries, where small, isolated lagoons are the norm. This statement does not entirely apply to Ireland, however, as although many of the Irish lagoons are quite isolated, many others have open connections to the sea. Physiographic characteristics are useful for describing the lagoon types in most cases, but very often a lagoon is in fact a combination of geomorphological types. Furthermore, the fauna and flora which the Habitats Directive is intended to protect often bears no relationship to the geomorphological type of lagoon.

Marine biotopes

The description of marine habitats is still in its relative infancy, and as a result, only seven marine habitats, one of which is “coastal lagoon,” were listed in Annex I of the Habitats Directive, compared with 180 terrestrial habitats. The Marine Nature Conservation Review (MNCR) biotope classification for Britain and Ireland (Connor *et al.* 1997a,b) attempts to address the need for a hierarchical classification of marine habitats based on a combination of the biological community together with the environmental factors of exposure, depth and substrate. The lagoons themselves have not been classified but a number of biotopes within them are recognised and it is expected to extend the system to other countries in NW Europe. Covey *et al.* (1996) listed 41 biotopes found in Scottish lagoons (Code: OB1-41) but in lagoons in England, Bamber (1997), found no sensible groupings of fauna and of the 13 biotopes he found, only five potential forms of the 41 biotopes listed for Scotland were recognised. It appears that many of the Scottish lagoons, known as "obs" are high salinity, rock substrate lagoons which correspond to the *Ruppia/Zostera* lagoons in Ireland, but are absent from England, whereas most of the lagoons in England and Wales (other than The Fleet, which is a "mixed community") correspond to the *Ruppia/Chaetomorpha* or *Potamogeton/Ruppia* lagoons in Ireland. Only two major lagoonal biotopes were recognised in England (Bamber 1997, Davies *et al.* 2001). One is a community associated with submerged vegetation coded "ENLag.Veg" referring to "**EN**glish **Lag**oon with **Veg**etation", irrespective of plant species, and the other coded "ENLag.IMS.Ann" which is "English lagoon with infralittoral muddy sand, dominated by annelids". Both of these biotopes are found also in Irish lagoons, but ENLag is clearly not an appropriate description for any lagoon outside England even though biologically it may be very similar. Meanwhile, Roden (1999) identified plant communities in Irish lagoons, not previously recognised elsewhere. At this stage, therefore, although the biotope classification is very useful in describing communities within lagoons, it has not led to a classification of lagoon types.

The problem in using marine biotopes for lagoon classification is the degree of detail needed because a hierarchical classification system based on associations has not yet been developed. There seems to be an endless continuum of biotopes and there needs to be a certain amount of simplification in order to classify lagoons. In small, isolated lagoons, the biological community could be classed as just one type of biotope, whereas in larger, more heterogeneous lagoons there may be any number of biotopes. For example, when analysed by station, one station in Athola is more similar to three of the stations in Aibhnín, whereas one in Aibhnín is more similar to three of those in Athola. This reflects the continuum in lagoon types, which is reflected in abundance of both fauna (Figs. 3.4.1 & 3.4.2) and flora (Figs. 3.4.3 & 3.4.4). Most of Aibhnín is dominated by *Ruppia* and *Zostera*, whereas only a small part of Athola has *Ruppia* and/or *Zostera*, but much of it is dominated by the sub-group with *Cladophora battersii*. This detail can be seen when using stations within the lagoon, but when using presence/absence data for the lagoon as a whole, both lagoons are classified as *Ruppia/Zostera*, which is precise enough at this initial level of classification.

Classification based on vegetation

The classification of terrestrial plant communities according to the "Zurich-Montpellier School" (Braun-Blanquet 1964) is applied widely both within and outside Europe but classification of aquatic plant communities has lagged behind that of terrestrial plants. In a study of *Ruppia*-dominated communities in western Europe, Verhoeven (1980a) distinguished two quite different plant associations both in the Mediterranean and in NW Europe, with one association dominated by *Ruppia maritima*, and the other by *Ruppia cirrhosa.* The difference in distribution of these two associations appeared to be related to salinity, size and permanence of the water body, and substrate type. Den Hartog (1971) mentions mean salinities in the range 2-7 ppt Cl^- for *R. maritima* and 7 – 15 for *R. cirrhosa* (S = 1.80655 Cl^-, Knudsen 1901), but according to Verhoeven, both species occur most frequently at average salinities of 3.5 – 10 ppt Cl^-, and do not show the sharp separation in salinity tolerance mentioned by den Hartog. Many of the plants were not in flower during the survey in Ireland, and as it is not possible to identify non-fruiting specimens in British or Irish material (Preston 1995, Roden 1999) many of the plants of this genus were not identified to species. It is quite possible that in the Irish classification the *Ruppia* of the *Potamogeton/Ruppia* group might well be *R. maritima,* whereas that of the *Ruppia/Zostera* group is more likely to be *R. cirrhosa* but there is a considerable overlap in the salinity ranges and *R. cirrhosa* was often found growing in low salinity lagoons. It is therefore more appropriate to be non-specific, and to regard both species as *Ruppia* sp., as do Covey and Thorpe (1994) for the Scottish lagoons. Verhoeven (1980a) classifies a number of sub-associations with *Chara canescens, Chara aspera* and *Zannichellia,* but all of these species occur in Irish lagoons at low salinities within the *Ruppia/Potamogeton* group. He also describes a Cladophoro-Ruppietum cirrhosae association in the Mediterranean, similar to that of the Chaetomorpho-Ruppietum but with a greater frequency of the former. *Cladophora* is also a very difficult genus to identify to species and is found in practically all lagoons in Ireland, in any salinity range and can show wide seasonal variation in abundance (Ch. 2), and therefore does not appear to be a useful genus for lagoon classification. Similarly, *Lamprothamnion papulosum* was found in a range of different Irish lagoon-types and salinities (4 – 30 psu). However, Verhoeven also recognises a *Ruppia/Chaetomorpha* and *Ruppia/Zostera* sub-association, which corresponds well to this Irish classification.

Roden (1999) recognised the same basic plant associations in Irish lagoons, with *Potamogeton pectinatus* and *Ruppia* sp. in low salinities (3-13 psu), *Ruppia* and *Chaetomorpha* in mid salinities (10 – 30 psu), and *Ruppia* with *Zostera* at higher salinities (> 15 psu), but also recognised a *Ruppia/Lamprothamnion* community and single genus stands of *Ruppia.*

Classification based on fauna

Verhoeven (1980a) also used fauna to classify *Ruppia*-dominated communities and compared the faunal with the floral classification. Whereas the floral classification was split into two sub-associations, based on the two *Ruppia* species, the clear split was not evident when using fauna. Again there was a differentiation in species associations between the Mediterranean and the NW European region, but within each region the groupings were much more similar to each other. Verhoeven found, however, that the fauna subdivided into a group of oligohaline species, a group of euhaline species, and a group of "true brackish" species, which were determined, not so much by the salinity itself, but the fact that one group had a connection to a freshwater source, one to a marine source, and the third group was a "blocked brackish-water", or semi-isolated. These three groupings correspond again to the *Ruppia/Potamogeton*, *Ruppia/Zostera* and *Ruppia/Chaetomorpha* lagoon types in Ireland. Bamber *et al.* (1992) identified six suites of species, mainly reflecting salinity but also a relationship between the suite of species and the lagoon type, with "bar-built" and sluiced lagoons supporting more lagoonal specialist species, as in the "semi-isolated *Ruppia/Chaetomorpha*" Irish lagoons. Covey (1999) found that species number increased with greater connection to the sea, whereas Sheader and Sheader (1989b) found number of species only increasing with size in "silled" lagoons. In Ireland, a species-area relationship was found for most lagoons of twenty surveyed with the exception of three high salinity ones (Drongawn, Aughinish, Lettermullen) where the presence of hard substrates favoured sessile invertebrates and algae (Healy and Oliver 1998). According to Verhoeven (1980a), in general, the salinity conditions, in particular fluctuations in salinity, are of crucial importance for the fauna composition and play a more definite role than for flora classification, where size and permanency of the waters are as important as salinity. In his final classification for NW Europe using flora and fauna, a distinction is again made between those dominated by *R. cirrhosa* and those by *R. maritima*, but many of the faunal associations occur in both.

3.6 Conclusions

I propose that the five basic types of Irish lagoon are:

Type 1. *Potamogeton/Ruppia* lagoons (+/- charophytes). Low salinity sites such as L. Gill, Durnesh L., L. Donnell. These may not contain *Ruppia* and may or may not contain charophytes. For example, at one end of the continuum in this group, Kilkeran contains no *Ruppia* or charophytes, and is completely dominated by *Potamogeton* but does contain lagoonal fauna. There are problems with the taxonomy of the rare lagoonal specialists *C. baltica, C. connivens* and *Tolypella* (Roden pers. comm.), but these are only found in one or two (generally low salinity) lagoons. Both *Chara canescens* and *Lamprothamnion papulosum* appear to be less restricted by salinity regime and might be regarded as sub-types of higher groups. Fauna is dominated by insect species, in particular *Sigara stagnalis*, lagoonal Coleoptera and freshwater molluscs, and often by abundant mysids and/or *Palaemontetes varians.*

Type 2. *Ruppia/Chaetomorpha* lagoons (+/- charophytes). Sheltered, "Mesohaline" lagoons, approximately 7-25 psu, characterised by soft mud and high trophic status. *Potamogeton* may occur in these lagoons, but is generally absent or in low abundance. Insect species are much rarer or less abundant and are replaced by crustaceans and lagoonal hydrobiids (e.g. *Idotea chelipes, Lekanesphaera hookeri, Hydrobia ventrosa*). The important characteristics of these lagoons are that salinity is much higher than Type 1, but they are relatively isolated and sheltered compared with Type 3.

Type 3. "Estuarine" lagoons. Lagoons which have both a large tidal exchange and freshwater inflow. Salinity is generally high, but may fluctuate considerably, both spatially and temporally on a daily basis. Substrate is generally fine, soft sediments, occasionally stony, and generally devoid of vegetation other than occasional fucoids. Lagoonal specialist fauna is also low in species number but usually includes *Cerastoderma glaucum* (adults), *Conopeum seurati,* and *Palaemonetes varians.* Migrant or "exotic" marine and freshwater species are frequent. Broadmeadow is a good example of this type, but this group also contains "shock lagoons" such as Lissagriffin Lake. Lagoons such as Cuskinny and Rosscarbery are largely devoid of vegetation except for an unusual community with *Gracilaria verrucosa*, and may be regarded as a sub-type, or transitional between Types 2 and 3.

Type 4. *Ruppia/Zostera* lagoons. These are the classic "clean, rock/peat West coast lagoons". Many also contain *Lamprothamnion* in a sub-type, and at higher salinities an unusual, rare community with *Cladophora battersii.* This lagoon type may be similar to some Scottish lagoons, and be rare type in European terms. Typical fauna in this group include *Onoba aculeus, Rissoa membranacea* and *Gonothyraea loveni* and a high proportion of sessile species.

Type 5. Mixed community lagoons. These are either the larger lagoons with a marked salinity gradient (L. Furnace, L. an tSaile) or groups of small, interconnected lagoons of various sizes and salinities (Kilcoole, Greenore), which contain any of the communities from the above lagoon types. The North Slobs is a good example of this group, and is particularly unusual in having a *Zostera angustifolia/Lamprothamnion* community.

No classification system for lagoons will perfectly describe every lagoon, as the various lagoon types are a continuum in terms of salinity, depth, substrate, size, degree of connection with a freshwater or marine supply, history and many other factors. The lagoon types can also be viewed as part of a continuum towards other habitats, for example from the low salinity lagoons to freshwater lakes, the "estuarine" lagoons to true estuaries and the *Ruppia/Zostera* lagoons to rocky shore intertidal and soft sediment subtidal habitats. However, the classification into five main types based on faunal and floral communities simplifies the task.

Morphological classifications

Many of the lagoons in Ireland, especially along the south coast of Cork, are completely artificial, created as a result of causeway construction to carry a road across an estuary or marine embayment (Healy 2003). Many have an outlet to the sea and therefore would be classed as Ecotype 1 after Barnes, but this outlet often has no sluice or sill and these lagoons appear to be unclassifiable using the classification used in the U.K. surveys. Others have sedimentary barriers and also a sluice, or are other combinations of physiographic types. For example, based on geomorphology, L. Murree may appear to be an isolated lagoon, receiving seawater only in storms, but it also has a cobble barrier, so could be described as a percolation (or sedimentary) lagoon. In fact, it is an unusual type of lagoon found in Ireland in limestone areas, very unusual in European terms, and described as a "karst lagoon" in survey reports (Oliver and Healy, 1998). Lough Murree receives seawater predominantly through underground fissures but also by percolation through the barrier and by occasional over-topping. Based on geomorphology it is difficult to describe, but using the proposed classification system, it is clearly a sub-type of the *Potamogeton/Ruppia lagoon* (a sub-type with abundant *C. canescens* and also *L. papulosum*).

Biological classification

Generally, vegetation is a more reliable descriptor than fauna. Most of the animals are mobile and can react more quickly to changes in salinity, especially in the lower salinity, insect dominated lagoons, as the insects can simply fly away if conditions become unfavourable and aquatic species may move to different parts of the lagoon. Plants are more permanent and reflect overall environmental conditions more accurately.

This classification is, of course, a generalisation, and some lagoons may still be difficult to classify due to the continuum between lagoon types. For example, in some *Ruppia/Zostera* lagoons, such as Loch an Aibhnín, there are *Ruppia/Chaetomorpha* communities in sheltered bays along the shoreline. *Chaetomorpha* can drift into different areas of the lagoon in response to changes in wind direction, and may therefore be present only at certain times of the year. In general, however, the dominant vegetation of the lagoon is *Ruppia/Zostera*, and the simple classification works well. In an assessment of English lagoons Bamber (1997) found that certain faunal species, notably *I. chelipes, C. insidiosum* and *Lekanesphaera* spp. were prevalent where submerged plants (*Ulva, Enteromorpha, Ruppia, Chaetomorpha*) were found, but the relationship was irrespective of the species of plant. On the other hand, many apparently similar lagoons in Ireland, in close proximity to each other and with very similar vegetation, have very different faunas, as also found in the UK by Barnes (1988), who suggests that the faunal community of East Anglian lagoons are “largely chance assemblages resulting from the vagaries of colonisation patterns”. It therefore seems more appropriate to classify the Irish lagoon types in terms of the dominant floral, rather than faunal species.

Most classifications are imposed on a continuum and a large degree of subjectivity must necessarily enter into any attempt to delimit communities and describe their structural components (Mason and Bryant 1974). On investigation, we realise that every single lagoon is different (Shardlow 2004), and yet there are features which certain lagoon types have in common. In this respect, this classification can be compared with that of water typology by Verdonschot (1994), in that there are no clear boundaries between the lagoon types but there are recognisable “centroids”. This proposed classification may be over-simplified, but with the confusing array of descriptive terms for lagoons, and the difficulty of achieving a meaningful measure of salinity, perhaps a simplification is to be desired. The Habitats Directive was, after all, designed to protect biological communities, and as lagoon geomorphology and biota may be regarded as independent variables (Barnes 1991a) it would be more appropriate to have a lagoon classification based on fauna and flora than on geomorphology. The model proposed is also useful in terms of management, as one can predict likely changes in the community, in response to a change in salinity, tidal current or degree of isolation.

CHAPTER 4.

IRISH COASTAL LAGOONS IN A EUROPEAN CONTEXT

4. Irish lagoons in a European context.

4.1 Introduction

Most people probably consider a lagoon as that defined in the Concise Oxford Dictionary; “a stretch of salt water separated from the sea by a low sandbank, coral reef etc.”. However, in the United States, Australia and New Zealand, “lagoon” refers to a small freshwater lake near a larger lake or river, and may also refer to “the enclosed water of an atoll” or “an artificial pool” for water treatment or retention.

In 1992, “coastal lagoon” was listed in Annex I (Code No. 1150) of the Habitats Directive (CEC 1992) as a “priority” habitat, in “special need of protection,” which obliges Member States to protect representative examples of this habitat within Special Areas of Conservation (SACs) and to monitor these selected sites, at least once every six years, to ensure that the conservation value of the site is maintained. The Interpretation Manual of the Directive (CEC 1996, 1999, 2003) defined “coastal lagoon” but this definition is still not precise and Member States may interpret it in different ways. What may be regarded in one country as a coastal lagoon, according to the Habitats Directive, may not receive the same consideration in another.

The aim of the Habitats Directive is to protect examples of habitats supporting important biological communities within Europe. These Special Areas of Conservation (SACs) areas protected under the Habitats Directive, together with sites selected as Special Protection Areas (SPAs) under the previous Birds Directive (EC 1979), will together form a network of conservation areas throughout Europe known as the NATURA 2000 Network.

Surveys of twenty coastal lagoons were carried out in Ireland in 1996 (Good and Butler 1998, Hatch and Healy 1998, Healy and Oliver 1998, Oliver and Healy 1998) and of sixteen lagoons in 1998 (Healy 1999 a, b; Oliver 1999, Roden 1999, Good and Butler 2000). An additional twenty four lagoons were surveyed in 2002-3 as part of the present study (Chapters 2 & 3) to provide faunal and floral data from sixty lagoons for statistical analysis. Now that a great deal of information is available concerning Irish lagoons it is possible to put this information into a European context. The intention of Natura 2000 is to create a Europe wide network of protected habitats, but information concerning coastal lagoon habitat and biota in other countries is still widely scattered and it is sometimes difficult to put the amount of habitat and conservation value of the habitats in different countries into perspective.

The objectives of the present study, therefore, are to summarise the research carried out so far in Irish coastal lagoons and compare these Irish lagoons with those in other European countries in relation to the various lagoon types, the amount of lagoonal habitat within each country, their characteristic fauna and flora and conservation status, and finally to consider the management and monitoring of coastal lagoons in order to put the Irish lagoons into a European context.

4.2 Coastal lagoons World-wide

Coastal lagoons are, according to the literature (Barnes 1980, 1994c), characteristic of microtidal areas (< 2m tidal range) and are particularly extensive along the coastlines of, for example, the eastern and Gulf-of-Mexico coasts of the USA, in Mexico itself, in Brazil, West Africa, Natal, the southern and eastern shores of the Indian peninsula, south-west and south-east Australia, Alaska, Siberia, in the Landes region of France, around the Mediterranean (e.g. near Venice, in the Gulf of Lions and around the Nile Delta), and around the southern Baltic, Black and Caspian Seas (Barnes, 1980). Cromwell (1971) calculated that 74.5% of the World's barrier/lagoonal coastlines are found in North America, Asia and Africa, and that barrier/lagoonal coastlines occupy 13% of the world's coastline, but that Europe with 5.3% is the continent with the least amount of coastline in this category. In this respect, on a world scale, lagoonal coastlines are relatively rare in Europe as a whole, and some lagoons in other parts of the world are massive in size compared to anything in Europe. For example, the Lagoa dos Patos, in southern Brazil, is 265 km long, compared with the largest in Ireland (Lady's Island Lake), which is only approximately 3 km long by 1.5 km wide. The barriers of these lagoons are generally formed by the onshore movement of an offshore sand bar, or by the formation of a spit enclosing an inlet or bay by longshore drift, or a combination of both processes. Additionally, lagoons may form as a result of land subsidence, redeposition of beach material following storms and by river channel changes in deltaic regions (Barnes 1980).

European lagoons

Barnes (1984) described four main types of lagoon in Europe:

1. **Estuarine lagoons** formed by barriers partially blocking existing drowned river valleys, and which usually have their long axis perpendicular to the coastline.

2. **Bahira lagoons** are pre-existing, partially land-locked coastal embayments, drowned by the post-glacial rise in sea level.
3. **Typical coastal lagoons** formed by the development of a spit, or by one or more offshore/longshore barriers, and except for those formed by tombolos, having their long axis parallel to the shore.
4. **Percolation lagoons** formed in low-lying land behind a longshore barrier through which seawater can percolate. These are often at least partly man-made as a result of reclamation of saltmarsh behind a barrier or due to sand/gravel extraction behind barriers for road/rail construction or sea defence.

The Habitats Directive (CEC 1992) listed “coastal lagoons” in Annex I of the Directive. The stated intention of the Directive is to protect the fauna and flora of the listed habitats, and for coastal lagoons in particular, it has long been realised that there are many examples of lagoonal communities found in coastal water bodies that do not fit comfortably within the definition of a “classic lagoon” as outlined above.

The Interpretation Manual of the Habitats Directive (CEC 1996 Version EUR 15/2) defined coastal lagoons as: “expanses of shallow coastal salt water, of varying salinity or water volume, wholly or partially separated from the sea by sand banks or shingle, or, less frequently, by rocks. Salinity may vary from brackish water to hypersalinity depending on rainfall, evaporation and through the addition of fresh seawater from storms, temporary flooding by the sea in winter or tidal exchange. With or without vegetation from Ruppietea maritimae, Potametea, Zosteretea or Charetea (CORINE 91:23.21 or 23.22).” The definition includes Baltic "flads and gloes", rock barriers and "salt basins and salt ponds....providing that they had their origin on a transformed old natural lagoon or on a saltmarsh, and are characterised by a minor impact from exploitation". This definition allows inclusion of certain lagoon types, that would not previously have been regarded as coastal lagoons. For example, Barnes

(1989a) listed 44 sites in England as coastal lagoons, but Smith & Laffoley (1992) listed 177 following the Habitats Directive. Barnes was, however, using the traditional definition of "true coastal lagoons" with a barrier of sand or shingle. The much broader Habitats Directive definition still, however, leaves certain other lagoon types unprotected, but it is up to member states to interpret the definition as they think best in the interests of nature conservation.

According to Barnes (1994c), within Europe, coastal lagoons are particularly abundant around the shores of the Baltic, Mediterranean and Black Seas and relatively rare in Northwest Europe. Jansson (1981) even referred to the whole of the Baltic as being like a gigantic lagoon, again confusing the correct interpretation of the definition. Following the Habitats Directive, a great deal of new surveys have been undertaken, especially in the U.K., and as a means of including unusual lagoon types, the following five lagoon types were listed by Covey and Thorpe (1996), based on Sheader and Sheader (1989):

1. **Saline lagoon inlets** with a permanent tidal inlet
2. **Isolated lagoons** completely separated from the sea by a barrier of rock or sediment, with seawater entering only by overtopping of the barrier, or by limited groundwater seepage (NOT percolation)
3. **Percolation lagoons** normally separated from the sea by shingle banks. Seawater enters by percolation through the shingle or by overtopping of the barrier.
4. **Sluiced saline lagoons** with a sea inlet modified by human mechanical interference (pipe, weir, non-return valve, culvert or combination)
5. **Silled saline lagoon** generally with rock basins which contain a sill between low and high tide levels.

Recently, Bamber (2004) listed coastal lagoons and "**coastal brackish ponds**" for Wales. Clearly there are many different types of lagoon on a global and European scale, but it is not always easy to make comparisons within Europe as the available published literature is widely scattered, and the various Member States are at different stages of centralising and computerising the information. Until recently, the occurrence of all or of the major, coastal lagoons within Europe had been systematically documented only for Denmark, Italy and Mediterranean Spain (Barnes 1994c). Even though documented, some documents are still hard to find, and even under the obligations of the Habitats Directive, Spain for example was not obliged to complete its list of SACs for coastal lagoon habitat until December 2005, and many countries are at fault for not having achieved earlier deadlines. There is an additional problem in Spain, in that data is retained within the autonomous communities and not centralised within the country.

As a result of this difficulty in obtaining information, statements concerning European lagoons are sometimes made that are quite erroneous. For example, it was recently stated at a seminar on managing coastal saline lagoons, that the UK has a large proportion of the saline lagoon resource found in Europe, with greater than 40% of the European resource (Reach 2004). The total area of the habitat in the UK is approximately 5,200 ha (Bamber *et al*. 2001b), whereas just one lagoon proposed as an SAC in Portugal (Ria Formosa), covers 10,000 ha (Cansela de Fonseca 2004). Italy has more than 150,000 ha of typical lagoonal habitat (Barnes 1994c), not to mention the large area of coastal lagoons in other parts of the Mediterranean and Baltic. Clearly, this is a miscalculation, presumably due to the difficulty of obtaining more accurate data.

4.3 Irish coastal lagoons

An inventory based on previous surveys (Healy *et al*. 1997b, Healy 2003) and updated in 2003/4 lists 89 sites (Table 4.3.1; Figure 4.3.1) in the Republic of Ireland and a further 25 are listed in Northern Ireland by Charlesworth and Quinn (2004) (Table 4.3.2).

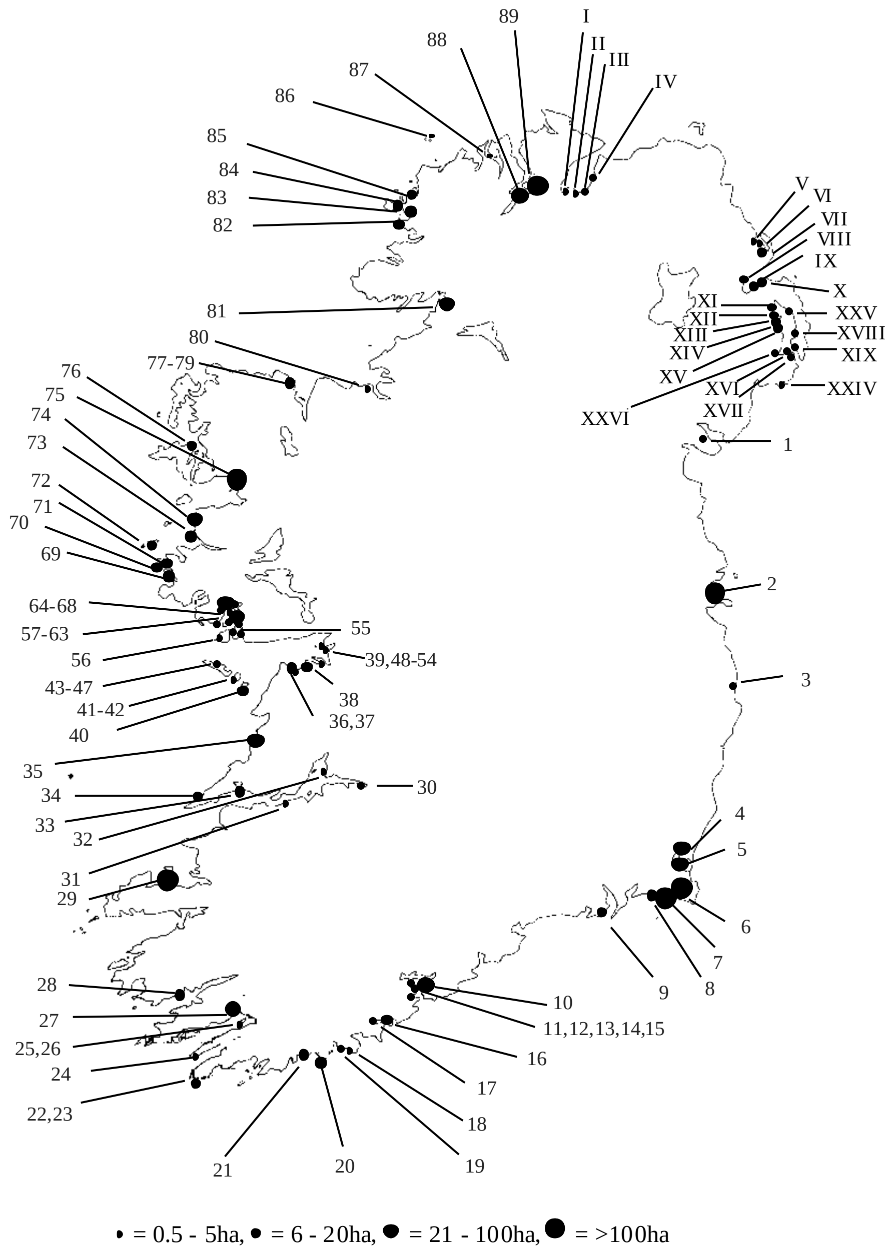

Figure 4.3.1 Location map of Irish coastal lagoons.
(Numbers refer to sites listed in Table 4.3.1, dots refer to size of lagoon)

Table 4.3.1. Size, location, salinity and year of survey of sites identified as coastal lagoons in the Republic of Ireland, 2004
(Code number refers to numbers used on Figure 4.3.1)

Code No.	Year of Survey	Site	County	Grid Ref	Approx. salinity (psu)	Size (ha)
1	2003	Greenore Golf Course	Louth	J 215 102	4-38	2.5
2	2003	Broadmeadow	Dublin	O 215 473	3-33	280
3	2003	Kilcoole	Wicklow	T 312 061	0-30	5
4	2002	North Slob channel	Wexford	T 090 248	4-30	50
5	2002	South Slob channel	Wexford	T 072 183	2-5	50
6	1996	Lady's Island Lake	Wexford	T 099 065	6-26	350
7	1996	Tacumshin	Wexford	T 050 065	0-26	450
8	1998	Ballyteige channels	Wexford	S 955 060	0-33	8
9		Lackaroe	Waterford	X 074 823	13	6
10	2002	Rostellan Lake	Cork	W 871 660	0-20	50
11		Ahanesk Lake	Cork	W 868 708	16-34	2
12	2002	Cuskinny	Cork	W 839 674	22-27	4
13		Slatty Bridge, Fota Is.	Cork	W 808 723	11-24	2
14		Raffeen Lake, Shanbally	Cork	W 758 647	33	4
15		Lough Beg. Curraghbinny	Cork	W 778 627	0-10	2
16	2002	Oysterhaven Lake, Clashroe	Cork	W 699 501	6-25	3
17	2003	Commoge Marsh, Kinsale	Cork	W 630 498	30-35	12
18	2003	Clogheen/White's Marsh	Cork	W 398 394	0-20	3
19	2002	Inchydoney	Cork	W 384 393	30-37	2
20	1996	Kilkeran	Cork	W 338 344	1-5	20
21	2002	Rosscarbery	Cork	W 290 367	14-24	20
22		Toormore	Cork	V 844 306	30-40	1.5
23	1996	Lissagriffin	Cork	V 775 265	6-28	15
24	1996	Farranamanagh	Cork	V 830 378	1-29	6
25		Reen Point Pools	Cork	V 888 399	30-35	1
26	1998	Kilmore L.	Cork	V 958 489	26-32	6.5
27	2002	Reenydonegan Lake	Cork	V 000 514	1-15	25
28	1996	Drongawn	Kerry	V 731 640	26-32	20
29	1996	Lough Gill	Kerry	Q 606 142	0-5	144
30		Blennerville lakes (2)	Kerry	Q 806 133	1-4	3
31	2003	Quayfield/Poulaweala	Limerick	R 297 527	0-20	2.5
32	2002	Shannon Airport Lagoon	Clare	R 350 620	0-13	2
33	2002	Scattery	Clare	Q 974 527	35	10
34	1996	Cloonconeen Pool	Clare	Q 836 497	30-35	7
35	1996	Lough Donnell	Clare	R 002 707	3-6	25
36		Muckinish	Clare	M 276 087	14-25	1
37	1996	Lough Murree	Clare	M 255 119	10-15	13
38	1996	Aughinish	Clare	M 286 134	25-40	8
39		Rossalia	Clare	M 310 116	27	3
40	1998	Loch Mór, Inish Oírr	Galway	L 989 019	1-10	6
41		Port na Cora, Inis Meain	Galway	L 937 066	4-15	0.5
42		Loch na gCadhan, Inis Meainn	Galway	L 944 063	2	2
43		Loch an tSaile, Arainn	Galway	L 878 081	16-34	0.5
44	1998	L. Phort Chorruch, Arainn	Galway	L 857 112	1-5	4
45	1998	Loch an Chara, Arainn	Galway	L 887 009	8-25	5
46		Loch Dearg, Arainn	Galway	L 808 126	15-30	4
47		Lough Amurvy, Arainn	Galway	L 778 114	2-17	1
48		Rincarna pools	Galway	M 370 166	31	0.5
49	1996	Bridge Lough, Knockakilleen	Galway	M 342 128	10-38	3
50		Doorus Lakes (4)	Galway	M 357 117	2-23	4.2

continued overleaf……………..

Table 4.3.1.cont.. Size, location and year of survey of sites identified as coastal lagoons in the Republic of Ireland, 2004(Code number refers to numbers used on Figure 4.3.1)

Code No.	Year of Survey	Site	County	Grid Ref	Approx. salinity (psu)	Size (ha)
51		Mweeloon pools (2)	Galway	M 335 196	20-25	1
52		Ardfry Point	Galway	M 332 208	10-12	0.5
53		Ardfry Oyster pond	Galway	M 351 211	22	1
54		Turreen Lough (Rinvile)	Galway	M 363 232	20-27	3
55		L. Faddacrussa	Galway	L 963 280	17	1
56	1996	Lettermullen	Galway	L 827 213	28-35	1
57	1998	Loch Fhada upper pools	Galway	L 930 300	13-33	2
58	1998	L. an Ghadai	Galway	L 934 299	3-15	5
59	1998	L. Fhada	Galway	L 939 305	8-25	8
60	1996	L. Tanaí	Galway	L 950 305	11-32	11
61	1998	L. an Aibhnín	Galway	L 947 315	18-27	55
62	1998	Loch Cara Fionnla	Galway	L 963 290	10-32	14
63		L. Cara na gCaorach	Galway	L 964 305	0-20	60
64	2002	L. Doire Bhanbh	Galway	L 961 384	10-20	1.5
65	1998	Loch an tSaile (L. Ahalia)	Galway	L 954 390	0-15	90
66	1996	L. Conaorcha (Aconeera)	Galway	L 875 369	0-14	28
67	1996	L. an Mhuilinn (Mill L.)	Galway	L 754 331	2-34	5
68		L. an Chaorain	Galway	L 784 315	3	1
69	2002	L. Ballyconneely	Galway	L 620 437	0-5	20
70	1998	L. Athola	Galway	L 626 484	6-33	11
71	2002	Lough Anillaun	Galway	L 613 581	0-1	15
72	1996	L. Bofin	Galway	L 525 656	13-36	12
73	1996	Corragaun Lough	Mayo	L 748 698	0-32	10
74	1996	Roonah Lough	Mayo	L 755 765	0-2	55
75	1996	Furnace Lough	Mayo	L 965 975	0-22	125
76		Dooniver Lough, Achill Is.	Mayo	F 738 074	0	3
77		Cartoon L., Killala Bay	Mayo	G 197 319	36	4
78		Portavaud W. Ballysadare Bay	Sligo	G 580 343	25	1
79		Portavaud E. Ballysadare Bay	Sligo	G 583 340	33	5
80	2003	Tanrego	Sligo	G 615 298	13-16	2.5
81	1996	Durnesh Lake	Donegal	G 878 695	0-7	83
82	1998	Maghery Lough	Donegal	B 723 094	15-27	19
83	1998	Sally's L.	Donegal	B 728 168	28-35	6
84	1998	Kincas L.	Donegal	B 752 197	2-31	6
85	1998	Moorlagh	Donegal	B 790 187	0-30	10
86		L. O Dheas, Tory Is.	Donegal	B 844 464	5	3
87	2003	Carrick Beg Lough	Donegal	C 157 366	22	2
88	2003	Blanket Nook Lough	Donegal	C 307 194	10-20	40
89	1998	Inch Lough	Donegal	C 352 230	1-8	160

Some of the 89 sites listed in the Republic are groups of small lagoons, listed under one name, but based on this list the total area of lagoonal habitat within Ireland is 2644 ha (2526ha in the Republic). Identification of coastal lagoons in Northern Ireland is ongoing. Table 4.3.2 is based on MSc theses by Carroll (1994), Donnan (1994) and Gorman (1994) who studied 24 lagoons out of 32 potential lagoons, but only 19 of the 24 are described as brackish (Carroll 1994). These nineteen are marked with asterisks, in addition to which are six other lagoons listed by Charlesworth and Quinn (2004). Many of the twenty five lagoons listed in Table 4.3.2 are very small and more than 25% are less than 1ha. Bamber *et al*. (2001b) mentions “25 lagoons covering approximately 41 ha” in Northern Ireland but according to Table 4.3.2, the total number of 25 lagoons listed for Northern Ireland cover almost 120ha.

Table 4.3.2 Inventory of coastal lagoons in Northern Ireland, with location, size and mean salinity.
(*= lagoons studied by Carroll (1994), Donnan (1994) and Gorman (1994)). Sites XX-XXV are additional sites listed by Charlesworth and Quinn (2004).

No.	Name	Grid ref.	Size (ha)	Mean salinity (psu)	Conservation status
I	Blackbrae*	C 495 239	8.17	30	ASSI/SPA
II	Donnybrewer*	C 513 238	9.49	28.5	ASSI/SPA
III	Longfield*	C 529 239	9.14	30.4	ASSI/SPA
IV	Myroe *	C 623 275	5.9	7.4	ASSI/SPA
V	Glynn*	J 405 065	6.4	31	ASSI/SPA
VI	Oldmill Bay*	J 453 963	5.17	31	ASSI/SPA
VII	Ballycarry*	J 945 464	8.82	32.5	ASSI/SPA
VIII	Whitehouse*	J 357 806	8.89	27.5	ASSI/SPA
IX	Victoria Park*	J 367 753	5.63	7	ASSI/SPA
1X	Harbour estate*	J 373 778	14.7	29.5	ASSI/SPA
XI	Castle Espie*	J 495 679	4.98	19	None
XII	Mahee Point*	J 540 646	0.56	5.5	ASSI/**SAC**/SPA
XIII	Cadew Point*	J 517 633	1.57	20.5	ASSI/**SAC**/SPA
XIV	Quarterland Bay*	J 524 587	0.46	31.5	ASSI/**SAC**/SPA
XV	Rathgorman*	J 529 581	0.11	27	SAC
XVI	Castleward*	J 500 575	0.24	30.4	ASSI/**SAC**/SPA
XVII	Black causeway*	J 584 488	0.23	25	ASSI/**SAC**/SPA
XVIII	Dorn*	J 590 560	?	33	ASSI/**SAC**/SPA
XIX	Granagh(3)*	J 604 486	0.46	31.5	SAC
XX	Ballyaghran		0.37	?	ASSI/**SAC**
XXI	Larne	? D 410 023	9.17	?	None
XXII	Dundrum South		2.59		ASSI/**SAC**
XXIII	Gransha	C 453 183	9	?	None
XXIV	Strand Lough	J 535 373	4	8	ASSI
XXV	Rosemount	J 582 675	3.75	?	ASSI
			Total = 119.8ha		

Previous unpublished lists include the Quoile pondage as a lagoon, which covers a large area (59ha), and when visited in 2003 was certainly permanent and “brackish” at 7 psu, but for the purposes of the Water Framework Directive, Charlesworth and Quinn regard the Quoile as an estuary and not a lagoon. Many of the small lagoons listed would probably not have been regarded as lagoons in the Republic unless they were of “exceptional conservation value”, whereas the Quoile pondage would have been.

When describing the distribution of coastal lagoons in Europe, Barnes (1994c) shows the entire habitat in Ireland concentrated in the southeast of Wexford due to the lack of available information for Ireland, and a restrictive definition of coastal lagoon. When describing coastal lagoon shores, Good and Butler (1998) distinguished sand barrier lagoons/saline lakes, shingle barrier lagoons, peat shore lagoons/saline lakes, karst lagoons/saline lakes and drumlin lagoons/saline lakes, whereas Healy and Oliver (1998) listed sedimentary lagoons, rock lagoons, natural saline lakes and artificial saline lakes. Healy (2003) subsequently modified this classification slightly by adding sub-types and referred to sedimentary lagoons, rock lagoons, saline lake lagoons and artificial lagoons.

When Barnes (1994c) wrote about coastal lagoons he was concentrating on the traditional definitions of natural lagoons with sand or shingle barriers, such as the classic examples in Wexford of Lady’s Island Lake and Tacumshin (Carter and Orford 1980, Orford and Carter 1982, Ruz 1989). One can still say that the classic percolation/sedimentary lagoons in Ireland are concentrated in the south east, but these two lagoons, covering approximately 350 ha and 450 ha each, account only for 30% of the habitat now regarded as lagoonal, and percolation/sedimentary lagoons are also found all around the coastline in Cork (Kilkeran, Reenydonegan), Kerry (L. Gill, 150 ha), Clare (L. Donnell), Galway (Ballyconneely, Anillaun, L. Bofin), Mayo (Corragaun L.,) and Donegal (L. Durnesh,) (Table 4.3.1, 4.3.3). There are many examples of communities of lagoonal flora and fauna (of high conservation value) found in habitats that do not fit comfortably within the classic definition of a lagoon (see Barnes 1991, Healy 2003). When analysed by morphological lagoon type (Table 4.3.3), more lagoons in the Republic are artificial than any other type (32.6%), but sedimentary lagoons are the second highest category of morphological type (25.8%) followed by “saline lake” lagoons (comprised of “silled” and “inlet” lagoons in UK terminology)(23.6%). Also noticeable in Table 4.3.3 is the high number of “karst” lagoons (13.5%) with subterranean connections to the sea. These are particularly important in European terms as they appear to be unique to Ireland along the Atlantic coast.

Table 4.3.3 Morphological lagoon types in the Republic of Ireland.
(* = rock lagoons formed in limestone and referred to as “karst lagoons”).

Sedimentary lagoons	Rock/Karst lagoons	Artificial lagoon	Saline Lake lagoon
Lady’s Island L.	Quayfield/Poulaweala*	Greenore	Drongawn
Tacumshin L.	Muckinish*	Broadmeadow	Mweeloon
Kilkeran	L. Murree*	Kilcoole	Turreen L.
Farranamanagh	L. Mor*	North Slob	L. an Ghadai
Reen Point	Phort na Cora*	South Slob	L. Fhada
Kilmore L.	L. na gCadhan*	Ballyteige	L. Tanai
Reenydonegan	L. an tSaile (Aran)*	Lackaroe	L. an Aibhnin
L. Gill	L. an Chara*	Rostellan	L. Cara Fionnla
Scattery	L. Phort Chorruch*	Ahanesk	L. Cara na gCaorach
Cloonconeen	L. Dearg*	Cuskinny	L. Doire Bhanabh
L. Donnell	L. Amurvy *	Slatty Bridge	L. an tSaile
Aughinish	Doorus Lakes*	Raffeen	L. Aconeera
Rincarna	Lettermullen	L. Beg	Mill Lough
Ardfry		Oysterhaven	L. Keeraun
Ballyconneely		Kinsale	L. Athola
L. Anillaun		White’s M./Clogheen	Furnace L.
L. Bofin		Inchydoney	Portavaud W.
Corragaun		Rosscarberry	Maghery
Roonah		Toormore	Sally’s
Dooniver L.		Blennerville	Kincas
Potavaud E.		Shannon	Moorlagh
Durnesh L.		Rossalia	
L. O Dheas		Bridge L.	
		Ardfry Oyster pond	
		Cartoon L.	
		Tanrego	
		Carrick Beg	
		Blanket Nook	
		Inch L.	

Three lagoons do not fit comfortably within the four main morphological types listed in Table 4.3.3. Lettermullen might be classed as a very large rockpool, but is regarded in this classification as the only “rock” lagoon which is not formed in limestone, Faddacrussa is a “marginal” lagoon described by Healy (2003) as a saltmarsh pool, and Loch Fhada upper pools, due to their small size are referred to as “saline pools”, in the same way that Bamber (2004) describes some of the small brackish water bodies in Wales. Some lagoons are combinations of morphological types, but in general a classification based on morphology is useful for management purposes, as for example most of the lagoons are artificial, and most of these have sluices. Many of the other types have also been modified to a certain extent by man, and may also be sluiced. In this respect, one of the most important aspects of management is the appropriate control of the seawater inlet, whereas in a completely natural lagoon this is likely to be impossible to control (see Section 4.6).

Apparently, lagoons with shingle barriers are relatively unusual and mostly confined to macro-tidal, glacial coastlines on W. European coasts (Barnes 1989a). Some of the high percentage of sedimentary lagoons along the Irish west and northwest coasts may be particularly unusual in that the barrier is composed of large cobbles (L. Donnell, L. Bofin, L. Murree, L. Anillaun), and are presumably particularly characteristic of the high energy, macrotidal, glacial coastlines, though a barrier like this is also found in Gallicia, Northwest Spain and on the volcanic island of Santo Jorge in the Azores. In some areas, lagoonal barriers can also be formed, at least partly, as a result of local landslides, or on volcanic slopes, resulting from an abundant supply of suitable material, and not necessarily restricted to "glacial" coastlines. The "karst" lagoons in the limestone areas of Galway and Clare (Healy and Oliver 1998, Healy 2003) are also unusual as there is no visible connection with the sea but seawater enters from subterranean fissures. The underlying bedrock is limestone, which is rare along the Atlantic coast apart from a stretch of the Asturian coastline, which has no coastal lagoons, though does have a marine sinkhole 100m from the sea into which tides enter.

Of particular interest in Ireland is the large number of "saline lake lagoons" along the west coast of Ireland and particularly in Connemara, composed mostly of granite, and very often with a (granite) "sill", or with a barrier of small peat islands (L. Athola). They appear to be very similar to lagoons in Scotland known as "obs". Though to a very large degree natural, many have been modified to some extent and using the

U.K. terminology could be referred to as “silled”, “sluiced” or as “lagoonal inlets” and it is not clear which would be the most appropriate morphological term to use. In this situation in particular the names “*Ruppia/Zostera”* type or “clean, west coast rock/peat” lagoon as proposed in the biological classification (Chapter 3) is a much better description of the lagoon type. Though appearing to be very natural, they may well owe their origin to a certain extent to former peat cuttings, and the channel through which seawater enters may have been cut, partly to drain the bog, but also for transporting the cut turf in small boats to the coast. Within Europe, this type of lagoon appears only to be found in Scotland and Ireland.

In number and spatial extent, the coastal lagoons in Ireland are a very small part of the European resource compared with the amount of lagoon habitat in the Mediterranean and Baltic Seas, but the 2,600 hectares in Ireland are an important part of the lagoon habitat along the Atlantic coast, as lagoons of any type along this coastline are relatively rare. Many of these lagoons with cobble barriers, or formed in limestone or granite/peat are of a very unusual type and therefore of great conservation value both morphologically and biologically (Section 4.4) in European terms.

4.4 Fauna and Flora

Biological classification of Irish lagoons

While to some extent the general geomorphology of a lagoon determines the nature of the communities it contains, it cannot be predictive as the actual species present depend on many other factors including, for example, salinity, substrate, stability and variability, chance colonisations and past history. In the biological classification of Irish lagoons (Chapter 2, Table 4.4.1), the low salinity, *Potamogeton/Ruppia* lagoons are grouped together. These lagoons are insect dominated and show the greatest seasonal variations in both abundance and presence/absence of faunal and floral taxa. These lagoons are the most likely to evolve, either naturally or by human intervention into fresh water lakes, thereby losing their lagoonal community and status as a "priority" habitat (see sections 4.6 & 4.7).

Table 4.4.1 Irish coastal lagoon types based on biological classification (Chapter 2)

Potamogeton/ Ruppia lagoon 0-14psu (approx.)	*Ruppia/ Chaetomorpha* lagoon 10-25psu(approx.)	*Ruppia/Zostera* lagoon 20-35psu(approx.)	"estuarine" lagoon 0-35psu(approx.)	Mixed community 0-40psu(approx.)
South Slob	Scattery	? Kilmore	Broadmeadow	Greenore
Tacumshin	Cloonconeen	Drongawn	Cuskinny	Kilcoole
? Lackaroe	Rossalia	? Rincarna	Slatty Bridge	North Slob
Rostellan	? Port na Cora	Ardfry Oyster ponds	? Raffeen	Lady's Island L.
Ahanesk	L. an Chara	Lettermullen	Kinsale	Ballyteige
L. Beg	Bridge L.	? L. Fhada	Inchydoney	? Oysterhaven
Kilkeran	? Ardfry	L. Tanai	Rosscarberry	White's/Clogheen
Reenydonegan	Turreen L.	L. an Aibhnin	Toormore	Quayfield/Poulawea
L. Gill	L. Fhada upper pools	Aconeera	Cara na gCoarach	L. an tSaile
Blennerville	Doire Bhanabh	L. Athola	Aughinish	Furnace L.
Shannon	Tanrego	Sally's L.	L. an tSaile, Aran	
(L. Murree)	Kincas L.	Maghery	Faddacrussa	
L. Mor	Carrick Beg		? Carafinla	
L. na gCadhan			Blanket Nook	
L. Phort Chorruch				
L. Amurvy				
L. an Ghadai			Lissagriffin *	
Ballyconneely			L. Donnell *	
L. Anillaun			Mill Lough *	
Dooniver			L. Bofin *	
L. O Dheas			Corragaun *	
Inch L.			Roonah *	
Durnesh			Moorlagh *	
			(* = shock lagoon)	

In the mid-salinity sites seasonal patterns are less marked and the characteristic biota are generally present throughout the year, though abundance may change and certain taxa may be more difficult to find in the winter. The same applies generally to the higher salinity "estuarine" and *Ruppia/Zostera* lagoons, though abundance and presence/absence of algal taxa may vary considerably through the year. The faunal taxa in the latter two lagoon types may vary through the year but the overall community does not change greatly. The "estuarine" lagoons marked with an asterisk in Table 4.3.5 are a type of lagoon referred to as "shock lagoons", similar to the "schockbiotopen" in Den Hartog's typological classification of brackish waters (1964a) which are subject to extreme fluctuations in salinity especially, but also current strength, temperature and other types of water chemistry. The substrates in these lagoons depend on the type of catchment area and the freshwater inputs. Many lagoons of this type on the west coast of Ireland have very coarse sediments as the freshwater inputs are coming from mountainous areas and the streams are erosive throughout their length as opposed to the sedimentary nature of inputs on the east and south coast. Very few species can tolerate the extreme variations of these "shock" lagoons and the permanent biological community is therefore depauperate, but is frequently augmented by temporary "allochthonous" colonist species brought into the lagoon by strong tides or floods in the catchment area.

Finally, in the "mixed community" lagoons any of these different conditions may exist in different parts of a large lagoon or lagoonal complex.

As in any classification some sites are difficult to classify and may belong to a subgroup within a continuum, and some lagoons in this list have not yet been fully surveyed so sufficient information on which to base a decision is not available (e.g. Reen pools, Muckinish, L. Dearg, Doorus lakes, Mweeloon, L. Keeraun, Cartoon, Portavaud E and

W.). However, the biological classification, as it is, is a useful way of describing the different types of Irish lagoon.

Lagoonal specialists

It is generally agreed that the biological community of coastal lagoons is derived from marine species that can tolerate dilution of seawater, freshwater species that can tolerate a measure of salinity and a group of brackish water species that are "distinctly more characteristic of lagoonal habitats than of estuaries or saltmarshes". The latter are referred to as lagoonal specialists and are broadly equivalent to the category of species inhabiting 'blocked brackish water' in the Netherlands and elsewhere (Verhoeven 1980a) and the species characterising 'brackish lentic communities' in Denmark (Muus 1967). Perhaps 'specialist' is the wrong word to use as most of these species can be found in neighbouring habitats, but far less commonly so, and 'characteristic species' may be a more appropriate description. However, lists of lagoonal specialists have been compiled in the U.K. (e.g. Barnes 1989a, Davidson *et al*. 1991, Bamber *et al.*1992b, Smith and Laffoley 1992, Downie 1996, JNCC 1996, Bamber *et al*. 2001b) and have varied in content as species have been added or deleted, depending on the opinion of various authors. For example, the most recent list available (Bamber *et al*. 2001b) is split into two lists (A and B) for species that are "distinctly more characteristic of lagoons and lagoon-like habitats than of other habitats" (List A) and those "whose UK population would be unsustainable without the presence of saline lagoons" (List B). All corixid and coleopteran species, which were on earlier versions of the lists, have been moved to List B, but a cranefly (*Geranomyia bezzia*) and a chironomid midge (*Gryptotendipes barbipes*) have been added to List A. Similarly, two of the charophyte species (*Chara baltica, Chara canescens*) have been moved from List A to List B, while *Chara connivens* and the hydroid, *Gonothyraea loveni*, which were on the JNCC list (1996) have been removed completely from the lists of Bamber *et al*. (2001b). The compilation and acceptance of lagoonal specialist lists is an ongoing process and likely to be subjected to continual reappraisal (e.g. Gilliland and Sanderson 2000).

Table 4.4.2 Proposed list of lagoonal specialist flora and fauna for Ireland
(**?** = proposed specialists, pending further information)

Flora	
Non-charophyte algae	Charophyte algae
Chaetomorpha linum	*Chara ?baltica*
Cladophora battersii **?**	*Chara canescens*
Spermaphyta	*Chara ?connivens*
Ruppia cirrhosa	*Lamprothamnion papulosum*
Ruppia maritima	*Tolypella ?nidifica*
Fauna	
Cnidaria	Insecta
Cordylophora caspia?	Coleoptera
Gonothyraea loveni	*Agabus conspersus*
Crustacea	*Enochrus bicolor*
Idotea chelipes	*Enochrus halophilus*
Jaera nordmanni?	*Enochrus melanocephalus?*
Lekanesphaera hookeri	*Ochthebius marinus*
Allomelita pellucida ?	*Ochthebius punctatus*
Corophium insidiosum	Hemiptera
Gammarus chevreuxi	*Notonecta viridis?*
Leptocheirus pilosus?	*Sigara stagnalis*
Palaemonetes varians	*Sigara selecta*
Mollusca	Diptera (Chironomidae)
Hydrobia ventrosa	*Glyptodentipes barbipes?*
Littorina tenebrosa	Bryozoa
Onoba aculeus	*Conopeum seurati*
Rissoa membranacea var.*?*	
Cerastoderma glaucum	

Lists of lagoonal specialists have also been proposed for Ireland by Oliver and Healy (1998), Roden (1999) and Healy (2003), and updated (Table 4.4.2) following additional surveys in 2002-3, the discovery of one species not previously recorded in Ireland (*Corophium insidiosum*) and a potential rediscovery (*Tolypella nidifica*). Some species previously regarded as lagoonal specialists have since been recorded at inland sites and are now omitted. Despite the proximity of the UK and its islands, several species on earlier UK lists have not been recorded in Ireland, though one may now be extinct in the UK (*Paracymus aeneus*). Several new species are proposed as lagoonal specialists in Ireland which were never on any UK list, but their validity has yet to be verified.

At the time of writing, official lists of lagoonal specialists with reference to the Habitats Directive are unavailable for countries other than Ireland and the U.K.. In the following account, lagoonal specialists are those previously listed for the U.K. and now regarded as such in Ireland, unless described as "proposed for Ireland", in which case they are species not previously listed as such in the U.K..

Floral lagoonal specialists

The charophytes are a difficult group to identify and there are certain taxonomic difficulties. Accounts of the following three species are taken from Roden (2004).

Chara ?baltica. This species was first reported by Hatch & Healy (1998) in L. Aconeera, identified as *C. baltica* by Jim Ryan and confirmed by Mr. Nick Stewart. However, recently Stewart wrote to C. Roden expressing reservations about his identification. The population was resampled and depending on one's interpretation of the cortex it keys out as either *Chara baltica* or *Chara aspera*, using standard works (e.g. Krause 1997, Moore 1986, Schubert and Blindow 2004). Another related lagoonal taxon, known from Brittany and southern Europe is *C. gallioides* which is larger than *C. aspera* and has larger reproductive organs and lacks bulbils. It has not been possible to obtain fertile material which would help in identification, from L. Aconeera and the species remains to be verified. (Roden (1999) recorded *C. baltica* in L. an tSaile in 1998, which is apparently the same species as the *Chara* in L. Aconeera, and similarly remains to be verified).

Another charophyte found in Ballyconneely L. since 1998 easily keys out as *Chara baltica* on the basis of size (>60cm), spines single or in pairs, large reproductive organs and long uncorticated branchlet end cells, as well as slight encrustation. However this identification has not been confirmed by an expert in the group and Schubert and Blindlow (2004) note differences between the form of *Chara baltica* found in the Baltic Sea and all other European populations identified as this species.

Chara ?connivens. Like the Tolypella species found in the North Slobs (see below), there is also a record for *Chara connivens* from this site. During fieldwork a spineless *Chara* species was collected from the North Slobs but it lacked any reproductive organs and its identity could not be established. An attempt to collect fertile material in September 2003 had to be abandoned as a dense algal bloom reduced visibility to a few cm. The identity of the form should be investigated as soon as possible.

Tolypella ?nidifica. *Tolypella* species have only been recorded from one Irish brackish site (North Slob, Co. Wexford). The species was collected in 1896 and identified by Groves and Bullock Webster (1924) who note the decayed state of the material and stated it was the only true *T. nidifica* known to them from Britain or Ireland. Despite this identification, the material was re-examined by Moore (1986) who concluded it was *Tolypella glomerata*. There are no records of further material being collected from the North Slob since 1896 until the present survey, when a large population was found there. Despite the identification as *T. glomerata* by Moore, examination of the fresh material agrees with the description of *T. nidifica* given in standard works noted previously. However this identification has not been confirmed.

Chara canescens was recorded in eight lagoons during the surveys - North Slob, Lady's Island L., and Tacumshin L., Co. Wexford, L. Gill, Co. Kerry, L. Murree, Co. Clare, Tanrego, Co. Sligo and Durnesh L. and Inch L., Co. Donegal (Hatch & Healy, 1998; Roden, 1998; Roden 2004). It was also recorded at Shannon Lagoon in 1996 (Hatch and Healy 1998), but not refound at that site in 2003 (Roden 2004). This species is listed in the Red Data Book for Britain and Ireland (Stewart and Church 1992) and on Annex II of the Habitats Directive (CEC 1992). Although recorded from several European countries it is believed to be declining. It is believed to be extinct in Holland, and there are only a few records from the U.K. since 1960. These Irish locations are very important in European terms, and it is especially encouraging to have found new sites.

Lamprothamnion papulosum was known from only three sites in Ireland before 1996 (Hatch and Healy 1998). As a result of the surveys it was relocated at two of these sites (Lady's Island L., Co. Wexford, L. Murree, Co. Clare), but not at Tacumshin L., Co. Wexford. It is also now known from an additional 10 sites, most of which are clustered in Connemara, but there are also new records from the North Slob, Co. Wexford, L. Bofin, Co. Galway and Maghery, Co. Donegal. This species is listed in the Red Data Book for Britain and Ireland (Stewart and Church 1992) and on Annex II of the Habitats Directive (CEC 1992). Although recorded from the Baltic to the Mediterranean and Black Sea and also South Africa, it is believed to be declining in Europe. There are only five recent records from the south of England, but there are 12 important sites in the Outer Hebrides (Bamber *et al*. 2001b). These Irish locations are very important in European terms, and it is especially encouraging to have found new sites.

Chaetomorpha linum. There is some doubt about the taxonomic status of the unattached lagoonal form of this species, and it was recorded by Hatch and Healy (1998) as *C. mediterranea*. It is a common, characteristic alga of semi-isolated Irish lagoons, recorded at 33 of the 60 lagoons surveyed.

Cladophora battersii is a rare species found at only two high salinity lagoons on the west coast (L. Athola, Co. Galway and Sally's L., Co. Donegal). Proposed as lagoonal specialist for Ireland by Roden (1999).

Cladophora aegagropila is a rare species recorded only in L. an tSaile during the lagoon surveys. Roden (1999) lists this species as a lagoonal specialist but it is also found in freshwater. Status as a lagoonal species remains uncertain at the moment.

***Ruppia* spp.** are the most characteristic aquatic plant taxa of Irish coastal lagoons. The species are hard to distinguish when not flowering, and remain uncertain at some sites, but *Ruppia* of one species or the other (*R. maritima, R. maritima var brevirostris, R. cirrhosa*) was found at 49 of the 60 lagoons surveyed, and is one of the most useful indicators of coastal lagoon status.

Ruppia maritima appears to be the more common of the species and was found at 28 of the lagoons surveyed. ***Ruppia cirrhosa*** is believed to tolerate higher salinities than the former species and to be less common, but neither of these statements is clearly supported in Irish lagoons and the two species were often found growing together. *Ruppia cirrhosa* was only identified at 21 lagoons, but species was not determined at 12 sites. ***Ruppia maritima var brevirostris*** was only positively identified at two sites (Ballyteige, Co. Wexford and Inch L., Co. Donegal).

Fauna

Cordylophora caspia. Hydroid recorded at four lagoons in Donegal (Kincas L., Inch L., Durnesh L., Blanket Nook) and at Rostellan, Co. Cork and an unsurveyed site (Rinmore) in Co. Galway and previously at Lady's Island L. (Healy *et al*. 1982). According to Arndt (1984), the species "appears to be an excellent bio-indicator for eutrophic brackish water in the horohaline zone". Proposed as a lagoonal specialist for Ireland by Oliver and Healy (1998).

Gonothyraea loveni. Hydroid listed as a lagoonal specialist in Britain by Downie (1996) and JNCC (1996). Recorded only at L. an Aibhnin. There is a record of its occurrence in the Belmullet Canal, Co. Mayo from material collected by P. Hayward in 1971 (B. Picton *pers comm.*) but there appear to be no other records of its occurrence in Ireland other than a record (as *G. hyalina*) in Co. Louth by Duerden (1894).

Idotea chelipes is a common, lagoonal, isopod crustacean, often found in association with the lagoonal form of *Chaetomorpha linum.* Found at 15 of the 60 lagoons surveyed, mostly at relatively high salinity.

Jaera nordmanni. Isopod crustacean recorded at 23 of the 60 lagoons surveyed and may occur at others where it was not recorded due to the fact that only adult males are easily identified. This species may occur in freshwater, as in L. Errol, Cape Clear, Co. Cork. Described in England (Barnes 1994, Hayward and Ryland 1995) as occurring in streams flowing down the shoreline, on south and west coasts only. All records in Ireland are from West Cork to Donegal. Proposed as a lagoonal specialist for Ireland by Oliver and Healy (1998).

Lekanesphaera hookeri is a common lagoonal isopod crustacean, found at 29 of the 60 lagoons surveyed.

Allomelita pellucida. Amphipod crustacean recorded at Kilcoole, Co. Wicklow, five sites in Cork (Cuskinny, Kilkeran, Lissagriffin, Farranamanagh, Reenydonegan) and in Furnace L., Co. Mayo. The only previous records are for L. Hyne and Glengarriff in Co. Cork and Furnace L. (Costello *et al.* 1989) and in L. Beg, Co. Cork (Galvin 1992). Proposed as a lagoonal specialist for Ireland by Oliver and Healy (1998).

Corophium insidiosum Amphipod crustacean recorded for the first time in Ireland at three lagoons in Co. Cork (Rostellan, Cuskinny, Rosscarbery), following Pinkster's prediction (1978) that it would be found in Ireland. These records from Co. Cork are of very high conservation interest.

Gammarus chevreuxi Amphipod crustacean confirmed only recently as an Irish species by the record of a small population in the Douglas Estuary (De Grave and Myers 1997). The record from Durnesh L., Co Donegal (Oliver and Healy 1998) is erroneous. Previously recorded from "N. Ireland, rarely" by Spooner in the Plymouth Marine Fauna (1957) and subsequently from Ireland by Pinkster (1978), but confirmation of these records was described as desirable by Costello *et al.* (1989). Recorded at Rostellan L. and Commoge Marsh, Co. Cork. Known only from six sites in England and Wales (Bamber *et al.* 2001b). These records from Co. Cork are of high conservation interest.

Leptocheirus pilosus Amphipod crustacean recorded at three lagoons in Co. Cork (Rostellan, Cuskinny, and Rosscarbery), in association with *C. insidiosum* and also at L. Athola, Co. Galway and Furnace L., Co. Mayo. The only other known Irish localities are the south side of Wexford Harbour (Costello *et al.* 1989) and on the North Slob, Co. Wexford (Galvin 1992). Proposed as a lagoonal specialist for Ireland by Oliver and Healy (1998).

Palaemonetes varians Decapod crustacean listed as a lagoonal specialist in the U.K. by Barnes (1989) and Bamber (1997), but apparently is no longer regarded as such. Although found in estuaries, this species appears to be far more characteristic of lagoons in Ireland (found in 48 of the 60 lagoons surveyed) and may require a lagoonal environment for reproduction. Therefore, it remains on the proposed list of lagoonal specialists for Ireland.

Notonecta viridis Hemipteran insect (back-swimmer)recorded on the east coast at Kilcoole, on the south coast at Lady's Island L., Tacumshin L., Ballyteige, Clogheen/White's Marsh and Kilkeran L. and also on the west coast at Reenydonegan, Co. Cork and L. Donnell, Co. Clare. A rare brackish water species in Ireland. According to Southwood and Leston (1959), it was recorded only for Wexford and North Kerry. Recorded previously in Lady's Island L (Healy *et al.* 1982) in Lady's Island L. and the North Slob by Galvin (1992) and from the Dingle Peninsula by McCarthy and Walton (1980). Proposed as a lagoonal specialist for Ireland by Oliver and Healy (1998).

Sigara selecta Hemipteran insect (water-boatman) abundant in L. an Chara in 1998. Previously recorded only from Ventry on the Dingle peninsula (McCarthy and Walton 1980). This species is listed as a lagoonal specialist in Britain, where it tolerates higher salinities than *S. stagnalis* (Scudder 1976). The previous record from Ventry was regarded by McCarthy and Walton as "difficult to explain since it has not previously been found at other brackish water sites recently investigated along the south coast". This record from the Aran Islands is therefore of great interest.

Sigara stagnalis Hemipteran insect (water-boatman). A common lagoonal specialist found at 30 of the 60 lagoons surveyed.

Glyptodentipes barbipes. Chironomid species included in a recent list of lagoonal specialists in the U.K. (Bamber *et al*. 2001b), and proposed in this report as an Irish lagoonal specialist until more is known of its status in Ireland. Recorded only at Ballyteige. This species, and several others, were identified by D. Murray from samples collected in 1998. Identification of chironomid larvae is a specialist subject and more samples await identification.

Agabus conspersus Water-beetle listed by Barnes (1989) and Bamber (1997) as a lagoonal specialist in the U.K. but is no longer regarded as such. This species remains on the proposed list of Irish lagoonal specialists until more is known of its status and ecology in Ireland. Identified from samples collected at Ballyteige and the North Slob by Galvin in 1991 and previously recorded in Lady's Island L. by Healy (1997). One specimen was taken at an unsurveyed site near Garretstown, Co. Cork in 1998. This brackish water species appears to have become rare and there are only two other recent Irish records: from a salt marsh in Co. Meath, and at Dundalk harbour, Co. Louth (Nelson *et al.* 1997).

Enochrus bicolor Water-beetle recorded at 12 lagoons of the 60 surveyed, from the southern half of the country from Co. Wicklow to Connemara including the Aran Islands. There are only two recent records from N. Ireland (Nelson *et al.* 1998).

Enochrus halophilus Water-beetle recorded only at Tacumshin (1996), and previously from samples collected from L. Beg, Co. Cork in 1992. One specimen was found in L. Murree by Pybus and Pybus (1980). There appear to be no other recent records.

Enochrus melanocephalus Water-beetle recorded from the North Slob in 2002 only. There appear to be no other recent records. This species remains on the proposed Irish list of lagoonal specialists, but its status as a lagoonal specialist is uncertain.

Ochthebius marinus Water-beetle identified from Tacumshin L. in 1996 and from Lady's Island and Tacumshin in 1991, and at Clogheen/White's Marsh, Co. Cork in 2003. Only recorded from one 10-km square in Ireland by Foster *et al.* (1992). Four recent records from Co. Down (Nelson *et al.* 1998).

Ochthebius punctatus Water-beetle recorded at L. an Chara, Inishmore and Ballyconneely, Co. Galway. Since 1988, recorded at seven brackish sites in Antrim and Down (Nelson *et al.* 1998).

Littorina "tenebrosa" Gastropod mollusc recorded on the North Slob and in a brackish pool close to L. Murree, Co. Clare and at six lagoons in Co. Galway. These are the only known sites in Ireland. The status of this taxon is still uncertain but specimens appear to be morphologically and ecologically distinct from *L. saxatilis.*

Onoba aculeus Gastropod mollusc recorded at Greenore Golf course, Co. Louth, Lettermullen Pool, L. an Aibhnin, and L. Athola, Co. Galway and Sally's Lake, Co. Donegal.

***Rissoa membranacea* var.** Gastropod mollusc recorded at eight of the 60 lagoons surveyed on the west coast from Co. Cork to Co. Galway and also at Castle Espie, Co. Down. These records refer to a 'lagoonal' variety of the species, proposed as a lagoonal specialist for Ireland by Oliver and Healy (1998).

Cerastoderma glaucum Bivalve mollusc. A common lagoonal specialist found at 21 of the 60 lagoons surveyed.

Conopeum seurati Brozoan recorded at 32 of the 60 lagoons surveyed, but is not listed in a recent review of Irish marine Bryozoa (Wyse Jackson 1991). Either the species is under-recorded or is truly a lagoonal specialist.

Other non-lagoonal specialists of interest:

Laomedea angulata Colonial hydroid which appears to be a very rare species, only recorded at Lettermullen Pool. It is described as "known from the south coast of England southwards; status in Ireland unclear" by Hayward and Ryland (1995).

Jaera forsmani Isopod crustacean recorded at Kilmore L., Co Cork, Drongawn L., Co. Kerry and at L. Fhada, L. an Aibhnin, Cara na gCaorach and L. Athola, Co. Galway. The only other Irish record of the species located is for L. Hyne, Co. Cork (De Grave and Holmes 1998).

Jaera ischiosetosa Isopod crustacean recorded at L. Murree, Co. Clare, L. an Chara, and L. Athola, Co. Galway, Furnace L., Co. Mayo and Maghery L. and Moorlagh, Co. Donegal. The only previous record appears to be for L. Hyne. Co. Cork (Goss Custard *et al.* 1979).

Ampithoe ramondi Amphipod crustacean recorded at Kilmore L., Co. Cork, Drongawn L., Co. Kerry, L. an Aibhnin, and L. Athola, Co. Galway and Sally's L., Co. Donegal. According to Lincoln (1979) all records from Britain are in the southwest. The record from Sally's L., Donegal may be the most northerly record of the species for the British Isles.

Erichthonius difformis Amphipod crustacean recorded in Drongawn L. in 1996. Up to, and including, the review of this genus (Myers and McGrath 1984) there was only one positive record of this species in Ireland, at Kinsale, Co. Cork.

Lembos longipes Amphipod crustacean recorded at Kilmore L, Co. Cork, Drongawn L., Co. Kerry, L. an Aibhnin, Co. Galway and at Furnace L., Co. Mayo. There are only three previous records for Ireland (Costello *et al.* 1989).

Notonecta obliqua Hemipteran insect (back-swimmer) recorded at Inch L. and at no other lagoon surveyed.

Cercyon sternalis Water-beetle recorded at L. Gill. There are only three other Irish records, from Kerry (Bullock 1935) and two other recent records from L. Gash, Co. Clare and Portumna, Co Galway (Owen 1997).

Helophorus fulgidicollis Water-beetle identified from samples collected at Kilkeran L. in 1991. A strictly brackish water species with recent records from only 2 sites in Co. Down (Nelson *et al.* 1998).

Hygrotus novemlineatus Water-beetle found at Inch L., Co. Donegal. This species appears to have declined in Northern Ireland, mirroring the trend in England (Nelson 1995).

Megasternum obscurum Water-beetle recorded at Ballytiege, Co. Wexford, and L. an Chara and L. an tSaile, Co. Galway and at Furnace L., Co. Mayo, but is otherwise described as rather rare in Ireland (Foster *et al.* 1992*)*.

Ochthebius auriculatus Water-beetle recorded at Aughinish L. There are only 2 recent records from Northern Ireland. Previous records are all from the east coast (Nelson et al. 1998).

Rhantus suturalis Water-beetle recorded only from Tacumshin and Ballyteige, Co. Wexford. Apparently a southern species which occurs in Ireland only sporadically (Foster 1981).

Aplexa hypnorum is a freshwater molluscan species underrecorded in Ireland (Kerney 1999). It was found at Roonah L., Co. Mayo and at Inch L., Co. Donegal in 1998.

Phallusia mammillata Ascidian (sea-squirt) recorded in Kilmore Lake, Co. Cork and is apparently restricted to Bantry Bay. In Britain, known with certainty only from the south coast (Millar 1970). Chiefly a Mediterranean species.

Styela clava Ascidian (sea-squirt) recorded in Kilmore L. The species has a restricted range and is apparently found only along the southern coast. Believed to be accidentally introduced, possibly from Korean waters (Millar 1970).

Ciona intestinalis Ascidian (sea-squirt) recorded at Kilmore L., Co. Cork, and at L. an Aibhnin, and L. Athola, Co. Galway. These are interesting records as they refer to bright red specimens which are not described in the literature but are apparently typical of "reduced salinity, peaty sites" (B. Picton pers comm*)*.

Syngnathus typhle Deep-nosed pipefish recorded at L. Tanaí, Co. Galway. Described as a “somewhat rare species” (Douglas 1989).

4.5 Geographic variation in lagoon fauna and flora

Many of the characteristic species inhabiting coastal lagoons in Ireland are found in all Member States which possess lagoons, whereas others are restricted by geographical range. In Ireland there is an overlap of generally "northern" species of both aquatic and terrestrial origin at the southern limit of their range and "southern" species at their northern limit. Species associated with the soft sediments and higher concentrations of nutrients and pollutants are more frequent on the east coast of Britain and Ireland and coastlines of the North Sea countries, and species more characteristic of the high energy rocky coasts in the west of Ireland, the U.K., France, Spain and Portugal.

Flora

At present, lists of lagoonal specialist species have been compiled only for the U.K. and Ireland, but many of these species are described as "characteristic" species of lagoons in France (Herard 2004), of "brackish lentic communities" in Denmark (Muus 1967) and of "blocked brackish waters" in the Baltic, Holland and the Mediterranean (Verhoeven 1980a). Certain species appear regularly on lists from lagoonal environments in other countries without reference to them being "specialists" and it is assumed that these are indeed specialists, "characteristically found more often in lagoons than any other habitat". Some other species (e.g. *Myriophyllum* spp., *Potamogeton* spp.) are not specialists but are commonly found in lagoons, and are an important element of the floral community of European lagoons. Some "southern" species such as *Althenia filiformis, Cymodocea nodosa* and *Tolypella hispanica* are found only in the Mediterranean or southern parts of the Atlantic coast, whereas several other species such as *Chara baltica* and *Chara canescens* are found in Ireland and the northern parts of the region, but appear to be absent from the Mediterranean. Most species are, however, found throughout the area and indeed in many other parts of the world, in suitable lagoonal environments. *Ruppia maritima*, for example is found in coastal sites throughout Europe, from Iceland and northern Scandinavia to the Baltic and Mediterranean and also in Asia, N. Africa, N. America and Australia (Preston and Croft 2001). Similarly cosmopolitan, *Ruppia cirrhosa* is found on all but the Arctic coasts of Europe and also in W. Asia, Africa, N. and S. America (Preston and Croft 2001) and *Lamprothamnion papulosum*, though it is a rare plant is found from the Baltic, along the Atlantic coast and into the Mediterranean (Moore 1986).

Ireland, with its rich habitat diversity, has a relatively large number of brackish plant species, with southern and northern distributions overlapping, and a much richer flora than Holland, for example, which lacking extensive stretches of exposed rocky coast has a poorer flora and appears to have lost all of its brackish charophytes due to eutrophication/pollution.

Fauna

Most of the characteristic faunal species are also found throughout the region, but there are some noticeable geographic differences in lagoons between countries, with certain species such as *Gammarus aequicauda* and *Carcinus mediterranea* only recorded in the Mediterranean and others having a more northern distribution (e.g. *Praunus flexuosus*).

Of the species found in lagoons throughout the region some, particularly some Crustacea show differences in size, colouration and life history strategy. The differences were ascribed by Healy (1990) to latitudinal gradients in temperature and the length of the growing season, but it was not clear whether these differences were due to the phenotypic responses of individuals or genetic adaptations (of genetically isolated populations) or to a combination of mechanisms.

Lekanesphaera hookeri, for example, is found in lagoons from the Baltic, along the Atlantic coast and in the Mediterranean and Black Seas, but those in the Baltic reproduce only once a year, the sub-species, *L. h. mediterranea*, in the warmer Mediterranean have a much longer breeding season, and reproduce three or four times a year, whereas those in Ireland, midway between these two extremes, normally reproduce twice, but can have a third generation in particularly warm years (Norton and Healy 1984).

Other species may have very different habitat requirements or tolerances in different geographical areas. *Sigara concinna*, was listed as a lagoonal specialist in the U.K. (Barnes 1989), but in Ireland there are more inland records than coastal, and while it occurs in both countries with a similar breeding season, it is a lagoonal specialist in one, but not in the other. *Notonecta viridis* on the other hand appears to be a lagoonal specialist in Ireland but is not regarded as such in England. It has been suggested that several Coleopteran species have a coastal distribution in the northern part of their range in response to altitudinal temperature differences rather than any relationship to salinity (Foster *et al*. 1992).

Based on his analysis of brackish water communities, Verhoeven (1980a) differentiated between Baltic, Northwest European and Mediterranean communities. The five basic lagoon community types recognised for Ireland (Chapter 3, Table 4.4.1) may be found in other European countries, but it is also possible that equivalent types characterised by a regional species might be found. Within Europe, one might distinguish the following four regional areas:

1. Baltic (microtidal, northern type)
2. Mediterranean (microtidal, southern type)
3. NW Atlantic coast (macrotidal, high salinity)
4. North Sea/Irish Sea/low countries (meso-tidal)

Within each area, one might expect to find four of the biological types from the Irish classification (*Potamogeton/Ruppia*, *Ruppia/Chaetomorpha*, “estuarine” and “mixed community"), but the west coast rock/peat *Ruppia/Zostera* lagoons would appear to be restricted to Scotland and Ireland.

In Portugal, the Ria Formosa is a very different morphological lagoon type, more like the marine, sandy, east coast US barrier island lagoons. Within the Mediterranean and on southern parts of the Atlantic coast, many of the lagoons, especially those which are managed for salt production frequently become hypersaline. Therefore, within Europe, one might recognise the following seven basic lagoon types:

1. *Potamogeton/Ruppia* type
2. *Ruppia/Chaetomorpha* type
3. *Ruppia/Zostera* type (found only in Scotland and Ireland)
4. "Estuarine" type
5. "Mixed community" type
6. Barrier island type
7. Hypersaline type (found only in southern parts of EU)

Water on Arctic coasts can also become hypersaline (up to 60psu) as a result of freezing (Lasserre 1979), but these are likely to possess a very different biota to those in the Mediterranean. Clearly, considerably more information is needed before a biological classification of European lagoons can be proposed, but it is hoped that the classification of Irish lagoons will encourage biologists in other countries to consider the idea.

4.6 Conservation Status of Irish lagoons

It is an obligation under the Habitats Directive to select representative examples of the listed habitats for protection within Special Areas of Conservation (SACs), and also to monitor these selected sites for maintenance of conservation status (Section 4.8), but it is still proving difficult to get information from other countries. Of the 89 sites listed for the Republic of Ireland, totalling 101 lagoons, 77.6% of these are within SACs (Table 4.6.1), and 87.6% of the total area of 2,585ha lie within an SAC.

At present, according to this list, the Republic of Ireland appears to compare favourably with certain other countries, especially to Northern Ireland which appears to have only 5.5% of lagoon habitat within an SAC. Portugal, on the other hand, has relatively few lagoons in number but one of these (Ria Formosa) is a very large lagoon (10,500 ha) with twice the area of lagoon habitat than all of the Republic, and this one lagoon is an SAC accounting for a very large percentage of the total for Portugal. Muus (1967) lists only seven lagoons for Denmark, but these seven cover over 35,000ha. The average size for each of these lagoons is twice the total area for Ireland, but it is not known what proportion of this area has been protected as an SAC.

Disparities between countries may also be partly due to different interpretations of the Habitats Directive and to differences in national legislation, as well as the fact that this is an ongoing process in which many countries are behind schedule. Many of the lagoons in Scotland are within a conservation area of some sort (e.g. Environmentally Sensitive Area, Site of Special Scientific Interest, Marine Consultation Area), though not necessarily an SAC. The alternative designation may afford equivalent or even greater protection than an SAC, and enforcement of regulations may be more effective.

Table 4.6.1 List of European countries for which information is currently available. Data taken from Charlesworth & Quinn 2004 (N. Ireland), Covey *et al.*1998 (Scotland & Inner Hebrides), Thorpe *et al.* 1998 (Outer Hebrides), Thorpe 1998 (Orkney & Shetland), Bamber *et al.* 1999 (Wales), Smith & Laffoley 1992 (England), Muus 1967 (Denmark), Herard pers comm. (France), Fonseca pers comm. (Portugal), Sacchi 1979 (Italy).

	No. of lagoons in National territory	No. of lagoons within SACs	% of total no. within SACs	Total area of habitat within National territory	Total area within SACs	% of total area within SACs	% of EU habitat
Rep. of Ireland	89 (101)	68 (76)	**77.6**	2585	2264.5	**87.6**	
Northern Ireland	25 (28)	9 (11)	**39.3**	119.8	6.6	**5.5**	
TOTAL IRELAND	114 (129)	77 (87)	**67.4**	2703.1	2271.1	**84**	**1.0**
Scotland + Inner Hebrides	33	2	**6.1**	288.3	27	**9.4**	
Outer Hebrides	72	20	**27.7**	2302.8	700.1	**30.4**	
Orkney + Shetland	34 (36)	2	**5.9**	1303.1	921	**70.7**	
TOTAL SCOTLAND	141	24	**17**	3894.2	1648.1	**42.3**	
England	177	46	**26**	1211.5	538	**44.4 ***	
Wales	4	4	**100**				
TOTAL U.K.	347	83	**23.9**	5200	1265	**24.3**	**2.0**
Denmark	7			35154			
Germany							
Holland							
Belgium							
France (Mediterranean)		25		65000	26000	**40**	
France (Atlantic)		23		15000+	15000		
Spain (Mediterranean)	25						
Spain (Atlantic)							
Portugal	12	1	**10**	12000	10500	**87.5**	
Italy				150000			
Greece							
Total				284939			

The Irish National Parks and Wildlife Service appear to have done an efficient job in proposing lagoon habitat for inclusion within SACs, but there have been several examples of deterioration in conservation value within some of these sites. Lady's Island Lake, for example, is an SAC and an SPA, and one of the very best examples of a percolation lagoon in the country, in its truest sense, and yet it suffers from serious eutrophication problems, resulting in 2003 in a well publicised fish kill. The neighbouring lagoon of Tacumshin is similarly an SPA and SAC, and also one of the best percolation lagoons in the country, but despite these designations, there have been deliberate large-scale attempts to lower water levels, to the extent that very large areas of the lagoon are completely dry in the summer.

Ireland is fortunate in that many parts of the country have not been very developed, and coastal lagoons lost, to the same extent as in many other parts of Europe. However, with increasing pressure from a growing, more affluent population, the conservation status of coastal lagoons is likely to diminish if the obligations of the Habitats Directive are not addressed fully.

4.7 Management

In many parts of the World lagoons have been managed for aquaculture for a very long time. Hawaiian islanders used coastal lagoons for the raising of selected fish species from pre-historic times through to the nineteenth century (Barnes 1980), and there are many examples of intensive use of lagoons in the Mediterranean for aquaculture, without any serious effect on the ecosystem. Lagoons are also used for recreational activities such as boating, fishing, bathing, and birdwatching again mostly without damaging effects. However, they can also be used for shipping and disposal of wastes much like an estuary, but with lower flushing rates in lagoons any harmful effects of these activities can be much greater. Because lagoons are usually shallow and sheltered they are easily drained, infilled and reclaimed for housing, agriculture or industry.

Barnes (1994) makes an interesting distinction between macro-tidal and micro-tidal lagoons in Europe, in terms of human use, in that lagoons in microtidal areas (Mediterranean, Baltic) have been used intensively for aquaculture, with the installation of permanent compartments and traps, whereas most significant lagoons, and the sedimentary barriers that enclose them along the macrotidal Atlantic coast, are incorporated into nature reserves – largely to protect the birds which frequent them and/or the flora of the shingle – and other than birdwatching there is no significant land/water use. This is particularly the case in England, where nearly all lagoons have become bird reserves and many were actually created as high tide feeding/roosting areas for winter visitors or as breeding grounds for Avocets, in particular. The same is also true for France, Germany, Holland and Denmark and it is no coincidence that the two largest lagoons in Ireland (Tacumshin L. and Lady's Island L.) were valued initially as important areas for birds (Ramsar sites, SPAs), though both were used also for small-scale fishing and wildfowling.

Threats

Ireland is fortunate in many respects that much of the coastline is still relatively natural compared with many other parts of Europe, and the pressures of population and development are less. However, the major threats are similar and pressures are increasing greatly with a growing, more affluent, population. As in all parts of Europe the main threats to coastal lagoons are:

1. Evolution into freshwater lakes
2. Damage to the barrier resulting in a fully tidal inlet or estuary
3. Eutrophication/Pollution
4. Infilling/drainage
5. Recreational use

1. Evolution into freshwater lakes

It is generally agreed that one of the major threats to coastal lagoons is the natural process of evolving into freshwater lakes by infilling with sediment from streams/rivers and windblown sand from the barrier, which raises the bed of the lagoon above the saline influence and encourages encroachment by vegetation. The process may be accelerated by onshore movement of barriers, reducing the size of the lagoon. This is an entirely natural process, about which very little can be done, and in an entirely natural world, especially with a rising sea level, would be balanced by the formation of new lagoons in newly flooded areas, or natural changes in coastal formations. With an increasing demand for land in a small country, and greater technological capabilities for coastal defence, this is unlikely to be allowed in most areas in Ireland. However, on the east coast of England, the cost of maintaining flood defences is becoming less acceptable, and even in Ireland the “soft option” of allowing certain areas on the south and east coast to flood is becoming more attractive than the costly maintenance of “hard” coastal defence systems.

A decline in the number of natural sedimentary lagoons (in Ireland) appears inevitable and many of the former lagoons, especially on the Mayo coast, which appear to be perfect examples of "true" coastal lagoons are in fact freshwater lakes. This also applies to the many large former lagoons in the Landes region of southwest France and in northwest Spain. Lough Gill (Co. Kerry) is an interesting example of a sedimentary lagoon between two tombolos, a classic "tombolo lagoon" as described by Barnes (1980), which is on the verge of becoming a freshwater lake, but partly due to deliberate management through installation of a weir. The weir is intended to reduce the amount of seawater entering the lagoon and to maintain minimum water levels for the trout fishery. This lagoon is an important site for an Annex II species, *Chara canescens,* which requires a certain amount of salt, and it is only by allowing enough seawater to enter the lagoon, that the "lake" remains as a coastal lagoon. With a higher weir, at least during the high Spring tides, the lagoon would become a freshwater lake, and the *C. canescens,* which Member States are obliged to protect, would probably not survive. This lagoon has suffered from eutrophication with algal blooms and subsequent fish kills and in 2003 the eastern area of the lagoon was dredged in an attempt to increase the flow rate and to flush nutrients from the lagoon. As a result, more saline water was allowed to enter the lagoon which remained in deeper parts of the lagoon. In that year water clarity was greatly improved, as was the standing crop of *C. canescens* and *Ruppia*, and this form of management appears to have been very successful and encouraging in that allowing greater flushing with seawater not only retains the lagoonal habitat but appears to improve water quality.

2. Damage to the barrier resulting in a fully tidal inlet or estuary

Lagoons can be lost by damage to the barrier by storms, or coastal erosion, sometimes caused by defence of a neighbouring stretch of coastline. Roonah L. in Co. Mayo was described as a lagoon in 1996, but the barrier was damaged by a storm and this lagoon may now be better described as a lagoonal estuary or tidal inlet. In the classification of Irish lagoons (Chapter 3), it was explained that the lagoon types form a continuum, and there is a point when it is hard to distinguish between a "lagoonal estuary" and an "estuarine lagoon". This stretch of coastline is highly dynamic and there are examples of several different types of coastal water body changing into another.

Sometimes damage to the barrier is inadvertently or deliberately caused by human activities. The barrier of Kilmore L. on Whiddy Island, Co. Cork was allegedly used by heavy machinery during the construction of the oil terminal, which lowered the barrier. On every tide seawater now enters this lagoon which at one time was used as a freshwater source (oligohaline lagoon). It is very likely that a sufficiently violent storm from the right direction will destroy this barrier, although it would be relatively inexpensive at present to rebuild the lowered barrier with the original cobbles that have been spread over a wide area.

The barrier of Ballycotton L. was deliberately breached to lower the water level and reduce the flooding of adjacent farmland, but unlike the barriers on other parts of the coast, which reseal after breaching (Lady's Island L., Kilkeran L.), it appears that not enough sediment is available to rebuild the barrier on this part of the coast and the former lake (or lagoon) is now a tidal inlet. As these natural lagoons disappear it is not surprising that many of the characteristic animals and plants are now found in artificial lagoons and drainage ditches, which in many places have replaced the natural ones, and this adds to the justification of protecting artificial lagoons as well as natural ones.

3. Eutrophication/Pollution

Deterioration in water quality has been a growing problem in all types of water body throughout Europe and includes the effects of nutrient enrichment, turbidity, toxic contamination and organic enrichment (Bamber *et al*. 2001b). Very often these effects are acting in combination and it is difficult to separate one from another. An increase in nutrients can increase the growth of algal species which can out compete higher plants and deoxygenate water, resulting in death of fauna, whereas toxic contamination by heavy metals, herbicides/pesticides and oil can kill fauna and flora directly. Lagoons with a tidal inlet generally are less threatened as with regular flushing by seawater, turbidity, nutrient concentration and organic content are naturally high and are less likely to build up to a damaging level. With new European Directives (e.g. Water Framework Directive) followed by national legislation, water quality should improve, but in some "closed systems" such as isolated or semi-isolated lagoons, water quality may have already been reduced to an unacceptably low level. In this case, the possibility of removing nutrient rich or contaminated sediment may have to be considered, as has been done in so many lakes in Holland (Gulati 1984).

The barrier of Lady's Island Lake is regularly breached to reduce water levels for a variety of reasons, but recently (2003) it was breached in order to flush water from the lagoon following a severe algal bloom and fish kill. This particular lagoon has a range of management problems explained by Healy (1997), but at present the major problem is caused by nutrient enrichment and considerable efforts are being put into resolving the problem. The impacts of water pollution are poorly studied and in many cases poorly understood. In an effort to improve our understanding, Johnston and Gilliland (2000) carried out a case study of the effects of nutrients in the Fleet, southern England. This study suggested a sensitivity of Lamprothamnion *papulosum* to phosphate levels in that it did not occur at sites in the Fleet where total phosphate concentration is more than 100ug/l. *Lamprothamnion papulosum* is thriving in L. Murree and also on the North Slob where nutrient levels are believed to be very high, though data concerning phosphate levels to support this statement is unavailable for these sites. The North Slob is a particularly interesting case as maximum amounts of fertiliser are applied to the fields in order to maximise the growth of grass as fodder for the wintering flock of Greenland White-fronted Geese. Despite very high levels of nutrients applied to the fields and apparent eutrophication with frequent algal blooms, the brackish drainage channels still support thriving populations of several rare charophyte species and of lagoonal specialist fauna. Although the charophytes are still thriving, and have survived for 100 years it would be better to practice caution and attempt to reduce the effects of nutrient runoff into the waterways. The North Slob would be an excellent site in which to study nutrient tolerance of rare charophytes, the effects of vegetated buffer zones along the channels and even the creation of new lagoons and their colonisation. This would greatly improve our understanding of water quality problems.

One of the most notable features of lagoons is the variability not only of salinity, but also temperature, pH, dissolved oxygen, turbidity and probably many other physico-chemical factors. It was suggested by Bamber *et al*. (1992b) that it is this variability that creates conditions of environmental stress which are comparatively intolerable to typical estuarine or marine species, allowing the more tolerant lagoonal specialists to survive in a community of reduced competition. It is therefore not only salinity that is essential for the survival of lagoon biota but also variability in saline conditions. Bamber *et al*. (2001b) state that generally U.K. lagoons notable for their specialist biotope or species interest have a salinity that ranges predominantly between 15 and 40psu and recommend for management purposes that lagoonal salinity should approach sea-water levels, but range predominantly between these levels of 15-40psu. Perhaps due to a difference in climate or ecology, many of the lagoons in Ireland have interesting biotas at lower salinities than those recommended in the U.K. (e.g. L. Murree, 10-12 psu). A lagoon with a salinity gradient, or a mosaic of different salinity pools provides suitable environments for a greater number of species, and a perfect opportunity for testing the salinity preferences of Irish lagoon biota. Ironically, at present, the salinity of many of the "sluiced lagoons" relies on a malfunctioning sluice because the non-return valve no longer opens and closes as it was intended. Complete repair of the sluice may either prevent seawater entering the lagoon or effectively drain the lagoon. In either case this will damage the existing lagoon habitat. Some thought, and finances, need to be put into the design and installation of a form of water control that retains water in the lagoon (of approx. at least 1 metre depth), while also allowing a certain amount of seawater to enter. Perhaps the combination of a sluice and a weir just below mean tide level would be effective. This control mechanism must be adjustable to prevent excessive flooding of local farmland while maintaining a saline influence in the lagoon.

4. Drainage/infilling

Lagoons in Europe have been drained over many centuries, which is one of the reasons for listing them as a priority habitat. Along the east coast of Ireland in particular many former lagoons have been drained, but with recent recognition as an important habitat, this in theory is far less likely to happen in the future. Having said that, great efforts have been made over the past few years to drain Tacumshin Lake, one of the best examples of a coastal lagoon in the country with a relatively high public profile. Allegedly, this drainage has been necessary in order to relieve flooding of local farmland, but some would say it is excessive. Some of the smaller, less noticeable lagoons in less populated parts of the country are generally more at risk, due to the fact that local people are unaware of their importance as lagoons. Very often the damage is done unwittingly by landowners who have traditionally regarded such areas as of no value and simply a good place to dispose of refuse, or to reclaim as farmland or a construction site. Several lagoons close to dockland in Northern Ireland have been infilled recently, to enlarge an industrial area. Small lagoons close to cities are particularly vulnerable to this threat and the only solution is an increase in public awareness by better publicity of the conservation value of the site as a coastal lagoon.

5. Recreational use

Recreational use includes activities such as boating, bathing, and fishing but also from the well-intentioned creation of bird reserves and amenity areas. Threats from water sports and fishing in Ireland are still relatively minor compared with the intensive use of small lagoons on the south coast of England, especially near cities like Southampton, and in the Mediterranean, but these potential threats are increasing. Mostly these threats have more to do with disturbance to breeding birds than to any serious deterioration in the quality of lagoonal habitat for aquatic plants and invertebrates, unless for example the use of jet skis disturbs sediment, uproots plants and increases turbidity. There are examples, however, of local fishing clubs wishing to close a tidal inlet and prevent seawater entering a lagoon in order to create a freshwater lake which can be stocked with trout. In general the response to this is that there are thousands of freshwater lakes in Ireland but less than one hundred coastal lagoons. An attempt was made recently (2002) to convert an important site in Ireland for a protected charophyte species (*Lamprothamnion papulosum*) into such a stocked trout lake.

The most serious threat to coastal lagoons through recreation ironically is the creation of well-intentioned bird reserves and amenity areas. It is largely due to the efforts of bird watchers that the first nature reserves were created and in protecting birds, many other species also gained protection. Many of the best nature reserves in Ireland were created primarily for their bird interest, and following the Birds Directive (EC 1979) many became Special Protection Areas (SPAs) for certain listed bird species. Many of these sites were also coastal lagoons and following the Habitats Directive many were also proposed as SACs based on designation as coastal lagoon habitat (section 4.2). Efforts have been made in the U.K. by the Royal Society for the

Protection of Birds (RSPB) and English Nature (EN) to manage coastal bird reserves for not only for wintering and breeding birds, especially the Avocet, *Avocetta avocetta*, but also as coastal lagoon habitat, as required by the Habitats Directive. A conference was held in the U.K. (Symes and Robertson 2004) and a guide to management and creation of saline lagoons has been produced by the Saline Working Group of English Nature, concentrating on coastal lagoons as a priority habitat and also as bird reserves (Bamber *et al*. 2001b).

Information resulting from these efforts in the U.K. is not widely available in Ireland where interest in coastal lagoons is still heavily biased towards their avifauna. For one lagoon in particular, in consultation with the RSPB and the Irish Wildbird Conservancy (now Birdwatch Ireland), the management plan for the lagoon as a local nature reserve in 1996 recommended closure of the sluice to prevent seawater entry, thereby turning the lagoon into a freshwater lake and "improving the habitat for birds". The RSPB are unlikely to make the same recommendation now, but the management plan for this lagoon in 2001 still advises closure of the sluice, which of course would probably destroy the priority habitat. It is quite possible that for certain bird species and many aquatic plants that a freshwater lake would increase the biological diversity of the site, as lagoons in general are characteristically species-poor. But the loss of the much rarer lagoonal community would be an overall decrease in diversity at the higher scale of local, regional, national or even European level. Birdwatchers often consider it desirable to deliberately lower water levels of lagoons, in the autumn especially, to produce very shallow areas or expose muddy substrates in which wading birds can feed, in the hope of attracting rare vagrant species. This is equally unacceptable in a lagoon habitat, as aquatic plants and fauna are likely to overheat or desiccate. In fact, 'lagoonal specialist' animals and plants are sub-littoral species and therefore cannot tolerate drainage.

Even without the bird interest, most people find the idea of a freshwater lake for boating, fishing or scenic value more attractive than a brackish lagoon, and have attempted to restrict the tidal inflow as well as landscape the banks as manicured picnic areas. Bamber *et al*. (2001) quotes examples of case studies in England where similar situations have prevailed and lagoon biota have been completely lost, through well-intentioned but misinformed mismanagement. The most important characteristics of a coastal lagoon to preserve are **"permanent, brackish water"**. Any attempt to prevent seawater entering a lagoon, or to drain or excessively reduce water levels for anything more than a very short period, are exactly what should not be allowed to happen. Coastal lagoons are an important part of Irish Heritage, not only for their specialist flora and fauna, but often for the birds and other vertebrates they support and often also as geomorphological features. All need to be considered and prioritised when drawing up a management plan.

As already stated, the threats to Irish coastal lagoons are not as great as in many other parts of Europe, and in many cases, especially in lagoons along the west coast of Ireland, no management at all is needed. The type of management required will depend to a large extent on the morphological type of lagoon. For example, in a "sluiced lagoon", the most important management requirement is most likely to be appropriate control and maintenance of the sluice, whereas in an "isolated lagoon" it may be controlling nutrient/pollutant inflow. In sedimentary lagoons, the condition of the barrier is likely to be of paramount importance. It is no longer legal to extract sediment from the foreshore, though it still happens, but the cost of maintaining natural barriers may prove to be prohibitively expensive in some cases. Each individual lagoon will have its own management problems which will have to be assessed individually.

The most important forms of management needed in lagoons are:

1. Identification of conservation priorities and definition of objectives.
2. Production of an appropriate and realistic management plan.
3. Maintenance of quality, salinity regime, depth and area of water.
4. Control of nutrient/pollutant inflows.
5. Maintenance of the barrier, and of the banks of the lagoon.
6. Appropriate maintenance of flood control mechanisms.
7. Improvement of public awareness of the importance of coastal lagoons.
8. Baseline biological survey.
9. Design and implementation of appropriate surveillance/monitoring strategies.

4.8 Monitoring

In addition to protecting representative examples of listed habitats, Article 11 of the Habitats Directive states that "Member States shall undertake **surveillance** of the conservation status of the natural habitats and species referred to in Article 2 with particular regard to priority natural habitats (one of which is coastal lagoons) and priority species". Article 17(1) then states that "Every six years from the date of expiry of the period laid down in Article 23, (June 2000, now deferred to June 2001?) Member States shall draw up a report on the implementation of the measures taken under this Directive". In other words, that there is an obligation on Member States to select good examples of the listed habitats within their country, protect them so that their conservation value is maintained, inspect them at least once in the six year period to ensure that their conservation value has not deteriorated and write a report on the findings, which must be forwarded to the EU Commission and made available to the public.

In order to help implement the Habitats Directive, the EU funded the UK Marine SACs LIFE Project, whose overall goal was to establish management schemes on 12 of the candidate SAC sites and to assess the interactions that can take place between human activities and the Annex I and II interest features on these sites (Davies *et al*., 2001). A secondary task of the project set out to "identify and develop appropriate methods for recording, monitoring and reporting natural characteristics and conditions of Annex I/II interests and relevant environmental factors", and the results of this were published as the *Marine Monitoring Handbook* by Davies *et al*., in 2001. A great deal of information concerning monitoring of all marine Annex I habitats, including lagoons, and Annex II species in Britain is contained in this manual, which emphasises the fact that this was the UK's approach to management and monitoring. These guidelines need not necessarily be adhered to in Ireland, or any other Member State, but in general it is sound advice based on a considerable amount of expertise and experience. Many of the suggested approaches have already been followed in Ireland, as part of the BioMar project (involving a partnership of the UK and Ireland), and also in France.

In this UK approach to SAC monitoring, a distinction is made between **surveillance** and **monitoring**, in that:

Surveillance is a continued programme of biological surveys systematically undertaken to provide a series of observations in time, whereas

Monitoring is surveillance undertaken to ensure that formulated standards are being maintained.

This distinction is very useful and is used for terrestrial sites in Ireland, but for most coastal lagoon SACs the standards are not well formulated, other than in the form "the brackish nature of the lagoon water shall be maintained" or "the characteristic lagoonal biota shall be maintained".

Although it is widely recognised that the biota of individual lagoons are often relatively species-poor, lagoons as a whole vary considerably in salinity, morphology and biological community. Chapter 3 proposed a biological classification based on five different lagoon types which require different sampling and monitoring methods, according to type. Traditionally, sweep netting is the most commonly used, standard method of surveying shallow, lentic and lotic (by kick-sampling) freshwaters. Estuarine surveys rely heavily on sediment cores, rocky shore surveys most commonly use quadrats along transects to record surface biota and sub-tidal surveys are mostly based on sub-aquatic visual searches or grab samples of the sediment. As lagoons vary so much, different methods, or a combination of methods may be required in different lagoons. For example, the "*Potamogeton/Ruppia"* type lagoons are relatively low salinity, often insect dominated lagoons, and as in freshwaters, the use of sweep nets is generally the most useful and rewarding faunal survey method. In "estuarine lagoons" with fine sediments and relatively few plants, much of the nekton is very mobile and difficult to catch in a sweep net (crab, flounder, gobies, prawns), and sediment cores to sample benthic infauna play an increasingly important role, as in the intertidal area of estuaries. In the higher salinity "*Ruppia/Zostera*" type lagoon, where over 50% of the fauna may be sessile on hard surfaces, this element of the community would not be recorded using either sweep nets or sediment cores, and visual searches to provide an abundance estimate are necessary, as on a rocky shore. In a river, one could survey using only kick-samples to give a fairly accurate record of the faunal community, but in a lagoon of any type, and especially in a "mixed community" lagoon type, a combination of survey methods is necessary in order to give a compete record. Vegetation surveys are generally much simpler as a basic percentage cover estimate can be used in all lagoon types.

As well as the biological aspects, monitoring of other environmental and physico-chemical features, such as the size and depth of the lagoon, condition of the barrier, salinity and quality of the lagoon water also needs to be carried out. In the U.K. attempts have been made to implement a Common Standards for Monitoring programme (JNCC 1998) and the Marine Monitoring Handbook (Davies *et al*. 2001) provides broad guidelines for the monitoring of coastal lagoons, suggesting a small number of techniques that are likely to provide comparable measures. These guidelines are very useful in terms of standardising techniques in order to make survey results comparable throughout Europe. However, many of the techniques are for much larger scale and more sophisticated surveys using for example, remote sensing and boat-based surveys, and are very much biased towards the high salinity, more characteristically "marine" sites. For example, although plankton sampling is listed as a suggested technique for measuring biotic composition, there is no mention of sweep-nets, which should be regarded as an essential method of sampling the invertebrate fauna of certain low salinity lagoons, especially. Nevertheless the Marine Monitoring Handbook is a useful summary of most methods and the authors admit that work is required on the comparability of some of these techniques and point out that advice will be updated when new information is available.

Based on a considerable amount of lagoon survey work in Britain, Bamber *et al*. (2001b) also provides guidelines for minimum requirements and good practice in survey protocol and methodology. Funding may not always be available, but some form of basic monitoring should be carried out annually in order to recognise in time when remedial measures may be necessary. The following suggestions are made based on the experience of the present study and previous surveys in Irish coastal lagoons, together with advice from the literature available:

1. Environmental features

a. Barrier

The condition of the barrier should be recorded, based on site visits. A series of aerial photographs, taken as part of the O.S. National Survey in 2000 are available and it is planned to repeat the survey every five years. In particular, this is relevant to natural sedimentary barriers, but also to artificial embankments which may be damaged by storms, or deliberately breached. A hand held GPS should be used to record the positions for mapping of the barrier and any breaches or damage.

b. Sluices, gates, weirs

Many lagoons, even relatively natural ones, have a water control structure installed and this should be inspected to see if it is working properly. If water levels are low enough it is often possible to approach the structure on foot to see if it is blocked damaged or held open by stones or branches. If water levels are higher, it is often possible to see that the “flap” is not in the position expected from the flow direction of the water. Manually operated gates need to be kept in working order.

c. Size and depth

Areal extent of the lagoon can be recorded by mapping (using GPS positions), possibly by aerial photography, or by visual inspection of old strand lines. At least for the smaller lagoons, maps are generally not very useful, as details of the lagoon may not have been very accurate or may not have been updated on the older 6" maps. The newer 1:50,000 maps are largely based on older maps that may not have been updated. Encroachment by reeds can be estimated quite easily in the smaller lagoons or mapped using GPS positions from an inflatable boat. Depths can be recorded from fixed staff gauges, by direct measurement while wading in shallow lagoons with a firm substrate or measuring with a staff or plumbline from a boat. Care should be taken to account for recent weather conditions (drought or flood) and tidal state in lagoons with a tidal inlet (see later). "Normal" depth can often be estimated from vegetation on the shoreline. The "average" or "normal" water level should ideally be related to Chart Datum, but this needs a local benchmark and has rarely been recorded for Irish lagoons, though for some of the more saline lagoons, the height of the sill in relation to mean high tide has been estimated.

d. Salinity

Salinity can be measured using a refractometer or conductivity meter. While a refractometer is robust, easily carried in the pocket and does not need calibrating or recharging, generally a conductivity meter is preferable as it is more accurate (at least to 0.1psu) and salinity can be measured at various depths with a long cable, to record vertical gradients and haloclines. Both refractometers and conductivity meters should be regularly checked with a standard solution and calibrated if necessary. Salinity of any inflows and adjacent water bodies should also be measured. In limestone areas, for example, saline and fresh water can enter through subterranean fissures from neighbouring water bodies. Salinity should be measured as often as possible and in as many different parts and depths of a lagoon in order to get a representative idea of the variation possible within the lagoon at any given time and through time. For lagoons with a tidal inlet, state of the tide should be recorded, but ideally comparative measurements should be made during spring and neap tides. Temperature, though perhaps not very meaningful, can easily be measured at the same time as salinity with a conductivity meter, but time of day should also be recorded.

e. Eutrophication/Pollution

Very little is known about any measure of water quality in Irish coastal lagoons and very few attempts have been made to improve the situation, until recently. Information from the U.K. suggests that *Lamprothamnion papulosum* may act as an indicator of elevated phosphorus concentrations (Johnson and Gilliland 2001), though there is no evidence to support this suggestion in Ireland. In lagoons with a permanent tidal inlet, nutrient levels are likely to be naturally high, but with regular flushing unlikely to reach unacceptably high concentrations. In closed lagoons, however, the presence of algal blooms, rafts of Enteromorpha and *Ulva* spp., filamentous algae and bacterial mats may indicate high nutrient levels, but this may be a perfectly natural, perhaps seasonal, occurrence.

The large-scale death of fish and invertebrates, on the other hand, and presence of noxious odours, may suggest a more serious situation and efforts, prompted by the EU Water Framework Directive are now being made to investigate the water quality of some of the larger coastal lagoons in Ireland. However, at present there is very little base line information to use for monitoring any change in water chemistry in Irish lagoons.

Biological data

a. Vegetation

Most vegetation can be monitored using visual estimates of abundance. There are various scales one can use. Traditionally, most botanists use a modification the Braun-Blanquet scale of 0-5 or DAFOR scale in which:

1 (D) = Dominant, >75% cover
2 (A) = Abundant, 50-75% cover
3 (F) = Frequent, 25 – 50% cover
4 (O) = Occasional, 5-25% cover
5 (R) = Rare, 1-5% cover

In this study an estimate of the actual percentage cover of each taxon from 0 – 100 was used and then log transformed for statistical analysis (Chapter 2). Both forms of abundance scale have their advantages, but in this situation, the estimate of true percentage seemed more appropriate. Most taxa can be estimated as described above but some, such as small red algal species, filamentous greens, charophytes and even some of the larger brown algae (e.g. *Sporochnys/Spermatochnus*) are impossible to identify in the field. Even in the laboratory, it is not always possible to positively identify some species immediately due to taxonomic problems, and one must seek specialist advice. Most of these species, however, have a low percentage cover, and it may be satisfactory to label them temporarily, for example, as Species 1 and Species 2.

With some of the rarer charophytes, however, this will not be satisfactory and sufficient samples will have to be collected for identification in the laboratory. Bearing in mind that it is unacceptable to collect large quantities of a rare species, it may be very difficult for monitoring purposes to give much more than a very crude estimate of abundance, and the record may have to remain only as present or absent. Bamber *et al*. (2001b) suggest using an Ekman grab for sampling deeper water. Grabs were not used in the surveys of Irish lagoons, but the use of a grapnell was employed at times, either from the shoreline or from a small boat. Ideally the lagoon should be surveyed by snorkeling at a time when visibility in the water is not impaired by algal blooms or suspended sediment.

b. Fauna

i) Abundance scales

As explained in Chapter 3, one of the main problems concerned with faunal data for statistical analysis the combination of estimated abundance data from visual searches with count data from other methods (cores, sweeps, light traps etc.) for statistical analysis. It may be decided that for monitoring purposes it is not necessary to analyse collected data statistically. However, some form of cluster analysis might be very useful for comparing an original data set with one obtained from monitoring in that any change in the data will be shown by data points outside the main “normal” cluster.

It is not possible to quantify samples collected from sweep-netting in terms of area or volume and therefore an abundance scale is needed as with data from visual searches, and due to differences in size and life-style, the abundance score for each taxon will be equivalent to a variable number of individuals of each different taxon. For example, when mysids are described as common, they will be far more numerous than a fish species which is described as common, and colonial species are described in terms of number of colonies rather than of individuals. The abundance score is therefore based on the density/dominance of a taxon, the number of samples taken and the knowledge of the species “normal” abundance in that habitat acquired through the experience of fieldworkers. The Marine Monitoring Handbook (Davies *et al*. 2001) recommends the use of a **SACFOR** scale of Superabundant, **A**bundant, **C**ommon, **F**requent, **O**ccasional and **R**are and provides criteria for the ranking of species in marine habitats. This scale was modified for use in coastal lagoons based on experience gained in lagoonal habitats (Bamber 1998, Bamber *et al.* 2001b). In Bamber’s SACFOR scale, the abundance is also related to biotope, which is a concept not in common use in Irish lagoons, and for the study of Irish lagoons was be replaced by the term “station”, so that (at each station) a species ranks as:

Superabundant – if in very large numbers in every sample

Abundant – if in large numbers in every sample

Common – if occurring in reasonable numbers in every sample

Frequent – if found in low numbers but in most samples, or reasonable numbers in a few samples

Occasional - if found rarely in a number of samples,

Rare - if found only once or twice,

In the present study, the term **frequent** was not used as the data was analysed by station, and based on three samples from sweep nets and sediment cores and one for light trap and visual searches at each station and therefore number of samples was considered too few to justify the use of “frequent”.

This SACFOR scale is very useful in terms of simplicity and an attempt to standardise sampling for comparative reasons, but as shown in Chapter 3, is not very appropriate for statistical analyses. Therefore, this abundance scale of 0 –5, was translated to a numerical figure representing a true number from 0 –1000 for each species for statistical analysis (as used in Adriatic lagoons by Sconfietti *et al*. 2003 and Marchini *et al*. 2004). This conversion scale for all faunal species recorded is shown in Appendix I.

ii) Sampling

Whatever form of sampling is used, the area should be searched visually first before any major disturbance, preferably by snorkeling. It is surprising how many species will be inquisitive enough to investigate a field biologist at work and also how many cryptic species will disappear when disturbed by someone wading. Most invertebrate samples will need to be collected for laboratory identification, as most small species (e.g. Amphipoda, Coleoptera, Annelida) cannot be identified in the field. Such collecting should always be kept to a minimum, however, and as much identification as possible should be done in the field. Some species such as hydrobiids can be identified much more easily when alive, but this can also be done in the field. It is usually recommended to fix samples using neutralised 4% Formalin, but some people are allergic to Formalin and 70% industrial alcohol is generally more acceptable, and recommended for some taxa (e.g. hydrobiids). Considerable care is needed in choosing labels for samples, that will remain legible for a long period. (Field samples should be checked as soon as possible in the laboratory, to make sure all are labeled satisfactorily)

iii) Sediment cores

Many of the published results of lagoon surveys in, for example Britain, Portugal and Italy, rely heavily if not exclusively on sediment cores for faunal sampling, which is a reflection of the lagoon type and fine, soft sediment type within the lagoon. In many of the Irish lagoons, however, it is not possible or useful to extract sediment cores. Some lagoons (e.g. Drongawn, L. Mor, L. Furnace) are too deep to use normal coring methods, and below approximately 4 – 5 meters, the water and sediment are dark, anoxic and virtually life-less so there is no value in extracting sediment cores. In other lagoons (e.g. L. an Aibhnín, L. Tanaí) the substrate consists of soft, unconsolidated peat, which is difficult to core, and contains very little fauna. Others consist of clean sand (e.g. L. Gill, L. Durnesh) also with very little infauna, and in some parts of karst lagoons, the substrate is limestone pavement and all infauna are found in sediment in the grykes which is impossible to core. So, in many Irish lagoons it is not possible, or it is impractical to sample using sediment cores.

Whenever possible, monitoring should be standardised so that results are comparable. The number of cores taken will partly depend on finances and time available. At least three cores should be taken at each station, for replication. In surveys of Irish lagoons, cores were sieved through a 1mm mesh, but many other workers recommend using a mesh size of 0.5 mm or even finer. The mesh size chosen will also depend to a certain extent on finances and time available, and also on taxonomic expertise, as the finer the mesh, the longer it will take to sieve samples, sort specimens and then identify smaller, often more difficult taxa. It would be very interesting to compare results from using different mesh sizes, and a finer mesh should be used in at least some of the "estuarine" lagoons in Ireland (e.g. Cuskinny L., Rosscarbery L.) to look, for example, for the lagoonal annelids *Alkmaria romijni* and *Armandia cirrhosa* as these are listed as lagoonal specialists in the U.K., but have not been recorded in Irish lagoons and possibly not at all in Ireland. It is possible that these small species would not be recorded using a 1mm mesh, although it seems unlikely.

In sediments where it is difficult to extract cores, it is still possible to sieve "handfuls" of sediment, in order to record the species present and an approximate non-quantitative estimate of abundance.

iv) Sweep nets

Sweep nets were used in all lagoons surveyed in Ireland and provided very useful data. Again there is a controversy about mesh size. A 1 mm mesh size was used in the Irish survey, but a 0.5 mm mesh is often recommended, and again the choice of mesh size will partly depend on finances and time available, as the finer mesh may collect more small specimens which will take longer to sort and identify. The fine mesh is also more difficult to use as it may become clogged with sediment or plant material and is then more difficult to push through the water. Generally a 1-mm mesh is considered to be suitable for Irish lagoon surveys.

At least three net samples should be collected at each sampling station, and sweeps should be for a timed period, for example, 1-minute. This period can be reduced if fauna is particularly abundant, or extended if sparse. If the net may becomes clogged the timing should be halted, the net cleared, and then the sweep (and timing) continued. The length of the timed period can be modified, but should be recorded in order to make previous and future sampling comparable.

Sweep nets are generally used while wading through the water, but in some situations this may be difficult as the lagoon may be too deep, or the substrate too soft to walk on, or weeds too dense to push the net through. However, it may be possible to drift across an area in a boat, while trailing the net, or even just using the boat as a buoyancy aid to help walk over soft sediment. In vegetation that is too dense to "sweep" efficiently, samples may be taken for "weed-washing" in the net, while still in the field.

v) Light traps

There is no mention of the use of light traps in reports available to the author of lagoon surveys in any other European country. Perspex light-traps with chemical lights were used to sample all lagoons selected for survey in Ireland at various stations within the lagoon. They are criticised because they may attract certain species, especially flying aquatic insects such as Coleoptera and Hemiptera from outside the sample area, but can provide very useful data, in that nearby cryptic, and difficult to find species are attracted to the trap. The traps can also provide a very large, relatively "clean" sample from an area that is difficult to sample because of very soft sediment or accumulations of filamentous algae. Although the trap must be left overnight, possibly involving extra survey time, retrieval of a large sample of small species can be very quick, and therefore the use of these traps is highly recommended for additional information in any intensive survey.

vi) Fyke nets

Fyke nets were used to survey all Irish lagoons, except some small ones where there was insufficient water depth or in those where the water was too deep. They can be very useful for recording fish species that would not be found by any other method, and therefore add to the species list of a site. A total of 18 fish species were recorded in fyke nets from 60 lagoons in Ireland, many of which would never have been seen otherwise, but these nets can be time consuming, and their use, again will depend on finances and time available, and the type of survey required.

vii) Visual searches

Visual searches are an essential part of any survey, and should be carried out before any fauna or sediment has been disturbed by other sampling methods. Over 50% of species recorded in the more saline lagoons are only recorded through visual searches. Ideally, the area should be snorkeled, but drifting over an area in a boat using a mask to look under water can yield a lot of information. Notes of species recorded and abundance should be made as soon as possible, while still in the memory, and a checklist of species recorded previously should be used. Additional searches should be made under stones and in sediments (in addition to cores), taking care to replace stones afterwards and disturbing the area as little as possible. In order to standardise the search, a period of one hour at each station is recommended, but the 5-minute rule can be applied.

General points

a. Timing

Results of this study (Chapter 2) have shown seasonal and inter-annual changes in abundance and presence/absence of biota which vary according to taxon and lagoon type. In the low salinity *Potamogeton/Ruppia* lagoons, there is a marked seasonal increase in both abundance and presence/absence of floral and faunal taxa. Seasonal differences are less obvious in the mid-salinity lagoons, but certain species which may be present throughout the year may be more difficult to find in the winter. Some taxa such as the genus *Ruppia* can only be positively identified to species when the plant is in flower in late summer. In the *Ruppia/Zostera* (higher salinity) lagoons, algal species can vary considerably through the year.

Generally, vegetation surveys of lagoons should be carried out from mid-summer to early winter, but more importantly should be monitored in the same seasonal period as the original survey to be comparable. Much of the fauna and flora of mid-salinity lagoons may be found throughout the year, but survey work is considerably easier and more efficient during the summer and early autumn. Surveys of mid-salinity and high salinity lagoonal fauna and flora could be carried out if necessary through much of the early winter, in spite of short days and the risk of bad weather. Generally, most species (other than caddis) are at their minimum abundance in late winter/early spring and this period from February to May should generally be avoided except for brief surveys of the more marine lagoons.

b) Weather

It is not always possible to choose the most suitable weather for surveying a lagoon, but there are times, during gales for example when sampling may be completely impossible, or very dangerous. Attempts should be made to avoid sampling after a period of heavy rainfall, as not only water levels are likely to be high and the sample area inaccessible, but salinity levels may be very different, aquatic species from the catchment area may have been washed into the lagoon, and lagoonal invertebrates may be less active, and difficult to find.

c) Tides

In lagoons with a tidal inlet, it is vital to be aware of the predicted local tides, published in Tide Tables and easily available. As explained by Hill (1994), tidal water enters a lagoon on a rising tide faster than it leaves on the falling tide. Because of this phenomenon, unlike on an open shore where the lowest water levels coincide with the extreme low water spring tide (ELWS), lowest water levels in tidally influenced lagoons occur following neap tides (ignoring flooding after heavy rainfall). Sampling is much more efficient if it is timed to be carried out at lowest water levels before the levels build up again, but it is even more important that monitoring be carried out during the same tidal period as the baseline survey.

If weather conditions are not suitable, monitoring should be postponed for two weeks, or even four weeks to coincide with similar water levels, rather than sample the following week during spring tides when water levels may be up to 1 meter higher in the sample area, and similar sampling methods (sweep netting, sediment cores) impossible, or at the very least, much more difficult. Not only are water levels higher at this time, but currents are also much stronger.

d) Boats

Surveys of lagoons in Ireland have often relied on the use of an inflatable boat, not only to gain access to parts of a lagoon some distance from any road, and to transport equipment but also as part of the survey methods such as the setting of fyke nets and recording of benthic data. With increasing European and National Health and Safety regulations, the use of small boats is becoming more regulated, in that the boat may need to be up to certain specifications, and the operator may need to have attended a small boat-handling course and carry safety first equipment.

CHAPTER 5

General Discussion

5. General discussion

As a result of the combined surveys of Irish coastal lagoons, sixty lagoons of the total number of approximately 101 lagoons listed for the Republic have now been surveyed. Most of the lagoons, which remain to be surveyed, are very small and while this figure represents only 59% of the total number, it is 86% of the total area of lagoon habitat in the country. Almost 90% of the lagoon habitat within the country is now protected within SACs and it is hoped to survey the entire habitat within the country in the near future.

5.1 Seasonal changes in flora and fauna in Irish coastal lagoons.

While there is a great deal known about seasonal changes in freshwater and marine systems, relatively little is known about these changes in semi-isolated brackish waters and particularly in Irish coastal lagoons, other than the studies of Parker (1977), Parker and West (1979) concerning *Neomysis integer*, and the study of Lady's Island Lake by Healy (1997). Results presented in Chapter 2 have shown that seasonal variations in fauna and flora differ considerably between lagoon types and that when seasons are combined, there are considerable differences between stations. Seasonal changes in both faunal abundance and presence/absence are greatest in the low salinity, insect-dominated lagoon (L. Gill). Seasonal changes in floral abundance are also greatest in this lagoon type, but changes in floral presence/absence are less significant, indicating that the floral species are present throughout the year, but these change in relative abundance through the year. In the highest salinity site (Athola), faunal changes occur but are not statistically significant, whereas changes in abundance and presence/absence of algal taxa are significant within the year 2003 but were not in the previous year. In this respect, as might be expected, the low salinity lagoon shows seasonal changes similar to those in a freshwater lake whereas the community of the high salinity sites behave more like that of a rocky shore, and that inter-annual changes may be as great as any seasonal change. In the mesohaline lagoons (Murree and Aibhnín) seasonal changes are only slight with most species present throughout the year. These lagoons are characterised by a higher proportion of lagoonal specialists, which are more tolerant of environmental changes and it would appear that on the relatively mild west coast of Ireland, the lagoonal community is present and at a similar population level throughout the year.

The relevance of these results in terms of monitoring is that in the low salinity sites it is much more critical to carry out any sampling work related to monitoring in as similar a seasonal period as possible to the baseline and any subsequent survey(s), but this is less critical in mid- or high-salinity sites. Of greater importance than seasonality in the more saline sites with an open inlet to the sea are differences in water levels caused by tidal and atmospheric conditions.

Significant differences were also found between stations in certain lagoons, and care should be taken to ensure that stations are selected to represent variation within the lagoon and that the selected sampling stations are easily re-locatable. If sites are chosen that do not represent the breadth of variation present in the lagoon, key species may be missed, and the total value of the lagoon may be under- or over-represented.

5.2 Biological classification of Irish coastal lagoons

The analysis of abundance and presence/absence data for fauna and flora from a total of 112 stations in 28 lagoons results in a classification of Irish coastal lagoons into four basic types of lagoon characterised by different vegetation communities, namely *Potamogeton/Ruppia, Ruppia/Chaetomorpha, Ruppia/Zostera*, and an “estuarine” type of lagoon, largely devoid of benthic vegetation. Further analysis of presence/absence data for flora and fauna from 60 lagoons again identifies these four main types plus a fifth “mixed community” type of lagoon, which are either large lagoons with a tidal influence and also a large freshwater component to the biota, or consist of a mosaic of small pools of different salinities resulting in a high species number with representatives of different salinity regimes.

In general, the floral data shows tighter clusters in the PCA and RDA analyses than the faunal data. Vegetation is also a more useful way of describing lagoon types than fauna as the fauna is largely mobile and can react to short-term changes in environmental conditions, whereas the vegetation is generally sessile and more likely to reflect more average longer-term environmental conditions. Furthermore, the fauna of apparently similar lagoons, sometimes close to each other may also be very different and Barnes (1988) suggests that the fauna of East Anglian lagoons are “largely chance assemblages resulting from the vagaries of colonisation patterns”. Using lagoonal specialist data for both fauna and flora also generally results in a wide scatter of data points both in the PCA and CCA analyses, with very few obvious clusters. Salinity is the dominant environmental factor in all analyses and whereas the whole community in general is sensitive in particular to different salinity regimes, lagoonal specialists are characteristically tolerant of a wide range of environmental conditions (especially salinity) and there are likely to be fewer organising factors. Many of the lagoonal specialists are also rare and are found in very few lagoons and several lagoons of very different salinities are grouped together based simply on their paucity of species.

Historically, brackish waters have been classified using some measure of salinity such as maximum, minimum, mean, range (e.g. Redeke 1922, Aguesse 1957, den Hartog 1964, Heerebout 1970, Remane and Schlieper 1971) and these have been used to explain species distributions to such an extent that, in estuaries for example, descriptions of the distributions of estuarine species have yielded more than a dozen salinity classification schemes (Bulger *et al.* 1993). Lagoons are still commonly described using salinity, based on the Venice system as oligohaline, mesohaline, euhaline, polyhaline (e.g Healy and Oliver 1998, Healy 2003), but the problem with using salinity to describe lagoons is that it is difficult to know which is the most relevant measure of salinity to record and also that salinity is so variable both temporally and spatially. It is quite possible in an isolated lagoon that one large inflow of seawater over a very short period of hours during a storm may be the determining factor in that particular lagoon, and this event is likely to go unrecorded, partly because it is the least likely time of the year that a biologist is will be sampling the lagoon. In some situations, such as nature reserves with full time staff it may be relatively easy to collect daily salinity measurements and data loggers to measure salinity are available, but very expensive at present. However, in a lagoon with a tidal influence, salinity should ideally be measured over the tidal cycle at various parts of the lagoon and various depths and even so, salinity data of one year may not be sufficient. Heerebout (1970) used data collected over 8 years for his classification of brackish waters.

Lagoons are also classified according to geomorphology. For example, surveys of coastal lagoons in the U.K. used a classification which recognised isolated, percolation, silled and sluiced lagoons and a fifth type referred to as lagoonal inlets (e.g. Sheader and Sheader 1989b, Brown *et al.* 1997, Thorpe *et al.* 1998, Bamber *et al.* 2001b). A similar approach was used in Irish lagoon surveys which recognised sedimentary lagoons, rock lagoons, natural saline lakes and artificial saline lakes (Healy and Oliver 1998, Healy 2003). However, while these morphological types are useful descriptions in terms of type of management required (Chapter 4, Section 5.7), they often bear little relationship to the biological communities they contain. Barnes (1991) described lagoon geomorphology and biota of lagoons as independent variables.

The intention of the Habitats Directive is to protect the biological community contained within the habitat, and although salinity and geomorphology are useful ways of describing lagoons, it would be very useful to have a classification of lagoons based on the biological community. Verhoeven classified “Ruppia based communities” according to fauna and flora, and many of these "communities" were lagoonal. Roden (1998) described the dominant vegetation communities in Irish lagoons, and the MNCR marine biotope classification of Connor *et al.* (1997a, b) was applied to lagoons in Scotland (Covey and Thorpe 1994) and in England and Wales (Bamber 1997, 2004). However, no attempt was made to classify the lagoons as a whole based on biota.

This proposed biological classification of Irish lagoons may be oversimplified, but perhaps with the confusing array of descriptive terms for lagoons, a simplification is desirable. Most classifications are imposed on a continuum and Shardlow (2004) points out that, on investigation, every single lagoon is different, and yet there are features which certain lagoon types have in common. In this respect this biological classification can be compared with that of water typology by Verdonschot (1994) in that there are no clear boundaries between the lagoon types but there are recognisable "centroids". Classifications based on salinity, hydrology and geomorphology all have their advantages but also limitations. The proposed classification may also have limitations but can be extended and applied to lagoons in other Member States as additional data becomes available and is a simple way of describing lagoons based on the biological community that the Habitats Directive is intended to protect.

5.3 Irish coastal lagoons in a European context

The definition of coastal lagoon used in the Interpretation manual of the Directive (CEC 1996) is based on a geographer's definition using geomorphology which broadly speaking is a "permanent body of brackish water behind a barrier, usually of sand or shingle". This definition refers to the classic "true" lagoons of for example Colombo (1977), Barnes (1980), and Bird (1984). In Ireland, as in other countries, there are unusual lagoon types with important lagoonal communities, that have been included as coastal lagoons, such as the granite/peat lagoons on the west coast and the karst lagoons in Clare and Galway, though not fitting comfortably within the definition of coastal lagoon referred to in the interpretation manual. As Barnes (1991a) asks "what is it we want to conserve, the vessel or the contents?"

The classic, sedimentary "true" lagoons are worth conserving in their own right as coastal landforms, but other lagoons outside this strict definition may also be worth conserving for their lagoonal community. The situation remains, however, in that what is regarded as a coastal lagoon in one Member State may not be regarded as such in another, and vice versa. For example some of the high salinity lagoons listed for Scotland contain communities that appear to differ little if at all from those of sea lochs, while some of the Norfolk Broads, with salinities up to 8psu and significant numbers of brackishwater animals are excluded (Healy 2003). In the Irish surveys, lagoons were identified largely on the presence of characteristic "lagoonal specialist" animals and plants as well as topography. In this respect, sites similar to those in the Norfolk Broads (e.g. Kilcoole) were included in the inventory of Irish lagoons, whereas those similar to some of the Scottish sites (L. Hyne, L. Ardbear) were not.

European lagoons

On a world scale, coastal lagoons are characteristic of micro-tidal areas (<2m tidal range) (Barnes 1980, 1984) and are typical and particularly extensive along the coastlines of, for example the Gulf of Mexico and Southeast USA, Brazil, West Africa, Southwest and Southeast Australia, Alaska and Siberia. Cromwell (1971) calculated that 74.5% of the World's barrier/lagoonal coastlines are found in North America, Asia and Africa and that these barrier/lagoonal coastlines occupy 13% of the world's coastline but Europe with only 5.3% is the continent with the least amount of coastline in this category. In this respect, coastal lagoons are relatively rare in Europe and many lagoons in other countries are massive compared with anything in Europe. For example, the Lagoa de Patos, in southern Brazil, is 265 km long compared with the largest in Ireland (Lady's Island Lake) which is only 3km long. Within Europe, itself, coastal lagoons are particularly abundant around the shores of the Baltic, Mediterranean, and Black Seas and relatively rare on the Atlantic coast (Barnes 1994).

Coastal lagoons have been documented for Denmark (Muus 1967), Italy (Sacchi 1979) and Mediterranean Spain (Comin and Parareda 1979), and more recently for England (Smith and Laffoley 1992), Scotland (Covey 1998, Thorpe 1998, Thorpe *et al*. 1998) Wales (Bamber 2004), Northern Ireland (Charlesworth and Quinn 2004), Portugal (Fonseca 2004) and the Republic of Ireland (Healy 2003, Section 4.3), but it is still difficult to get information from other countries and to make accurate comparisons. This is partly due to the historical "neglect" of the habitat, the fact that documentation required by the Habitats Directive is only partially completed by some Member States, and that a lot of the information is contained in government reports, the "grey literature" that is not freely available. So, in this respect it is difficult to make accurate comparisons and erroneous statements are sometimes made. For example, Reach (2004) stated recently that "The UK has a large proportion of the saline lagoon resource found in Europe, with greater than 40% of the European resource". It is hard to imagine where this figure came from, as lagoons are relatively rare on the Atlantic coast. The total area of lagoon habitat in the UK is approximately 5,200 ha (Bamber *et al.* 2001), whereas just one lagoon on the Atlantic coast of Portugal (Ria Formosa) proposed as an SAC covers 10,500ha (Fonseca pers. comm.) and Italy has more than 150,000 ha of typical lagoonal habitat (Barnes 1994).

It is interesting to point out here that the length of coastline of Ireland has been calculated by Neilson and Costello (1999) as 7,524 km and the coastline of the UK, excluding Northern Ireland is approximately 13,000km (Walker 1988). Criteria for description as "coastal lagoon" vary as do calculations of coastline length according to methods and maps used, but these figures are approximately directly proportional to the amount of lagoonal habitat in Ireland (2,703ha) and the UK (5,200ha).

Lagoonal fauna and flora

The lagoonal specialists referred to are brackishwater animals and plants that are "distinctly more characteristic of lagoonal habitats than of estuaries or saltmarshes" (Barnes 1989). Various lists have been proposed in the U.K. (Barnes 1989, Davidson *et al.* 1991, Bamber *et al.* 1992, Smith and Laffoley 1992), which vary according to author. Recently, Bamber *et al.* (2001b) have produced a list with A and B categories based on previous lists. All beetle and corixid species that were on previous lists have been 'downgraded' to the B list of species "whose U.K. population would be unsustainable without the presence of saline lagoons (i.e. >30% of current sites are lagoonal) as these species are also found in other habitats in the U.K., but added a cranefly (*Geranomyia bezzia*) and a chironomid midge (*Glyptotendipes barbipes*), and interestingly a bird (*Recurvirosta avocetta*) to the A list of "distinctly more characteristic of lagoons" species.

Lists of lagoonal specialists have also been compiled for Ireland (Oliver and Healy 1998, Healy 2003, Section 4.4) which varies slightly from the U.K. list as some species on the U.K. list have not been recorded in Ireland (e.g. *Gammarus insensibilis*) and others appear to be associated with lagoons in Ireland but are not in the U.K. (e.g. *Notonecta viridis*). The updated list presented in Chapter 4 includes an amphipod species (*Corophium insidiosum*) regarded as a lagoonal specialist in the U.K. and only recorded in Ireland for the first time in 2003, as well as the chironomid species mentioned above. The latter is included in the list tentatively as it has been recorded in lagoons in Ireland but very little is known of its ecology in this country.

Comparisons of the biota of Irish lagoons have been made with species lists from England, but most of the English lagoons, excluding the Fleet are very small and of very similar types. If Scotland was included and comparisons were made between Ireland and the U.K., the species lists may not be so different. Ireland is after all very much like a miniature of the U.K. and though it is a smaller country, it has a very long, indented and varied coastline. It is often quoted as an example of Island Biogeography that Ireland has fewer species than the larger island of Britain, which in turn has fewer than the mainland of France, but this principle might not be as applicable to highly-dispersive marine species.

Of the lagoonal specialists found in England, most, apart from those only found in one or two localities, have now been found in Ireland. Slight mysteries still remain, in that for example, *Gammarus insensibilis*, an essentially Mediterranean and Black Seas species (Barnes 1994) is found in lagoons in England from Dorset to Lincolnshire (Bamber *et al.* 2001b), and there is a single record for Ireland, from L. Hyne, Co. Cork (Kitching and Thain 1983). This species has not been found in any of the lagoons surveyed in Ireland, but may well be found in the near future. Another species, *Hydrobia acuta* (= *neglecta*) is also a southern species, very similar to *H. ventrosa*, which according to Bamber *et al.* (2001b) is found in East Anglian, Scottish and Irish lagoons. There appears to be one record of this species from the Aran Islands (Kerney 1999), curiously in what appears to be L. an Chara where *S. selecta* was found. This species may have been overlooked, or mis-identified, but has not so far been recorded during any of the surveys of Irish lagoons. Three other small species of polychaete (*Armandia cirrhosa*, *Alkmaria romijni, Ficopmatus enigmaticus*) are also found in the U.K., and are regarded as lagoonal specialists but have not been recorded in any Irish lagoon. The latter, *F. enigmaticus,* is an introduced species which has been recorded in Cork Harbour (Minchin *et al.* 1995), but neither of the other two species appear to have been recorded in Ireland. All three species are small and may have been overlooked or not collected from 1mm sieves rather than the 0.5mm sieves used in the U.K., but are quite likely to appear eventually.

A great deal of work in terrestrial ecosystems and in freshwater aquatic systems relies on some form of diversity index in order to compare different sites. No attempt was made in this study of Irish lagoons to use such indices. Lagoons are, almost by definition, low diversity systems, as relatively few species can tolerate the environmental fluctuations inherent in brackish water. Hence, lagoons tend to be dominated by either common euryhaline species or much rarer lagoonal specialist species. Diversity indices have been used in other surveys of lagoons but the lagoons compared are perhaps more similar to each other than the 60 lagoons surveyed in Ireland. In this respect, perhaps it is useful to compare lagoons of similar size and type using biological indices. However, without using a statistical analysis, it is clear that among Irish lagoons, the high salinity west coast lagoons and the large, low salinity, or "mixed community" lagoons are considerably more diverse than the small or medium sized mid-salinity lagoons and in this case simple species number (species richness) and number of lagoonal specialist species would appear to be a more useful way of comparing lagoons. It is also important to remember that some of the lagoons with both very low species richness and diversity are among the most important lagoons in terms of conservation value. For example L. Murree has a very low number of both faunal and floral taxa (17 and 9, respectively) and only four lagoonal specialist fauna, all of which are relatively common species, but has five lagoonal specialist plants, two of which are rare, red data, Annex II charophytes, and despite the very low species richness and diversity it is one of the most important lagoons in the country.

These lists of "lagoonal specialists" are continuously evolving as more information is acquired, and normally littoral species (*Cyathura carinata*) may in the near future be added to the Irish list as it is regarded as a "characteristic" lagoonal species in France (Herard 2004).

Geographic variation in lagoon fauna and flora

Of the species inhabiting coastal lagoons in Europe, there are some distinctly northern species (e.g. *Chara baltica, Praunus flexuosus, Littorina tenebrosa*) and some distinctly southern species (e.g. *Cymodocea nodosa, Althenia filiformis, Gammarus aequicauda*) and Ireland has a relatively rich fauna with representatives from both regions. There is also an east-west diversity with species from the clean, high energy, West Coast and those from softer sediment, higher nutrient East Coast. However, despite the slight differences in lagoonal biota between the neighbouring islands of Britain and Ireland already discussed, many of the characteristic species inhabiting coastal lagoons are found in coastal lagoons throughout Europe, though many of these species differ in ecology and physiology. For example, Healy (1990) showed that for eight species of marine isopod, including two common lagoonal specialists found throughout the region (*Idotea chelipes, Lekanesphaera hookeri*), all species exhibit a decrease in minimum brood size and in maximum size with decreasing latitude, and that female life span, age at first breeding, and to some extent brood size decrease from north to south while length of the breeding season, number of broods per female and the number of generations per year tend to increase towards the south.

Differences are ascribed to latitudinal gradients in temperature and the length of the growing season but it is not known whether these differences are due to the phenotypic responses of individuals or to genetic adaptations of populations to different ecosystems in warm and cold climates (Healy 1990). Norton and Healy (1984) showed for *Lekanesphaera hookeri* that life span in the Baltic is 12-20 months, in Wexford, Ireland is 12-15 months, and the Mediterranean it is 10-11 months and maximum size is 10.5 and 8.0, 10.5 and 7.5 and 10.0 and 5.5 mm, for males and females, respectively. In the Baltic, breeding is confined to summer and individuals have a relatively long life span (Kinne 1954, Jensen 1955) whereas in the Mediterranean reproduction was almost continuous and individuals were short-lived (Giraud-Laplane 1962). The population in Wexford is intermediate in size, life span and breeding season (Norton and Healy 1984).

This not only shows a geographical difference in the physiology of a species found throughout the region, but also helps explain the statistical lack of seasonal variation in faunal populations in the three mid- and high-salinity lagoons of the four studied in Chapter 3. These lagoons were also on the West Coast where winter temperatures would not be as low as in Wexford, and where these differences may be more similar to the Mediterranean than to the Baltic or Wexford. Similarly, *Idotea pelagica*, a northern species, breeds only in the summer in NE England with the maximum release of juveniles in August –September (Sheader 1977), whereas in SE Ireland the breeding season lasts from December to August (Healy and O'Neill 1984). This extensive season starts when the water is near its coldest and ends when it is near its warmest, as might be expected from Orton's prediction (Orton 1920) for a northern species at the southern edge of its range. It also means that specimens are found throughout the year and abundance of the population throughout the year is relatively uniform.

Lagoons have received less attention because as transitional waters they have often been ignored by both marine and freshwater biologists, as they do not appear to belong to either discipline. In the Habitats Directive lagoons are listed as a marine habitat, but for example, *Conopeum seurati*, is a common lagoonal specialist recorded in 50% of lagoons surveyed in Ireland, and yet is not listed in a checklist of Irish marine Bryozoa by Wyse Jackson (1991), indicating either that lagoon fauna were not regarded as marine fauna or that species lists from lagoons were simply overlooked. There is also the problem of where to draw the line between marine and freshwater biota, or continental and marine waters. In Spain, the Inventory of Andalucian Wetlands (Junta de Andalucia 2002), differentiates between Continental and Coastal lakes, and the latter, referred to as “lagunas costeras” includes both freshwater and brackish lakes. In this particular situation, coastal lagoons are studied by limnologists and not by marine biologists.

It is unfortunate that the two disciplines have always been kept so separate, because, as shown in Chapter 3, there is a continuum of lagoon types which are transitional from freshwater to estuarine and marine systems. Both freshwater and marine systems have many ecological features in common, in terms of biotic processes such as competition and predation, and adaptations to the environment. The dominant features of "aquatic systems" are determined by the physical properties of water and by the mechanisms by which organisms interact with each other and with the environment. In this respect, the fundamental division between marine and freshwater systems is untenable from an ecological perspective (Dobson and Frid 1998). Taxonomically, however, they are very different and this is what has caused the major division. It is generally (but not entirely) agreed that life began in the sea and colonisation of freshwater requires efficient osmoregulatory mechanisms. Not only is overall diversity different between the two systems but the dominant groups are taxonomically different. Margulis and Scharz (1988) list 33 phyla in the animal kingdom, of which 30 occur in the sea and 16 are confined to the sea compared with only 14 animal phyla found in freshwaters. The most obvious difference observed in low salinity lagoons compared with high salinity lagoons is the dominance of insects and angiosperms in the former, compared with dominance of crustaceans and brown and red algae in the latter.

In these transitional waters of estuaries and lagoons it is not possible to draw a precise line between freshwater and marine organisms as many (euryhaline) species can occur in both, and therefore in a separate inventory of marine and freshwater species, many of these species might occur on both or neither list. Also, the list of lagoonal specialists varies from one author to another, as some of these species may also occur in both freshwater, marine and also estuarine systems as well as saltmarshes and brackish drainage ditches. With some of the coleopteran species in particular, it is not even clear whether they should be regarded as aquatic or terrestrial, never mind freshwater or lagoonal. For similar reasons, bird species have not been included in the species lists of Irish lagoons, because they generally are studied by those outside the realm of either marine or freshwater biology, although in the U.K. the avocet *Recurvirostra avosetta* is now regarded as a lagoonal specialist (Bamber *et al.* 2001b) and the spoonbill *Platalea leucorolia* is almost entirely restricted to this habitat in Europe.

At the other end of the scale there is confusion about the cut-off point between macro- and meiofauna, so that certain groups such as Enchytraeids are rarely identified. Other groups such as insect larvae, including relatively large and conspicuous fauna such as chironomids are identified by some researchers but not by others. Partly, this is again due to the division between marine and freshwater biology, in that marine biologists have greater taxonomic expertise with crustaceans and polychaetes, for example, whereas freshwater biologists will be capable of more insect identification. A similar problem exists when the surveyor of the lagoon is either a botanist or zoologist and in many surveys even important groups such as charophytes remain unidentified.

The result of this disparity is an incomplete species list for lagoons and the difficulty of comparing the biota of different lagoons. In a perfect world, the survey should be carried out by a multi-disciplinary team able to identify all taxonomic groups, but this is rarely possible.

Conservation status of coastal lagoons

It is an obligation under the Habitats Directive to select representative examples of Annex I habitats for protection within Special Areas of Conservation (SACs), and despite the difficulty of finding data from lagoons in other Member States initial comparisons can be made in order to put the Irish lagoons into a European context. Of the 89 sites listed for the Republic, totalling 101 lagoons (Section 4.6), 77.6% are within SACs and 87.6% of the total area of 2,585 ha is within an SAC. This figure appears to compare favourably with other Member States, based on available information. For example, it appears that up to 1996 only 9.4% of lagoons in Scotland and the Hebrides are within SACs (Covey *et al*. 1998) and the total for the U.K. appears to be 24.3% (Table 4.6.1). On the other hand, approximately 98% of the lagoon habitat in Portugal lies within an SAC due to the fact that one very large lagoon, the Ria Formosa, which accounts for most of the lagoon habitat in that country is an SAC.

Care must be taken when comparing these figures, however, as the selection of sites is not necessarily complete, and also that the lagoons in Scotland, for example, which are not within an SAC may be protected by other legislation that is as legally binding as the national laws which implement the Habitats Directive. Some of these other national laws may actually be more effective in protecting threatened habitats and species, as although the NPWS have done a good job of including a large number of lagoons within SACs, there are examples in Ireland of poor law enforcement of the legislation designed to protect lagoons. Ireland is fortunate in that much of the coastline is still relatively natural and undeveloped compared with other Member States, but with increasing affluence and population, more and more pressure is coming to bear on this valuable resource.

5.4 Management

Coastal lagoons in many parts of the World have been managed for aquaculture for many centuries but very little interest has been shown regarding Irish coastal lagoons in this respect. Barnes (1994) makes an interesting distinction between macro-tidal and micro-tidal lagoons in Europe in terms of human usage, in that lagoons in micro-tidal areas (Mediterranean, Baltic) have been used intensively for aquaculture with the installation of permanent compartments and traps, whereas along the macro-tidal

Atlantic coast most significant lagoons and the sedimentary barriers that enclose them are incorporated into nature reserves, and other than bird-watching there is no significant land/water use. Barnes is referring to the classic "true" sedimentary lagoons, such as Tacumshin and Lady's Island Lake in Ireland, but the same is also true of other lagoon types, including artificial lagoons (e.g. North Slobs, Inch Lough).

Many parts of the Irish coastline are still relatively natural and threats to Irish lagoons are not as great as in many other parts of Europe. In many cases, especially along the West Coast, no active intervention is needed, and the principle of "if it's not broken, don't fix it" is highly appropriate. However, monitoring plans should be established, and the presence of the lagoons should be integrated into watershed-level management plans.

One of the major threats to coastal lagoons is the entirely natural process of evolution into freshwater lakes by infilling with sediment from streams/rivers and windblown sand from the barrier, accelerated by onshore movement of the barriers, reducing the size of the lagoon. This evolution would normally be followed by total infilling and transformation into dry land. Under entirely natural conditions new lagoons would form in other parts of the coastline through flooding of low lying land and changes in coastal morphology, but with increasing value of land in a small country with a growing, more affluent population this is unlikely to be allowed, unless coastal protection becomes inhibitively expensive. Many former lagoons, especially along the Mayo coast (e.g. Cross L.) which appear to be perfect examples of "true" sedimentary lagoons are in fact freshwater lakes. The same also applies to former lagoons in Southwest France and Northwest Spain.

Lough Gill in Co. Kerry is an interesting example of a "true" sedimentary lagoon on the verge of becoming a freshwater lake and it is entirely through management of the artificial channel with a sluice and a weir that determines whether it remains as a lagoon or becomes a freshwater lake. Nature conservationists would prefer it to remain as a lagoon as there are only approximately 100 lagoons in the country compared with many thousands of freshwater lakes, but there are conflicts of interest from farmers, golfers, anglers, birdwatchers and tourists. There is an obligation under the Habitats Directive to protect L. Gill as a coastal lagoon, but it is also fortunate in some ways from the nature conservationists point of view, that it appears that eutrophication problems in the lake are relieved by allowing saltwater to enter, which retains the brackish nature of the water and therefore status as a coastal lagoon, and also increases the flushing rate of accumulated nutrients.

Most of the other threats to coastal lagoons, such as damage to the barrier through extraction of sediments, eutrophication/pollution, and infilling/drainage are easy to understand and relatively easy to prevent or remedy, but the threat from recreational amenity use such as the well-intentioned creation of bird reserves or lakes for angling and boating is, in some situations, the most problematical. The most fundamental characteristics of a coastal lagoon that must be maintained are the **permanent, brackish water**, but this is what some people, even some "conservationists," find hardest to understand.

It is largely due to the efforts of bird-watchers that the first nature reserves were created and the Birds' Directive (EC 1979) became part of European legislation. In protecting birds, many other species gained protection. However, with the Habitats Directive there is now an obligation to protect coastal lagoon habitat (some of which was actually created specifically in the UK for the Avocet, *R. avocetta*) as well as to protect certain bird species. In the U.K. the Royal Society for the Protection of Birds (RSPB) and English Nature (EN) have recently made great efforts to balance these two requirements (Bamber *et al*. 2001b, Symes and Robertson 2004). However, birdwatchers often want to lower water levels in lagoons in order to expose sediments especially in the autumn in the hope of attracting rare wading birds. This is sometimes taken to the extreme of near total drainage which is detrimental to other aquatic biota even in the short-term, especially during times of high temperatures. Even more serious and long-term, it is common to hear people involved in management plans of coastal lagoons that have become nature reserves suggest closing a sluice to convert a lagoon into a freshwater lake, in order to “improve” it for birds and “increase biodiversity”. Others also make the same suggestion to convert a lagoon into a freshwater lake for trout angling or simply as a boating lake. Lagoons, almost by definition, are species poor and conversion to a freshwater lake is very likely to increase biodiversity at least for some taxonomic groups (e.g. Angiosperms, Insects, Avifauna), but only at a very local scale.

Two lagoons in particular, in Co. Cork, where this threat occurred also happen to be two of only three sites in the country where a rare amphipod (*Gammarus chevreuxi*) has been recorded. This species is listed as a lagoonal specialist in Britain and Ireland and the conversion of these two lagoons into freshwater lakes may increase the local species richness and biodiversity but seriously threaten regional and national biodiversity by causing the extinction of this species in two of only three known sites in the country.

Bamber *et al.* (2001b) quote similar case studies in the UK and in La Mancha, Central Spain, birdwatchers wanted to divert sewage water from local villages into (brackish) inland saline lakes with unusual chemistry and bacterial communities again to “improve” them for birds (Oliver and Florin 1995). The problem here is one of perception in that the word brackish comes from Middle Low German “brack” or Middle Dutch “brac” meaning “obsolete” and historically, brackish waters and marshes have been considered as useless and the adjective is often used as a synonym for dirty or contaminated (Healy 2003). The only form of management that can improve this situation is through improving perception and public awareness of the Habitats Directive and the interest, conservation value and rarity of this habitat and its associated biota.

Other management issues are largely determined by the morphological or hydrological type of lagoon, whereas the biological type as recognised by the classification described in Chapter 3 is more relevant in terms of monitoring. For example, in the sluiced lagoons the most important form of management is the appropriate functioning of the sluice, whereas in an isolated lagoon the inflow of nutrients or pollutants is likely to be far more important, and in a percolation lagoon, damage to the barrier, though possibly natural, may be the major management problem.

5.5 Monitoring

The Habitats Directive not only obliges Member States to protect representative examples of coastal lagoons but also to monitor these selected sites at least every 6 years from the date of acceptance for maintenance of the conservation value for which the site was selected. While it is widely accepted that the biological community of individual lagoons is characteristically species-poor, lagoons as a whole vary considerably in salinity, morphology and biota. Results in Chapter 2 show differences in seasonal changes in the four different lagoon types studied, and Chapter 3 proposes a classification of Irish lagoons into five basic lagoon types. Whereas the morphological type of lagoon to a large extent determines the form of management required, the results of the study of seasonal changes and of the biological classification are highly relevant to the methods and timing of monitoring required in different lagoons. For example, the low salinity "*Potamogeton/Ruppia*" lagoons are largely dominated by insects and seasonal changes are greater than in other lagoon types. In these lagoons a large component of the fauna is nektonic, and therefore sweep-netting is the most productive method of faunal sampling and it is very important to time any monitoring to coincide with the season equivalent to the initial baseline survey. On the other hand, in many of the higher salinity, rock/peat "*Ruppia/Zostera*" lagoons, seasonal changes in fauna are less marked, so timing is less critical but over 50% of the fauna may be sessile species and can only be surveyed by making visual counts or estimates. In "estuarine" lagoons, sediment cores play a much greater part in the sampling procedure and in "mixed community" lagoons a combination of methods is required.

There is a long history of the use of biological indices of water quality in freshwaters but only recently have attempts been made to use such indices in brackish waters. In estuaries, due to the complex and constantly changing environment and consequent paucity of species, Jeffrey *et al.* (1985) proposed the use of two simple indices, the Biological Quality Index and the Pollution Load Index, to describe the pollution status of Irish estuaries and Wilson and Jeffrey (1987) extended the use of these indices to the range of estuarine conditions throughout Europe. These indices, however, are based on areas of an estuary affected by an obvious point source of pollution together with chemical analysis of the sediment and this procedure does not generally appear to be applicable to Irish lagoons. In general, the study of water quality in lagoons on the Atlantic coast of Europe is very much in its infancy. Parameters normally measured in freshwater such as dissolved oxygen concentration, oxygen demand, turbidity, nutrient levels (especially phosphorous) and organic content are often quite naturally at levels in brackish water that are equivalent to levels which would indicate pollution in freshwaters. These water quality parameters can also change rapidly depending on tides and rainfall.

When relying on individual bio-indicators of pollution, the physical stress caused by natural, often frequent, changes in salinity and temperature may completely swamp the effects of a pollutant, as shown by Wilson (1983, 1984) in that the oxygen consumption of *Cerastoderma edule* is more affected by a 50% change in salinity than by a 10^3-fold increase in Ni concentration. An attempt to improve our understanding of the effects of nutrients in lagoons has been made in the U.K. by studying The Fleet (Johnston and Gilliland 2000), and it has been suggested that, for example, *Lamprothamnion papulosum* may be sensitive to elevated phosphorous levels and therefore act as a bio-indicator for this particular nutrient. However, at present there is no evidence in Ireland to support this suggestion, as *L. papulosum* is still present in lagoons in Ireland which appear to be highly eutrophic and would be expected to have high phosphorous levels. A recent fish-kill in Lady's Island Lake, Co. Wexford, has however, prompted a study of water quality in that particular lagoon and eventually more information may be obtained.

5.6 Conclusions and recommendations

Sixty of the approximately 101 lagoons in the Republic of Ireland have now been surveyed. This number represents 86% of the total area of lagoon habitat in the country. A total of 450 faunal and 250 floral species have been identified from Irish lagoons and this appears to be a high number compared with the limited amount of information from other countries. Ireland possesses a very small percentage (<1%) of the lagoonal habitat in Europe, but several unusual lagoon types and rare species in European terms. A large proportion (87%) of the habitat in Ireland is protected within Special Areas of Conservation, and Ireland is fortunate in that much of the coastline is still relatively natural compared with other European countries.

Management

There are fewer management problems for most of the Irish lagoons as a result of less pressure from a small human population, but these pressures are increasing and one of the most contentious management problems is the well-intentioned creation of public amenity areas.

The most important forms of management needed in lagoons are:

1. Baseline biological survey and morphological description.
2. Identification of conservation priorities and definition of objectives.
3. Production of an appropriate and realistic management plan.
4. Maintenance of quality, salinity regime, depth and area of water.
5. Control of nutrient/pollutant inflows.
6. Maintenance of the barrier and of the baks of the lagoon.
7. Appropriate maintenance of flood control mechanisms.
8. Improvement of public awareness of the importance of coastal lagoons.
9. Design and implementation of appropriate surveillance/monitoring strategies.

Monitoring

It is an obligation under the Habitats Directive not only to protect representative examples of coastal lagoons but also to monitor the selected sites for maintenance of conservation value. Monitoring of lagoons should be as similar as possible to the sampling procedure employed for the baseline survey. The following minimum recommendations are made:

1. Careful selection of appropriate (relocatable) sampling stations within each lagoon
2. Sweep nets. Three sweep net samples (1mm mesh) from each station, for a timed period (e.g. 1min). Samples stored in 70% alcohol.
3. Sediment cores. At least 3 samples of 3 cores (0.005m^2) combined, wherever substrates permit, sieved through a 1mm mesh. Samples stored in 70% alcohol.
4. Visual searches for a maximum of 1 hour. Five-minute rule applied in low diversity sites. Full species list compiled. Percentage cover of vegetation estimated (0-100). Abundance score, based on modified SACFOR scale (0-6) for fauna.
5. Light traps. Optional but recommended. Left overnight at each station.
6. Fyke nets. Optional but recommended. Left overnight at each station.

Further work

For the study of seasonal changes, four lagoon types were selected based on salinity and morphological types, but the biological classification reveals that these four lagoons represent only two of the "biological" types (*Potamogeton/Ruppia* and *Ruppia/Zostera*) found in Ireland. In the future it would be very interesting to study seasonal changes in examples of *Ruppia/Chaetomorpha* and "estuarine" lagoons.

Eighty six percent of the total area of lagoonal habitat in the country has now been surveyed and though the remaining unsurveyed sites are small, some may still be very important in conservation terms and it is considered important to have a complete inventory of lagoon habitat within the country and to survey, at least briefly, the entire known habitat. For example, one lagoonal specialist, *Sigara selecta*, had been recorded only once before in Ireland (McCarthy and Walton 1980), but was found in very high numbers in a small, relatively uninteresting-looking lagoon on the Aran islands. Several other small, "inconspicuous" lagoons in the country were found to harbour important colonies, not just small numbers, of rare or interesting plants and animals, and would easily have been overlooked. Many of these small lagoons have been visited but only briefly, and not sampled, and many of the rare species, such as beetles, corixids, amphipods and charophytes can only be identified with certainty in the laboratory. For such a rare "priority" habitat, it would be very useful to have a complete inventory of both lagoons and lagoonal biota for the country.

Several small, especially benthic, species appear on faunal lists for other countries that are only rarely recorded, or have not been recorded at all in Ireland. This may partly be due to the fact that a smaller mesh size (0.5mm or less) is used compared with the 1mm mesh used in Irish surveys, but also due to a difference in taxonomic expertise as the smaller mesh retains smaller, often more difficult to identify species (e.g. dipteran larvae, oligochaetes, nematodes, copepods, ostracods).

Since Barnes (1980) described coastal lagoons as a "neglected habitat", the situation has improved considerably. Lagoons are a rare habitat in Europe, but many rare habitats have received a considerable amount of attention as a result of their rarity value. Providing funds are available, the following recommendations for further work are suggested:

1. Complete the inventory of Irish coastal lagoons.
2. Survey remaining lagoons (approx. 30) that were visited only briefly
3. Sample seasonally at least two examples of "*Ruppia/Chaetomorpha*" lagoons and two of the "estuarine" type lagoons. Compare seasonal changes with those in "*Potamogeton/Ruppia*" and *"Ruppia/Zostera*" type lagoons.
4. Sample representatives of muddy substrates in Irish lagoons, identify smaller fauna and compare results of using 0.5mm mesh and 1mm mesh. This will allow the identification of additional species, which can then be incorporated in future biodiversity monitoring in lagoons.

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