Plant and animal community changes associated with the Cardiff Bay Barrage

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Abstract

The closure of the Cardiff Bay Barrage in November 1999 signified the end of a period of slow estuarine maturation, and the beginning of a period of more rapid freshwater succession. Such a marked ecological change has rarely been studied, and provides an opportunity to gain insights into the consequences of both natural and anthropogenic changes in the wetland environment.

The current thesis describes the results of a study into the changes in habitats, plants, invertebrates and birds which have occurred as a result of Barrage closure. It includes overviews of the background to the Cardiff Bay Barrage project, the pre-Barrage estuary, and the post-Barrage ecological succession. Four main chapters are dedicated to outlining the changes in habitats, macrophytes, macroinvertebrates and birds.

The overall habitat diversity of Cardiff Bay increased as a result of Barrage closure, mainly because of the establishment of clear habitat zones in formerly uniform inter-tidal areas. Macrophytes were found to have increased from less than 30 species to over 80 in the same post-Barrage area.

Macroinvertebrate diversity also increased significantly – although this was countered by a reduction in overall abundance – a result of the generally lower productivity of freshwater versus estuarine habitats. Birds likewise showed an overall increase in diversity at the expense of a loss in abundance, especially of wading birds. Most of the increase in diversity was due to an increase in herbivorous and piscivorous species. Birds of the Gwent Levels Wetland Reserve (part of the compensation package for the loss of the Taff/Ely SSSI in Cardiff Bay), were also subject to a brief analysis. This area now attracts a wide diversity and abundance of wetland birds, and has fulfilled one of its primary objectives by attracting Nationally Important numbers of Shovelers *Anas clypeata*, Pintails *Anas acuta* and Black-Tailed Godwits *Limosa limosa*.

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1. Introduction

1.1. Preamble

The closure of the Cardiff Bay Barrage in November 1999 signified the end of the Taff and Ely estuaries that comprised Cardiff Bay at the time and the beginning of a new era of freshwater ecological change and development. Dramatic changes of this sort rarely occur under natural circumstances, the most critical of them being the replacement of a fluctuating brackish water tidal and mudflat regime with a permanent freshwater lake.

The Barrage (which was first proposed in 1986) was built, primarily as a means to improve the amenity and economic value of the area. As such, the project came under fire from two main groups of objectors – those who were worried about water quality and potential ground water issues, and those who were concerned about the loss of ecologically valuable habitats (the Taff/Ely SSSI). In the case of the latter, it was expected that there would be loss of estuarine biodiversity, which in turn would reduce the ecological value of the area. It was undisputed that the building of the Barrage would change the enclosed area from an estuarine habitat incorporating tidal mudflats and salt-marshes, into a freshwater habitat with predominantly open aquatic habitats, and relatively small areas of freshwater marshland. Whether this change would lead to an overall loss in biodiversity, and what the ecological and conservation value of the newly created habitats would be was not clear, and there are no safe ecological prediction models which could determine this outcome with any certainty.

Therefore, a detailed ecological analysis of the whole site, including the major new habitats and select groups, from primary producers to predators, was needed to see if a pattern could be identified. Crucially, this pattern would enable predictions to be made more accurately for future projects of this kind - of which there are certain to be many. Throughout the current research, there is an emphasis on birds – because they were the main reason why Cardiff Bay, and more specifically the estuaries of the rivers Taff and Ely had been previously designated and protected as a wildlife site. As birds are dependent on plants and invertebrates as food resources, all the trophic levels need to be considered in such analysis. Plants also have a strong role in determining the character of the habitats present.

1.2. Aims and Objectives of Research

The practical work for thesis, undertaken between May 2003 and May 2006 was aimed at fulfilling one primary aim, and several objectives, as outlined below:

Aim:

- To investigate the ecosystems of the Cardiff Bay area to assess its ecological conservation value, especially in terms of its bird populations, compare it with what was there before the closure of the Barrage in 1999, and suggest ways in which the area would develop ecologically over time.

Objectives:

- To determine the past and new habitats present in the Bay.
- To collect and analyse data on selected components of the ecosystem within the major habitats and representing the main trophic levels, specifically plants, invertebrates and birds.
- To assess these data by comparison with previously collected data on plants, invertebrates and birds in the Pre-Barrage Bay.
- To determine from data collected in 2003, 2004 and 2005, the ecological changes that have occurred since the Barrage was built.
- To suggest how, based on the data collected and other examples from the literature, the ecology of the area might change in the future.

These questions provide substantial scope, and although they focus on only a small fraction of the total 'ecology' of Cardiff Bay, the four key focus areas (habitats, macrophytes, macro-invertebrates and birds) were selected as being most important to quantify the major changes which have occurred in the area. They are also all especially relevant to the changes in bird populations which have occurred, and which are a major focus of the entire project.

It is hoped that the outcome of this research will provide a useful insight into the sorts of ecological changes that are likely to occur in the case of future estuarine reclamation/development schemes, and that it will provide an indication of the extent to which the new habitats can provide some recompense for the loss of those present in the 'natural' state. With the ever increasing development and reclamation of wetland habitats, along with the natural losses which are predicted to occur as a result of sea-level rises, it is hoped that studies such as this may help in managing such changes more effectively.

1.3. Wetlands and Wetland Losses

1.3.1. Wetlands

Wetlands are amongst the most valuable natural resources on earth, and yet until recently have been thought of as unproductive, sometimes even unhealthy lands, and, despite their importance, they continue to be among the most impacted and degraded of all ecological systems (Ramsar Convention Bureau, 1996). In general, wetlands can be defined as being any areas which are transitional between terrestrial and aquatic ecosystems and, which are characteristically dependent upon constant, or recurring shallow inundation (or saturation) by water. Perhaps the most universally accepted definition is that of the 1971 Ramsar Convention (Carp, 1972) which defines wetlands as:

'Areas of marsh, fen, peat-land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed 6 m (just over 19 ft)'

It is estimated that in terms of productivity, wetlands are rivalled only by some tropical rainforests, and by areas of the most intensively cultivated land in the world, such as the prime corn fields in the Midwest of the USA (Williams, 1990). The most productive of all wetland types are the coastal inter-tidal wetlands with net primary production reaching as much as 1000 to more than 3000 g C m^{-2} yr^{-1} (Ray & McCormick-Ray, 2004). The extremely high productivity of these areas is a consequence of a variety of factors, the most influential of which are the tidal regimes to which coastal wetlands are subjected, which result in high nutrient input from watersheds and coastal upwellings; in addition to fast turnover rates of aquatic organisms.

In addition, wetlands provide important habitats for a wide variety of plants, and animals, and are particularly important for waders, and wildfowl. In fact it was the importance of wetland habitat to birds that first bought the consequences of wetland losses to the public attention during the 1960s, when European scientists and conservationists linked the decline of waterfowl populations with wetland habitat loss caused by land drainage and pollution (Ramsar Convention Bureau, 1996).

1.3.2 Wetland Losses

The losses of wetlands worldwide have been estimated at 50% of those that existed since 1900, most of which occurred in the first 50 years of the last century, an estimate including inland wetlands and possibly mangroves, but not large estuaries and marine wetlands such as reefs and sea grasses (Dugan, 1993; OECD, 1996 as cited in Spiers, 1999). More specifically, losses of wetlands documented in the U.K include an estimated 23% of estuaries and 50% of salt marshes since Roman times; in addition to an estimated 40% loss of wet grasslands (Davidson *et al.*, 1991; RSPB 1993 as cited in Moser *et al.*, 1996).

It becomes obvious when we look at the amount of published work on wetlands that occurred prior to the 1960s, that the rate of wetland losses during the last century can be correlated with the state of knowledge of these ecosystems during the period. Prior to the 1960s knowledge of wetland ecosystems was extremely poor, and interest in these systems was non existent, they were simply seen as neither sound land nor good water (Williams, 1990). However, during the past 44 years, knowledge of these ecosystems has vastly increased with the realisation of the many functions and values of wetland habitats. This has resulted in many detailed studies of almost every aspect of wetland ecology, which, in turn, has led to a wide variety of legislation aimed at protecting wetlands, and promoting their wise use across the world, the most important of which are summarised in Williams (1990). However, even with their increased protection, in the UK alone wetland losses are continuing at a rate of >100 ha per year (Atkinson *et al.*, 2004)

Another, relatively new factor that is also important to consider when looking at coastal wetland losses is the effect of sea level rise through 'global warming'. It has been estimated that a 1 m rise in sea level could threaten up to half of the world's coastal wetlands which are designated as Internationally important (>168,000 km^2), with those surviving becoming substantially changed (Nicholls *et al.*, 1999; Nicholls, 2004).

When we consider future threats such as this, in addition to the direct human reclamation, and other wetland losses which at present, cause an estimated 1% loss of global wetland stock per year (Hoozemans, 1993 as cited in Nicholls *et al.*, 1999), it becomes obvious that there is a substantial requirement for a new way of thinking about these delicate, yet important habitats.

1.4. Estuarine Barrages

Because this project focuses on the ecological changes which have occurred as a result of the construction of the Cardiff Bay barrage, it is perhaps wise to give a brief background to these man-made structures and their uses.

Estuarine, or tidal barrages as they are alternatively known, are man-made structures which are designed to impede the flow of water in estuaries. Barrages may be constructed with the aim of obstructing the outflow of freshwater from the riverine to the estuarine side of the structure; or for obstructing/preventing the inflow of saline/brackish waters from the estuarine to the riverine side of the structure, although this may not always be the case (such as in the case of tidal power barrages which may utilise the ebb and flow of the tide).

Estuarine barrages may be used for several reasons – for storm/high tide surge protection, for tidal power generation, and perhaps most recently and controversially for improving the amenity value of adjoining areas (McLusky & Elliot, 2004). The concept of the barrage is by no means a recent one; in fact there is evidence to suggest that people have used barrages, even for tidal power, for well over 1000 years. In 1999, a tide operated mill was discovered at the Nendrum Monastic site on Stanford Lough on the east coast of Northern Ireland – a dendrochronological study of which dated the mill back to as early as 619 AD (Charlier *et al.*, 2004). There are many examples of many different types of barrages scattered throughout the world, however, it is only within the last few decades that there has been real growth in the consideration of barrage usage on a large scale. In the U.K. alone, several large scale barrages have been built (at Cardiff Bay, the Tees, Wansbeck and Hull Estuaries, and the rivers Thames and Tawe for example) and many more are under serious consideration (McLusky & Elliot, 2004). The following text aims to give a brief background to the 3 main types of estuarine barrages, with relation to past, present and future schemes in both the UK and worldwide.

1.4.1. Tidal Power Barrages

As already mentioned, the idea of using barrages to harness the immense energy produced by the tides is not a new one, but is one that is likely to become ever more commonplace over the coming years. In fact most of the future large-scale barrage schemes appear to be focussed on tidal (hydroelectric) power generation, which has become a dominant issue as a result of global warming and our realisation that more sustainable energy sources must be utilised in the future. There are currently only four large-scale tidal power barrages, although only two of these are of any real commercial value (**see Table 1.1**). The first and by far the largest of the extant commercial scale tidal power barrages was built in 1967 in the La Rance estuary near St. Malo (France) and has an output capacity of 240 megawatts – enough to power 250,000 homes (Charlier, 1997; Electricitie de France, Date Unknown). The second commercial scale barrage, although built as an experimental system in 1984, still has a significant output capacity of 18 megawatts – enough to provide power to around 4,000 homes in the town of Annapolis Royal in the Bay of Fundy, Canada (Nova Scotia Power, Date Unknown). The other two large scale systems (located in China and Russia) do not produce enough electricity to be of any real commercial value, producing only 3.9 and 0.4 MW respectively (Gorlov, 2001). There are many small scale tidal-power barrages in operation throughout the world which are for non-commercial power generation, and to cover these would be far beyond the scope of this introduction.

Table 1.1: Operating Large Scale Tidal Power Barrages (based upon Gorlov, 2001)

Year of Construction	Country	Site	Installed Capacity (MW)	Basin Area (km^2)	Mean Tidal Range (m)
1967	France	La Rance	240	22	8.6
1984	Canada	Annapolis	18	15	6.4
1985	China	Jhianxhia	3.9	1.4	5.1
1968	Russia	Kislaya Guba	0.4	1.1	2.3

Although the great need to take advantage of sustainable resources has been an issue for several decades, until present few tidal power barrages have passed beyond the conceptual design stage for a variety of ecological, sociological and economical reasons (Burt & Cruickshank, 1996) – which will be further reviewed later on as they are not only relevant to tidal power schemes.

As a result of much improved technology and growing moral and political obligations to prevent further global climate change, the number and scale of proposed tidal power schemes far outweighs those already functioning throughout the world. In a report commissioned by the World Energy Council (Craig, 2001) 26 potential tidal energy projects were under consideration, 5 of which are located in the UK (See **Table 1.2**). The most notable of the proposed UK barrages, is the Severn Estuary Tidal Energy Barrage, which if built would be among the largest in the world – with an installed capacity 36 times greater than that of the La Rance installation. The Severn scheme was first considered seriously way back in 1925 with a relatively small output of 800 MW – though this first attempt was prevented purely on economic grounds.

Table 1.2: Prospective sites for tidal energy projects (Based upon Craig, 2001)

Country	**Site**	**Installed capacity (MW)**
Argentina	San José	5040
	Golfo Nuevo	6570
	Rio Deseado	180
	Santa Cruz	2420
	Rio Gallegos	1900
Australia	Secure Bay	1480
	Walcott Inlet	2800
Canada	Cobequid	5338
	Cumberland	1400
	Shepody	1800
India	Gulf of Kutch	900
	Gulf of Khambat	7000
Korea (Rep.)	Garolim	400
	Cheonsu	Unknown
Mexico	Rio Colorado	Unknown
UK	Severn	8640
	Mersey	700
	Duddon	100
	Wyre	64
	Conwy	33
USA	Pasamaquoddy	Unknown
	Knik Arm	2900
	Turnagain Arm	6500
Russian Fed.	Mezen	15000
	Tugur	7800
	Penzhinsk	87 400

1.4.2. Surge Protection Barrages

As with tidal power barrages, examples of estuarine surge protection barrages can be found throughout the world, though all are aimed at protecting surrounding (usually low lying) land from tidal surges, and the risk of significant flooding. It is likely that this type of barrier will also become a far more common occurrence over the coming years with imminent threat of significant global sea level rise – which in the last century alone has risen by 10-25 cm (Watkinson *et al.*, 2004). Generally surge protection barrages are only employed as such (using movable barriers) when necessary, i.e. when tidal surges are predicted, and the permanent structures are as small as possible to cause least obstruction to the flow under 'normal' conditions (Burt & Cruickshank, 1996). For this reason, this type of barrage is probably of least relevance to the current project, as ecological interference tends to be minimal.

UK examples include the Hull, and the more famous Thames barrier opened in 1980 and 1984 respectively – both of which were built as a consequence of the 1953 storm surge (McLusky & Elliot, 2004). Much larger schemes exist, are under construction, or are planned for many parts of the world. One such scheme which is nearing completion is a huge 25.4 km long barrage known as the St. Petersburg flood protection barrier, located in Neva Bay, north east Russia (NEDECO, 2002)

1.4.3. Amenity Barrages

As mentioned previously, this type of barrage is perhaps the most recently conceived of all the types in use at present. This is also the most relevant type of barrage in relation to the current project – the Cardiff Bay Barrage is predominantly an amenity barrage, although it also serves as a surge protection barrage (for more detailed information see Chapter 2). The primary objective of such barrages is to improve the aesthetics of an estuary - and this usually involves total tidal exclusion with the aim of flooding unsightly mudflats and creating what is essentially a freshwater lake.

As well as the Cardiff Bay Barrage (1999), amenity barrages have been built in the Tees (1995) and Wansbeck (1975) estuaries in North-Eastern England, and in the Tawe (1992) estuary in Swansea. With the exception of the Wansbeck barrage which was built to improve the value of the area for water sports, all of the other barrages were built with the express purpose of regenerating depressed urban areas (Burt & Cruickshank, 1996).

1.4.4. Ecological Impacts of Estuarine Barrages

The ecological impact of estuarine barrages varies between the different types of barrage and essentially depends how much the physical environment is changed following their construction. As mentioned previously, surge protection barriers probably have the lowest impact on the ecology of an area in the long term, as they are essentially temporary barriers, which result in very little physical change to an estuary when not in use. Of all the barrage types, amenity barrages probably have the greatest ecological impact as they serve to completely change the physical environment – often by total tidal exclusion, resulting in a drastic change from a tidally fluctuating brackish water body to non-tidal fresh water body in a relatively short period of time. This is the case in the current project, as will be discussed in the following sections.

1.5. Environmental Impact Assessment

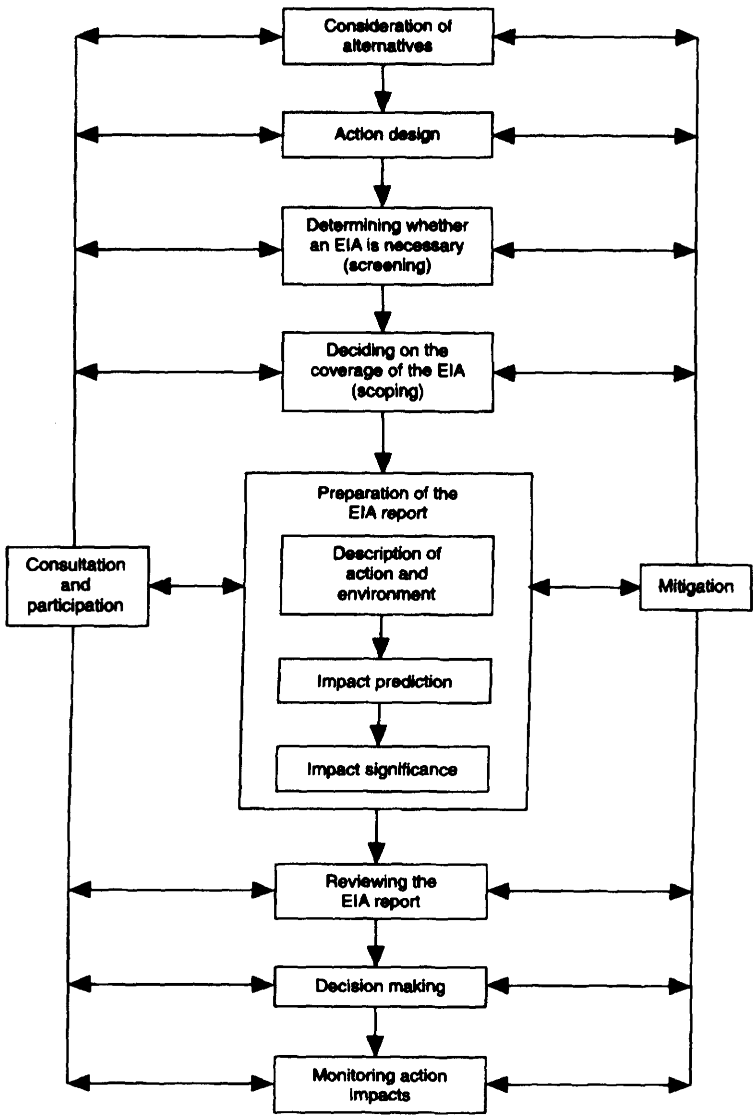
At its most basic level environmental impact assessment (EIA) can be defined as:

"The process of predicting and evaluating the effects of an action, or series of actions, on the environment, then using the conclusions as a tool in planning and decision-making." (Pritchard, 1996).

First developed in the USA, as a result of the National Environmental Policy Act (NEPA) of 1969, it was aimed at providing a systematic and integrative process for considering whether or not a proposal should be given approval depending on the possible/predicted impacts of the project (Wood, 1995). Although there are many varied approaches to the EIA process in the many countries which have now adopted the system as a means of safeguarding ecologically valuable habitats, the basic process, which is cyclical in nature, can be represented as a series of iterative steps, as illustrated in **Figure 1.1** by Wood (1995).

In principle the EIA should lead to the abandonment of environmentally unacceptable actions and to the mitigation to the point of acceptability of the environmental effects of the proposals which are approved (Wood, 1995). Therefore, if projects are to be approved, then the 'mitigation of impacts' can be described as the principal aim of the EIA process, and mitigation (in ecological terms) is also of most interest in the context of this work. The terminology related to the amelioration of impacts of a project is discussed in Section 1.6.

Figure 1.1: The cyclical Environmental Impact Assessment Process (from Wood, 1995).



1.5.1. EIA in the UK

Although the UK has possessed a land use planning system since 1948 (Wood, 1995), Environmental Impact Assessment (EIA) was formally introduced to the UK in the form of several laws which implemented the 1985 European Community Directive on EIA, otherwise known as Directive 85/337/EEC (Glasson *et al.*, 1999). The Directive was given legal effect in England and Wales through the Town and Country Planning Regulations 1988 (Wood, 1995). The Directive's definition of EIA is:

"The identification, description, and assessment, of the direct, and indirect effects of a project on: human beings, fauna and flora; soil, water, air, climate, and the landscape; the interaction of these factors; and on material assets, and the cultural heritage" (Gilpin, 1995).

1.5.2. EIA elsewhere

A wide variety of different EIA strategies are used by different countries, but the only one drawn upon in this thesis (in addition to the UK implementation of the European EIA requirements) is that of the USA.

1.6. Compensation and Mitigation Defined

As mentioned in the previous section 'mitigation of impacts' is the primary aim of the EIA process. Another term used widely with regards to the EIA process is 'compensation'. The two terms are often confused, and for this reason there is often confusion about their true meanings. This section aims to briefly summarise the true meanings of the terms, solely in the context of the UK EIA system.

Because of the scale of the Cardiff Bay Barrage project, and the likely significant environmental impacts that it would give rise to, it was (as in all modern large scale developments) necessary for the Cardiff Bay Development Corporation to consider alternatives, and at the very least consider a range of 'compensatory/mitigatory' measures in order for the Cardiff Bay Barrage Bill to be passed – as discussed in **Section 2.3**.

The terminology related to mitigation can be somewhat confusing, as terms tend to have different definitions within the various EIA systems of the world. Mitigation can be seen as either a universal term for the 'alleviation of the severity of impacts', or it can be seen as one of a hierarchy of steps involved in the same process. The Department of the Environment (1994b cited in Wood, 1995) uses the first approach, and classifies mitigation measures into avoidance (using an alternative approach to eliminate an impact), reduction (lessening the severity of an impact), and remedy (which may involve enhancement or compensation), but this can lead to the synonymous use of the terms compensation and mitigation, this is incorrect, and may lead to confusion over the true meaning of each. A far more simple and appropriate approach, and the one that will be used in this work, is to separate the various terms into a hierarchy of actions aimed at dealing with likely significant impacts. These are as follows (in descending order of importance as in Byron, 2000):

1. **Avoidance** - Requires the modification of a development proposal or operation in order to prevent or limit a possible impact. Changing the location or design of a building is a simple example.
2. **Mitigation** - The purposeful implementation of decisions or activities that are designed to reduce the undesirable impacts of a proposed action on the affected environment.
3. **Enhancement** - The genuine improvement of the interest of a site or area. Improvements over and above those required for mitigation/compensation.
4. **Compensation** - may be a measure(s) taken to counteract an adverse effect, which cannot be entirely mitigated. The suitability of that measure should be agreed with relevant authorities, parties and specialists.

As previously mentioned the proposed barrage was to have significant impacts on the ecology of Cardiff Bay, and in order to continue with the project (and gain acceptance of the bill) it was necessary for acceptable alternatives to be considered and for mitigatory measures to be planned, as detailed in the following sections.

1.7 Ecological Value Defined

The concept of 'Ecological Value' is one that is of the utmost importance when making comparisons between habitats, particularly where anthropogenic actions have been involved, as in the current study. It is at the forefront of Environmental

Impact Assessment, and often provides the basis on which environmental decisions are made.

However to define ecological value is extremely difficult, as the 'value' is often based upon a wide array of measurements and observations which are aimed at providing an overall representation of the habitat or area in question. **Table 1.3** summarises some of the measurements of Ecological Value proposed for the identification of marine and wetland protected areas (from Clouston, 2002).

Table 1.3: Criteria used for the identification of Marine and Wetland Protected Areas (from Clouston, 2002)

Representative Attributes	Ecosystem Viability	Ecological Attributes
• Comprehensiveness • Adequacy • Representativeness • Biogeographic Importance • Uniqueness • Habitat Variety • Naturalness • International or National Importance	• Integrity • Health • Resilience	• Productivity • Dependency – contains nursery or juvenile areas, or feeding, breeding or resting areas • Biological diversity and organisation

The above criteria provide a valuable overview of the types of criteria used to assess the Ecological Value of an area, though there are undoubtedly many more that are used throughout the world.

It is clear from those criteria outlined in **Tab.1.3**, and from a review of the literature in general, that all measures of Ecological Value used at present, rely on the assessment of the habitat/areas on a real-time basis, and very rarely include assessments based on the likely future state of the habitats in question. For instance, it is my view that inter-tidal wetland habitats deserve a higher Ecological Value assigned to them, than do freshwater habitats - based purely on the fact that future sea level rise and the introduction of tidal energy schemes such as the Severn Barrage represent a much greater risk to the former than to the latter.

Where possible, the current study attempts to compare the pre- and post-Barrage habitats of Cardiff Bay, by using the concepts of ecological value, although it is clear that there are huge limitations in the scope of such a classification.

2. Background to the Cardiff Bay Barrage

2.1. General Overview

Cardiff Bay, otherwise known as the Taff/Ely estuary is located on the North (Welsh) coast of the Severn estuary, in Southeast Wales, UK (51°27'N, 3°10'W), as illustrated in **Fig. 2.1**. The area, previously known as 'the port of Cardiff', was the focus for the UK's international trade in coal from the 1850s to the 1920s (Beresford, 1995) and reached its peak in trade in 1913 when it exported a record 13.5 million tonnes of coal, making it the biggest coal exporting port in the world (CHA, 2003). However, the area experienced decades of dwindling trade and dereliction due to technological changes in the ports and shipping industries, reduction in coal consumption, and shift in the pattern of trade away from west coast ports (Beresford, 1995). Ultimately this led to the creation of what was to become the second largest regeneration scheme in Europe (CHA, 2003), all initiated via the construction of the Cardiff Bay Barrage.

In 1986, the then Secretary of State for Wales, Nicholas Edwards (now Lord Crickhowell) proposed that further studies be undertaken into the feasibility of constructing a barrage across Cardiff Bay. In April 1987 the Cardiff Bay Development Corporation (CBDC) was formed by the Secretary of State, and his barrage interests became incorporated into the primary objectives of the corporation. At its onset the mission statement for the regeneration programme was:

"to put Cardiff on the international map as a superlative maritime city which will stand comparison with any such city in the world, thereby enhancing the image and economic well-being of Cardiff and Wales as a whole" (CBDC, 1996).

The primary aims and objectives identified for the regeneration project were set out by CBDC, and the Welsh Secretary stated these should be "substantially completed within 10 years" – the five main objectives were:

1. To promote development and provide a superb environment, in which people will want to live, work and play.
2. To re-unite the City of Cardiff with its waterfront.
3. To bring forward a mix of development which would create a wide range of job opportunities and would reflect the hopes and aspirations of the communities of the area.
4. To achieve the highest standard of design and quality in all types of development and investment.
5. To establish the area as a recognised centre of excellence and innovation in the field of urban regeneration.

(CHA, 2003)

Soon after public notification of the scheme, one of the main elements of the Corporation's strategy – the Barrage construction itself, received significant opposition from community and environmental groups. The reasons for opposition were diverse, but those that received most attention were public health concerns as a result of poor water quality; risk of damage to properties through elevated ground water levels; and most importantly in the context of this study, the loss of a nationally important feeding area for Dunlin, Redshank, and other waders and wildfowl, represented by the Taff/Ely SSSI (**See Fig. 2.2, 2.3** and **2.4**).

Despite these reservations, the Bill ultimately received Royal Assent as the 'Cardiff Bay Barrage Act 1993' on the 3 November 1993, and Barrage construction began in May 1994. Construction of the main workings of the Barrage took approximately 5 ½ years, and Cardiff Bay was eventually impounded with saltwater on the 4 November 1999, with the intention that the bay would be dredged during the saline impoundment, and then filled with freshwater in March 2000. However, following consultations between Cardiff Bay Development Corporation, the National Assembly for Wales, and the Environment Agency (which acts as an environmental regulator for the Bay), a decision was made to prolong saltwater impoundment for an additional year, in order that Cardiff County Council could establish a Harbour Authority (now known as 'Cardiff Harbour Authority'), and could re-consider dredging and other measures aimed at maintaining, and improving water quality.

The Bay was finally impounded with freshwater at the beginning of April 2001, although it was already of very low salinity due to the high flows of the contributory rivers during the preceding winter months. The barrage, as it exists today, consists of an 800 m long stone, sand, and concrete barrage incorporating locks, sluices, bascule bridges, a fish pass, and a control centre. The controlled flows out of the barrage result in a permanent inner bay level of 4.5 metres O.D, creating an enclosed freshwater lake of approximately 200 hectares, and a permanent waterfront of approximately 12.8 km (as illustrated in **Figs. 2.3** and **2.4**).

Figure 2.1: Location of Cardiff Bay within the UK and the Severn Estuary.

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Figure 2.2: Cardiff Bay pre-barrage, illustrating the extensive inter-tidal mudflats, SSSI boundary, and salt marsh.

Figure 2.3: Cardiff Bay post-barrage, illustrating the loss of inter-tidal mudflats, and loss of some marshland.

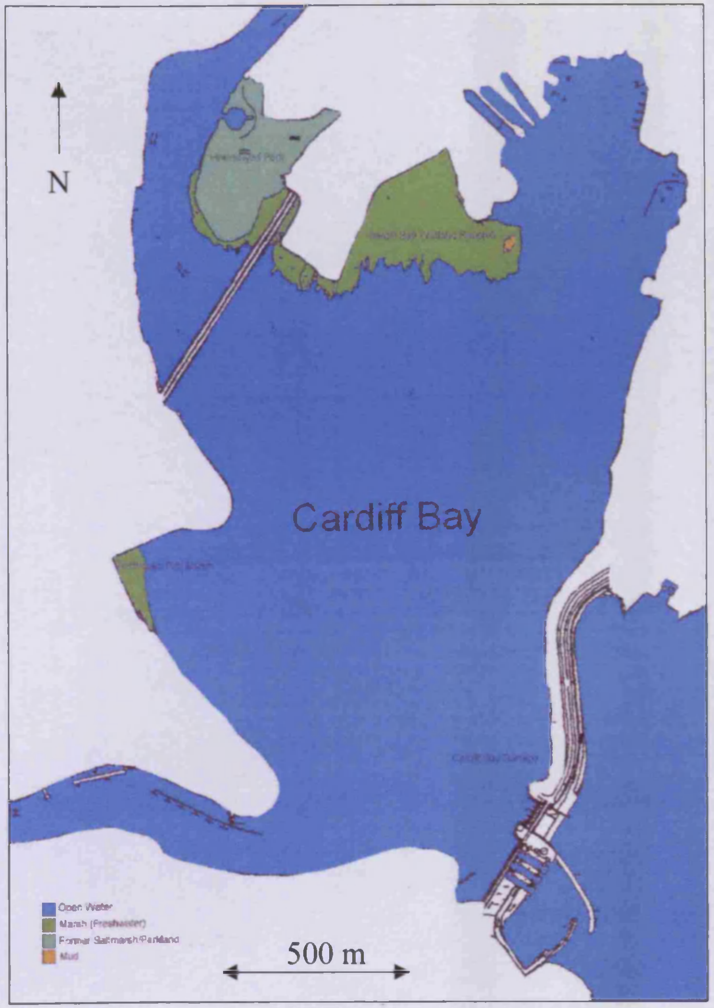


Figure 2.4: Aerial photograph of Cardiff Bay (post-barrage) showing numbered points of interest: 1) Cardiff Bay Barrage; 2) Cardiff Bay Wetland Reserve (Windsor Esplanade); 3) River Taff estuary; 4) River Ely estuary; 5) Former Salt Marsh (Prospect Place).

2.2. Pre-Barrage Conservation Interest and Designations within Cardiff Bay:

Prior to the construction and closure of Cardiff Bay Barrage, the Taff/Ely estuary, from which the Bay is formed, contained approximately 150 ha of inter-tidal mudflats (Burton *et al*., 2002), and several areas of salt marsh (approximately 15 ha) – most notably at Windsor esplanade, Penarth flats, and some small areas in the estuaries of the River Taff and Ely **(Fig. 2.2)**.

The Bay itself, was originally notified as a 'Site of Special Scientific Interest' (the Taff/Ely SSSI) in 1980 (**App. 2.1**), and was later notified under the 1981 Wildlife and Countryside Act. The SSSI covered a significant proportion (165 hectares/407.7 acres) of the inter-tidal areas of the bay, and also included the salt marsh area now known as Cardiff Bay Wetland Reserve (**Figs. 2.3** and **2.4**). SSSI designation was given primarily for the sites' provision of feeding grounds for around 8000 birds during the winter months, and for the fact that it held higher densities of waders for its size, than any other site within the Severn Estuary. The primary species for which SSSI designation was given were Redshank *Tringa totanus*, Dunlin *Calidris alpina*, and Curlew *Numenius arquata*, however the mudflats also supported smaller numbers of Knot *Calidris canutus*, Grey plover *Pluvialis squatarola*, Ringed Plover *Charadrius hiaticula*, Mallard *Anas platyrhynchos*, and Widgeon *Anas penelope*.

It is important to realise that, alone, Cardiff Bay would probably have had very little conservation interest at all, and it might be suggested that the major reason for its ecological importance (particularly with relation to birds) can be derived from its specific location within the wider area of the Severn Estuary. Taking an even wider view, it is suggested that the ornithological importance of the Severn itself, arises from its position amongst a number of Estuaries along the Western coast of Europe which, because they remain ice free in winter, support large numbers of migratory birds en route between Siberia, Canada, Africa and Europe (Prater, 1981; Hack, 1997). Having one of the mildest climates of any of the large estuaries in Britain, the Severn is also of particular importance during hard winters, and this has been well documented throughout the years, with extremely high peak numbers of certain species occurring during harsh winters periods e.g. in 1979, 1982, and 1986 (Ferns, 1994).

In addition various physical aspects of the Severn Estuary (length, shape, orientation, position) combine to create the second largest tidal range in the world, which in turn results in the water column holding an estimated 10 million tonnes of suspended sediments (including a considerable amount of organic matter), thus resulting in the extremely high productivity and reduced diversity that is characteristic of this estuary, and in turn the abundant food resources required by large numbers of wintering waders and wildfowl.

Therefore it is not surprising that the Severn holds several statutory designations for its own conservation interest (**App. 2.2**), and it is necessary to outline these in order to comprehend the impact of the Cardiff Bay Barrage as part of a wider system.

Perhaps the first of the major Severn designations was the main Severn Estuary SSSI (notified in 1989), which covers the whole inter-tidal area from beyond the old Severn Bridge, to an imaginary line between Lavernock Point and Brean Down - making up an area of 15,950 hectares.

In 1995 the Severn Estuary was designated as a Special Protection Area (SPA) under EC Directive on the Conservation of Wild Birds (79/409/EEC) for its bird populations of European importance, and in the same year, was designated by Ramsar for inclusion on the 'List of Wetlands of International Importance (the Ramsar List)' which confers upon it the prestige of international recognition and obliges the government to take all steps necessary to ensure the maintenance of the ecological character of the site.

Additionally, the Severn Estuary has been put forward as a 'Possible Special Area of Conservation' (pSAC) under the EU Habitats Directive (Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora) 1992, in view of several of the important habitats that the area provides, if notified, this designation will provide the highest level of protection available for the future of the estuary.

Other Severn Estuary related designations that are also of interest in the context of this study (because of their relation to the compensatory measures discussed below) include two of the six 'Gwent Levels SSSI's', the Whitson SSSI; and the Nash/Goldcliff SSSI (**App. 2.3**).

2.3 Predicted impacts outlined in the Cardiff Bay Environmental Statement

As outlined previously, the main purpose of the Environmental Impact Assessment (or 'Environmental Statement' as it is known in the case of Cardiff Bay) is to predict and evaluate the effects of an action upon the environment.

The Environmental Statement for the '1989 Cardiff Bay Barrage Bill' was prepared by the Environmental Advisory Unit of Liverpool University (EAU, 1991). The statement was submitted to the 1991/2 session of parliament, and was thus used as the primary source of information used to inform any decisions made with regards to the impacts of the project. It was deemed of importance therefore, to include a summary of the main ecological impacts predicted by the statement, in a comprehensive list for easy reference.

The relevant predicted impacts (along with the relevant page number), are listed in the order in which they occur in 'Section C' of the statement (EAU, 1991), as follows:

1. *"There is some risk that permanent losses to populations of* ***Dunlin****, breeding* ***Shelduck*** *and, to some extent,* ***Redshank****, will occur if the mudflats of Cardiff Bay are permanently inundated." (p.63)*

2. *"Wildfowl species which feed by dabbling at the waters edge (such as* ***Mallard, Shoveler*** *and* ***Teal****), or diving in deeper water (such as* ***Tufted Duck*** *and* ***Pochard****), may continue to be found in the Bay after Barrage construction." (p.63)*

3. *"In the short-term, species such as* ***Teal, Mallard*** *and* ***Pochard*** *which are now found in the Bay, may decrease in number owing to disturbance during construction, and until new vegetation communities become established." (p.63)*

4. *"In the short-term, loss of saltmarsh habitats and disturbance during construction will mean a substantial reduction in the* ***passerine*** *bird populations which currently feed there" (p.63)*

5. *"It is expected that the wintering and breeding populations of **Snipe** will be lost in the short-term, and probably permanently" (p.63)*

6. *"The period following tidal exclusion can be expected to be characterised by extreme fluctuations in environmental parameters and the death of many marine organisms (invertebrates) within the lake" (P.64)*
7. *"**Hediste diversicolor** can tolerate low salinities and may persist for long periods after tidal exclusion" (P.64)*

8. *"In the longer term, the existing invertebrate fauna will be replaced by species characteristic of freshwater environments" (P.64)*

9. *"In any remaining saltmarsh above 4.5m OD, the sediments will gradually dry out and become desalinated. Should vegetation change be allowed to occur naturally, plants characteristic of saline and brackish habitats, will be gradually replaced by those of grassland and ultimately scrub and woodland. In the drier areas, invasion by grasses such as **Creeping Bent** (Agrostis stolonifera), **Couch** (Elymus repens), and **Yorkshire Fog** (Holcus lanatus) may occur." (p.64)*

10. *"At the lake margin, plants such as the **Common Reed** (Phragmites australis), **Reedmace** (Typha latifolia and Typha angustifolia), and **Reed Canary-Grass** (Phalaris arundinacea), together with reeds and rushes, can be expected to spread. At a later stage, **Reed Sweet Grass** (Glyceria maxima) may become established. In shallow marginal waters, species such as the pondweeds (**Potamogeton spp**. and **Elodea spp**.) may be found, as well as the algae Cladophora and Enteromorpha" (p.65)*

As can be seen, considering the size and impact of the project, very few direct predictions were made, leaving considerable scope for subjective personal views.

2.4. Compensation and Mitigation for the Construction of Cardiff Bay Barrage

The decisions, and issues related to the 'amelioration of impacts' from the Cardiff Bay Barrage were, as previously mentioned, complex in nature, and detailed discussions of these are beyond the scope of this thesis, primarily due to their political nature.

In brief, the result of over 10 years of legal dispute, which involved the consideration of alternative barrage types and compensatory habitats, was the development of a compensatory wetland some 15 km away from Cardiff Bay itself – the Gwent Levels Wetland Reserve (**Fig. 2.6**), which formed part of a wider package of compensation agreed between the U.K Government and the E.C. The wetland area in question lies to the East of Cardiff on an area of low lying land in the Uskmouth and Goldcliff areas of Newport, as illustrated in **Figures 2.5** and **2.6**.

Additionally, a small area of former salt marsh was developed as a non-compensatory freshwater wetland reserve within Cardiff Bay itself (**Figs. 2.5** and **2.7**). It is important to clarify that this area was never discussed in terms of compensation or mitigation, but was instead part of the Cardiff Bay Regeneration Strategy's aim to bring back conservation interest to the bay itself (as discussed in section 1.4.2), and for this reason it is these main areas which will be discussed in the following sections. The key events leading up to the decision on what compensation should be offered for the Cardiff Bay losses are summarised in **Table 2.1.** Further information relating to the negotiations for environmental compensation in Cardiff Bay are discussed more thoroughly in a series of publications by Richard Cowell (See Cowell, 2000; Cowell & Thomas, 2002; and Cowell, 2003), and are summarised in the proceedings of the Lands Tribunal Decision for the Gwent Levels (ACQ/93-97, 1999).

Table 2.1: Cardiff Bay Barrage and Compensation Key Events (Adapted from Cowell, 2003).

Date	Event
1985	Cardiff Bay identified as candidate for an Urban Development Corporation.
1987	Cardiff Bay Development Corporation established; barrage proposal announced, and debates over possible mitigation/compensation begin.
1987/88	Idea of mitigation (like-for-like compensation) at Wentloog, put forward.
1990	Nature Conservancy Council proposes boundary for Lower Severn Estuary Special Protection Area (under the 1979 EC Birds Directive), to include Cardiff Bay.
1991	British Government excludes Cardiff Bay from the Lower Severn Estuary Special Protection Area; legal challenges mounted by environmental NGO's.
1992	Wentloog mitigation proposal dropped from the Cardiff Bay Barrage Bill.
1992	Ideas for major wetland creation scheme on the Gwent Levels began to be developed by the CBDC, Welsh Office, RSPB, CCW, and various consultants.
1993	Cardiff Bay Barrage Bill is enacted; announcement made about proposal to develop a 'major bird reserve' on the Gwent Levels.
1994	European Commission officers inform the Welsh Office that provision of environmental compensation could address the impacts of barrage decision under the 1992 Habitats Directive, but that further work on compensation proposals was required.
1995	Idea of creating major wetlands reserve at Goldcliff-Uskmouth, developed.
1996	Planning application made to develop the wetlands reserve at Goldcliff-Uskmouth.
1997	Public enquiry held in Newport into the wetlands reserve scheme; consent granted by the Welsh Secretary later that year.
1998	Work begins on site at Goldcliff-Uskmouth.
2000	Goldcliff-Uskmouth reserve is officially opened by the chairman of the CBDC.
2001	Work begins on converting old salt marsh in Cardiff Bay to a freshwater wetland reserve.
2002	The reserve, named the 'Gwent Levels Wetlands Reserve', receives commendation in the RTPI's annual planning achievement award.
2004	Cardiff Bay's Wetland Reserve (Phase 3) officially opened to public on 2^{nd} February – world wetlands day.

Figure 2.5: Location of Cardiff Bay Wetland Reserve in Cardiff Bay (red arrow) and Gwent Levels Compensatory Wetlands (between green arrows) within the Severn Estuary.

Figure 2.6: Gwent Levels Wetlands Reserve:

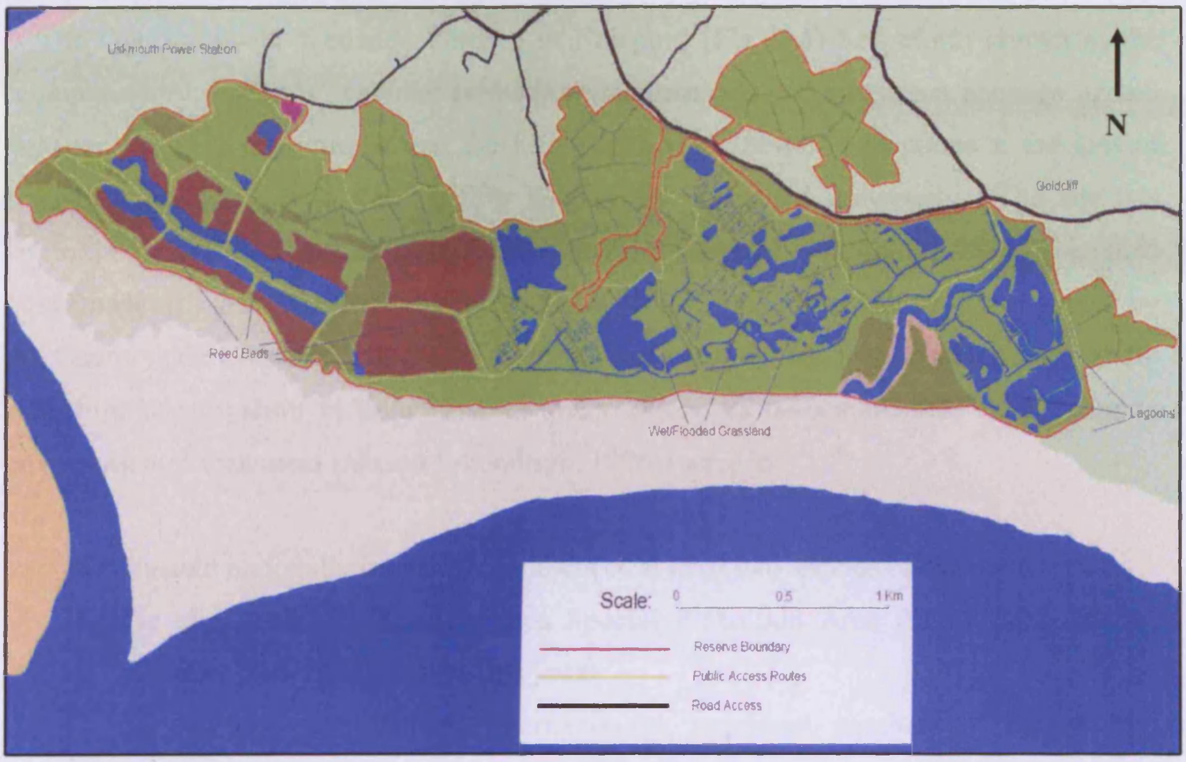
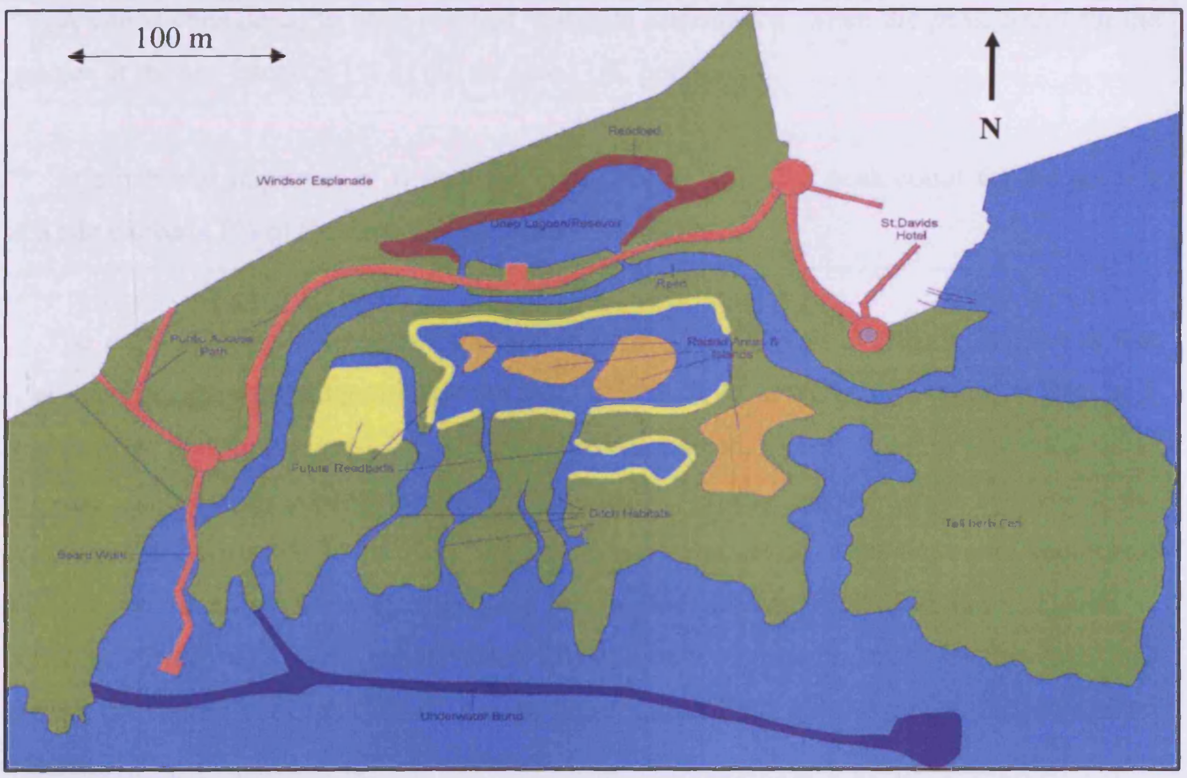


Figure 2.7: Cardiff Bay Wetlands Reserve:



(i). The Gwent Levels Wetlands Reserve

The Gwent Levels Wetlands Reserve in Newport, **(Fig. 2.6)** henceforth known as the 'compensatory wetlands' was the primary component of a compensation package agreed between the U.K government and the E.C, which was offered in response to the loss of inter-tidal habitats within the Taff/Ely Estuary, as mentioned previously. The site lies approximately 15 km east of Cardiff Bay, covers an area of 438.6 ha of SSSI designated land (made up of the Whitson, and Nash/Goldcliff SSSI's), and is managed and owned by the Countryside Council for Wales (CCW). As expected, the site was designed specifically with bird conservation in mind and the main objectives (as summarised in the reserve environmental Statement (Mason Pittendrigh, 1996)) were to:

1. Sustain nationally important numbers of at least two species of waterfowl.*
2. Be eligible for designation as a Special Protection Area (SPA) alongside the Severn Estuary SPA within five years.
3. In the long term, attract internationally important numbers of certain bird species.**

* A site is considered to have reached 'national importance' when the peak count for the species at the site exceeds 1% of the recorded UK population.

** 'International Importance' is attained for a species when the peak count for the species at a site exceeds 1% of the recorded European population.

The reason for the controversy surrounding the Gwent Levels Wetlands Reserve is that it was not designed as mitigation for the loss of the inter-tidal wetlands of Cardiff Bay, as it was decided that this was not a feasible option, but instead, its construction was intended to provide some sort of compensation. This essentially means that the target habitats of the area were not expected to be able to support the numbers or even the same species of waders that were lost from Cardiff Bay, but instead, it was hoped that the attraction of different species with some conservation importance would compensate for this loss, thus raising interesting questions about how the importance of one species can be judged against another.

Three broad types of wetland habitat were created within the reserve, all chosen with a view to achieving suitable habitats for a variety of target bird species. These were 'wet reed-beds', 'shallow saline lagoons' and 'freshwater wet & flooded grassland' (Mason Pittendrigh, 1996).

With regards to the first of these habitats, approximately 86 ha of wet reed bed area have been constructed on a site adjacent to the former Uskmouth Power Station (at the western side of the reserve), in lagoons which were formerly used for pulverised fuel ash (P.F.A) storage. As well as being listed in the U.K. Biodiversity Action Plan (UK B.A.P) as being a priority habitat, this is a particularly important habitat for the conservation of certain nationally rare breeding birds (as noted in the UK B.A.P, 1995).

The second of the habitat types, the shallow saline lagoons, make up an area of approximately 11 ha, at the Eastern side of the reserve, and are aimed at providing areas suitable for wintering and breeding waterfowl, and in particular to provide supplementary feeding and roosting habitat for birds present on the Severn Estuary. This is also a U.K B.A.P. (1995) priority habitat.

The final broad habitat type (freshwater wet & flooded grassland) is also notified under the U.K B.A.P as a priority habitat (listed as 'coastal & floodplain grazing marsh') this habitat is the most extensive on the reserve with 62 ha of wet grassland, and 68 ha of flooded grassland in the area known as 'saltmarsh' (between Goldcliff and Uskmouth), and an additional 31 ha of wet grassland at the Uskmouth site – making a total of some 161 ha. The main rationale for selection of this habitat type was its potential to support nationally, and internationally important numbers of some wintering waterfowl species.

The listed species, and the predicted numbers of each, as considered by the 'Target Bird and Management sub-group for the reserve', are given in **Table 2.2**.

ii. The Cardiff Bay Wetland Reserve

Although it does not form any part of the compensatory measures offered by the Cardiff Bay Barrage Bill, the Cardiff Bay site is still of utmost importance with relation to this study, as it represents an area which has undergone a marked ecological change, and thus is the primary area of focus for the remainder of this thesis.

The Cardiff Bay Wetlands Reserve **(Fig. 2.7)** was developed after the completion of the Gwent Levels site, with the aim of bringing back conservation interest to the bay area itself, as outlined by the 'Cardiff Bay Regeneration Strategy' (as cited in 'Environmental Advisory Unit', 1991) which stated that:

"The creation of new freshwater and other natural or semi-natural habitats must be an integral part of the strategy"

In addition there was a requirement set out by the bill itself stating that:

"When operating the barrage ...the Development Corporation shall have regard to the desirability of developing and conserving flora and fauna in the inland bay".

The aforementioned reserve has an area of *c.* 8.15 hectares (Highways & Parks, 2003) and is located on the northern shore of Cardiff Bay, between the St. David's Hotel and the estuary of the River Taff. The area was officially opened as a wildlife reserve in July of 2002, in what was previously an area of raised salt marsh (the Taff/Ely saltmarsh) up until the closure of the Cardiff Bay Barrage in April 2001.

Construction of the man-made features of the reserve began in 2001. Initially, these included a large reed-fringed reservoir in the northern area of the site aimed at attracting a diversity of invertebrates and other wildlife for the purpose of pond dipping - being the only purpose built aquatic habitat to which the public have direct access through the provision of a dipping platform which was added during a second phase of construction work in 2003.

Table 2.2: Target bird numbers and species for the Gwent Levels Wetlands Reserve (Mason Pittendrigh, 1996).

	Goldcliff			**Saltmarsh**			**Uskmouth**		
	Wintering	**Passage**	**Breeding (no. Prs)**	**Wintering**	**Passage**	**Breeding (no. Prs)**	**Wintering**	**Passage**	**Breeding (no. Prs)**
Dunlin	2000	<200							
Redshank	500		10-15			30-50			
Ringed Plover		<200 [A]	5						
Sanderling		<200							
Lapwing	100-200		10-15	2000		50-100			
Oystercatcher			2						
Curlew	20-40			200		3-5			
Whimbrel		<40 [B]			40-50				
Snipe				300-400					
Black-tailed Godwit					50-100				
Mallard	D								
Shoveler	D			50-100 [B]		2			1-2
Shelduck	D		10 [C]						
Wigeon	300-500			2000-3000					
Tufted Duck			D [C]						
Gadwall				40-50					4-5
Garganey						1 [D]		D	D
Teal				500-1000					
Bewick's Swan				<40 [F]					
Water Rail									10 [D]
Marsh Harrier									1-2
Bittern									1 [E]
Bearded Tit							D		D
Cetti's Warbler									10-12

A = Particularly important for Spring passage

B = Associated with wet ground/saltmarsh

C = Associated with vegetated islands

D = Low numbers/difficult to count and predict

E = Reed beds designed to attract this species (20 years to reach target).

F = Low numbers initially

A reen or 'moat' runs the entire length of the reserve from East to West. Constructed primarily as a means of preventing public access onto the majority of the reserve; it essentially bisects the area into a northern publicly accessible area, and a southern publicly inaccessible area which contains the majority of bird targeted habitats. Thus, the reserve south of the reen consists of a number of lagoons, scrapes, islands and floating bird refuges as well as a large extent of tall-herb fen, grassland, and Willow *Salix* spp. and Alder *Alnus glutinosa* carr. To the south of the reserve, lying just beneath the surface of the waters of the Bay is a 360 m long raised stone bund which runs the entire length of the southern shoreline of the Reserve and is intended to reduce erosion via wave action.

Beyond the stone bund is a purpose built boom to prevent the wetlands being inundated with water-borne debris during periods of high water levels, and to prevent access by boat to the southern edge of the reserve. Public access to the reserve is via a gravel walkway which runs from the car park adjacent to St. David's Hotel, between the reservoir and the reen, to the west of the reserve where there is a 105 m long board-walk and viewing area.

The target habitats for the Cardiff Bay Wetlands Reserve, as set out in the 'Cardiff Bay Wetlands Management Proposals' (Highways & Parks, 2003), are:

- Reed beds
- Tall-herb fen
- Ditch habitats
- Freshwater 'open' lagoons.

Management of these habitats is aimed at supporting nationally important numbers of resident and over wintering waterfowl – particularly Shelduck *Tadorna tadorna,* Teal *Anas crecca,* Tufted Duck *Aythya fuligula,* Pochard *Aythya ferina,* and Snipe *Gallinago gallinago.* Of the target habitats chosen, the reed beds are aimed at encouraging nationally important species such as Bittern *Botaurus stellaris,* Water Rail *Rallus aquaticus,* and various passerines, and the tall-herb fen is aimed at attracting nationally declining seed eating passerines, all of which are summarised in **Table 2.3**.

Table 2.3: Target bird numbers and species for the Cardiff Bay Wetlands Reserve (Highways & Parks, 2003).

	Species	Target Populations
Breeding Birds	Great Crested Grebe	3+ Pairs
	Mute Swan	1-2 Pairs
	Shelduck	2+ Pairs
	Mallard	5+ Pairs
	Coot	5+ Pairs
	Black-headed Gull	2-10 Pairs
	Reed Warbler	2+ Pairs
	Sedge Warbler	3+ Pairs
	Cetti's Warbler	1+ Pairs
	Sand Martin	10+ Pairs
	Reed Bunting	3+ Pairs
Wintering Birds	Great Crested Grebe	10+
	Little Grebe	1+
	Bittern	1+
	Grey Heron	1+
	Teal	40+
	Tufted Duck	10+
	Pochard	20+
	Goosander	2+
	Snipe	10+
	Water Rail	1+
	Water Pipit	1+
	Linnet	20+
	Chaffinch	10+
	Gadwall	5+
	Coot	50+
	Shoveler	5+
	Reed Bunting	10+
Passage Birds	Little Egret	1+
	Grey Heron	1+
	Waders	20+ (5+ Species)
	Sand Martin	50+ (Roost)
	Water Pipit	1+

3. Habitat Changes in Cardiff Bay

3.1 Introduction

Cardiff Bay has long been subject to a range of human influences, which have shaped and changed the variety and extent of habitats present in the area. In addition, natural processes have continually changed the physical properties of the area (and therefore its suitability as a habitat for organisms). These natural processes have acted over an even longer time scale, and are generally less noticeable than the man-made changes, as more gradual transitions have been involved.

Cardiff Bay was formed by a combination of over 200 years of reclamation of formerly inter-tidal areas associated with the development and expansion of Cardiff Docks (Ferns, 1987). The end result was the formation of a semi-enclosed 'bay' - recognisable as Cardiff Bay in the years leading up to barrage closure. This highlights the fact that, although certain habitats may have been lost as a result of change, some of them would not have existed in the same form under natural circumstances.

The importance of habitats in determining the diversity of species present in an area is well known, and is one of the central tenets of ecology – commonly known as the 'habitat heterogeneity hypothesis' (Tews *et al.*, 2004). This hypothesis can be summarised as follows - the greater the habitat heterogeneity, the greater the species diversity. In the majority of terrestrial ecosystems, plants are the main determinant of the physical structure of the habitat and thus have substantial influence on the distribution and interactions of animal species. Tews *et al.* (2004), in a literature survey (including the results of 85 separate studies) on the effect of habitat heterogeneity on species diversity, found a positive correlation between the two in 85% although most were biased towards studies of vertebrates and habitats under anthropogenic influence. This highlights the importance of including the general changes in habitat heterogeneity that have occurred in Cardiff Bay as part of the present study, if it is to be successful in explaining the changes in biodiversity.

Using various reports and assessments as information sources, this chapter aims to outline the major habitat types present in both the pre- and post-Barrage periods; it attempts to do this in an ordered and logical way by listing each habitat, in a hierarchical manner. This habitat classification is not meant to be a historical review of all of the habitats that have ever been present in Cardiff Bay – rather it focuses on a comparison between the habitats present in a period immediately prior to barrage construction, and the habitats present in a period immediately after Barrage construction (i.e. within a five year period either side of Barrage construction).

3.2. Methods

3.2.1. Broad habitat Comparisons

Information concerning Cardiff Bay's pre- and post-Barrage habitats was compiled using a variety of habitat classification systems. Data concerning the various habitat types and their distributions before barrage construction were obtained from a variety of both published and unpublished sources, including published maps of the area. Much of past survey work has tended to focus on either of the two main types of habitat present in the pre-barrage era – namely saltmarsh and inter-tidal mudflat. In addition, most of the habitat information available has been collated as secondary objectives of particular surveys (for example, assessing habitat type in order to explain the distribution of wading bird species). In many cases, actual habitat descriptions have not been as detailed as they may have otherwise been.

In more recent times, several habitat surveys have been undertaken solely for the purpose of assessing the conservation value of the Bay. In many cases these were part of the consultations relating to the construction of Cardiff Bay Barrage, and were a direct result of the compulsory Environmental Statement (and preceding Environmental Assessment) required in order to outline the likely environmental impacts of the development (e.g. Environmental Advisory Unit, 1991).

In order to provide a clear inventory of the habitats present in pre- and post-Barrage situations it was first necessary to classify the various habitats into 'broad' habitat types. This was partly a consequence of the wide range of habitat classification systems that exist, all relying on different methods of defining habitats. It was imperative therefore, that a broad classification method was defined, relevant to both pre- and post-Barrage environments.

The classifications of 'broad' habitat types listed throughout this section are based almost exclusively on the U.S. Department of the Interiors' '*Classification of Wetlands & Deepwater Habitats of the United States'* (Cowardin *et al*., 1979). Although intended for US habitats this system was found to be equally useful in providing a starting point for the classification of Cardiff Bay's habitats into 'habitat systems', 'sub-systems', and 'classes' (See **App. 3.1** and **3.2).** The system does not rely heavily on the 'Dominance Type' (i.e. the dominant species of flora and fauna) to define a habitat type, which means that, not only can it be applied in other geographical locations (where dominant species may differ significantly), but also allows it to be used in studies such as this, where changes in the habitat type alone are best used to describe the changes in the inhabiting species.

UK specific habitat classifications - notably, the '*Marine Habitat Classification for Britain and Ireland*' (Connor *et al*., 2004), and the UKBAP's (UK Biodiversity Action Plan) '*Broad and Priority Habitat System*' (UKBAP. 1999) were used to provide alternative naming of the US habitat classifications where it was deemed that these would better define and/or conform to the habitat type in question (for example the UKBAP's term 'mudflats' is probably far more familiar to the UK ecologist than the term 'Unconsolidated Mud Shore' as used in the US system. In addition, one major habitat type in Cardiff Bay was not covered by any of the classification systems used, and therefore, instead of ignoring it, a new class was used to define it – this being the 'Open Water' habitat class, as will be explained later in this report.

3.2.2. Comparison of Marsh Habitat Extent

The change in the extent of marsh vegetation in Cardiff Bay was examined as part of a separate case study of this important habitat type. Comparisons were made by mapping and measuring the extent of all marsh habitats (be they freshwater marsh as in Cardiff Bay at present, or saltmarsh as in the pre-Barrage situation) using historical maps of the Cardiff Bay area. For this purpose, digital maps were obtained from 'Historic Digimap®' (the historical map collection of Digimap http://digimap.edina.ac.uk) and were analysed using the mapping software 'Map Maker Pro 3.5". A total of 8 different maps were analysed from various stages in the development of Cardiff Bay, the earliest being from 1885, with subsequent maps from 1922, 1947, 1965, 1974, 1984, 1996, and finally, 2006. All maps were derived from the total extent given by Ordnance Survey tile st17se (Grid Ref: 315000,170000 - 320000,175000) which covers a total area of 25 km^2. However, because the map tile encompasses a significant area outside the boundaries of Cardiff Bay, a smaller area of approximately 11.5 km^2 is shown in the results section. The resulting measurements were subsequently compared to those derived by Smith (1979); Dent (1987); Ferns (1987); Kirby (1988); and Way (1988).

3.3. Results

3.3.1 Pre-Barrage Habitats

Using Cowardin's classification, the pre-barrage habitats of Cardiff Bay (within the study area) are loosely grouped into only one 'habitat system' (**Fig. 3.1**) – 'Estuarine Habitat'. This system includes all areas subject to brackish/saline water conditions within an 'estuary', which, in turn, is defined as "*a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage*" (Pritchard, 1967). The absence of the 'Riverine System' is noteworthy, however the 'Estuarine Habitat' is likely to have extended far outside the defined study area, and thus prevented recording of such an environment. The Riverine habitat system was defined by Cowardin as: "*all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees,* *shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts in excess of 0.5‰* " (Cowardin *et al.*, 1979). The tidal influence of the Severn Estuary is known to have affected both the Rivers Taff and Ely (see Section **3.3.3**) to a point much further upstream than enclosed in the study area. Although difficult to confirm without detailed data regarding the river channel salinity, it is likely that the upper limit of the estuarine system and the lower limits of the Taff and Ely riverine systems were located at the first weirs on each of the rivers (which would have prevented mixing of saline and fresh water). However, if salinities proved to be low enough for the 'Riverine' system to be present within the defined study area, then the Taff and Ely would have been typical of the 'Tidal Riverine' sub-system.

(i). Pre-Barrage Estuarine Habitats

(a). Sub-tidal

Sub-tidal estuarine habitats are restricted to estuarine areas in which the substrate is continuously submerged throughout the entire tidal cycle. Within the confines of Cardiff Bay in the pre-Barrage situation these habitats were restricted to three main areas; the channels of the River Taff; and the River Ely; and the shipping 'entrance channel' to the Roath Basin and Dock (**see Fig. 3.2**). In all three areas sediments were continually submerged for the entire tidal cycle providing permanent aquatic 'refuges' for a range of organisms.

It is likely that each of these three areas would have had significantly different water quality characteristics at low tide; this would be particularly noticeable between the river, and the shipping channels. For example, parameters, such as dissolved oxygen, temperature, light penetration and turbulence would have fluctuated far more noticeably over the tidal cycle in the river channels as conditions changed from brackish conditions with low flow rates at high tide, to predominantly freshwater conditions with comparatively high flow rates at low tide. In comparison, the shipping channel, with no such flow through of water at low tide, would have remained a relatively constant habitat throughout the whole tidal cycle.

The sub-tidal habitats can be further divided into two 'habitat classes' - 'Unconsolidated Bottom' following Cowardin *et al.* (1979) and 'Open Water', not included in Cowardin *et al.* (1979). The class 'Unconsolidated Bottom' is probably better described simply as 'Sub-tidal Sediment' (Connor *et al.*, 2004), and in Cardiff Bay, this habitat occurred in the benthic areas of the Taff and Ely, and the Shipping Channels. These areas are likely to have been important habitats for a variety of benthic invertebrate species, and hence would have made attractive aquatic feeding grounds - particularly at low tides when inter-tidal sediments would not have been available. The specific sediment type (which determines the sub-class of the habitat) is unclear due to lack of background data, but is likely to have been either mud or sand in the two river channels depending on the energy of river flows, and would have almost definitely been mud in the case of the shipping channel. According to Connor *et al.* (2004) 'Unconsolidated Bottom'/'Sub-tidal Sediment' habitats which have mud as their dominant sediment type (specifically termed 'sub-littoral mud in variable salinity' (estuaries)) "typically support communities characterised by oligochaetes and polychaetes such as *Amphelochaeta marioni"*.

The rest of the sub-tidal habitat would have been classified as being of the **'Open Water'** habitat class – i.e. the water column overlying the aforementioned sediments at low tide. This habitat class is rarely included in published classification systems but has been included here for its importance as a habitat to a variety of organisms. Little detailed information is known of this habitat but it is likely that several fish species, particularly flatfish such as the flounder, *Platychthys flesus*, would have used this habitat as a feeding area at low tide.

Figure 3.1: Flow chart illustrating the hierarchy of habitat classification used in this report (based upon Cowardin *et al.*, 1979)

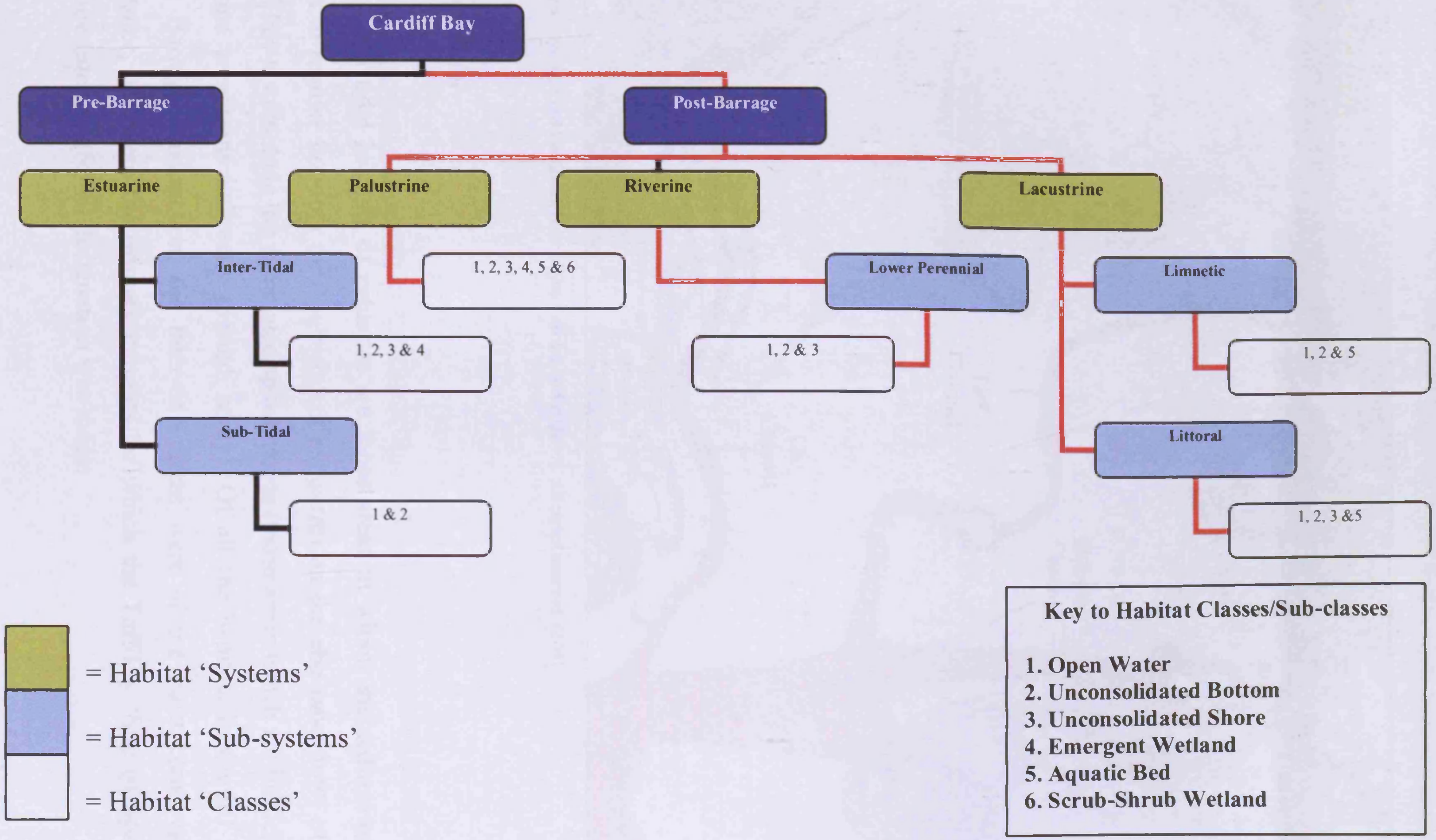
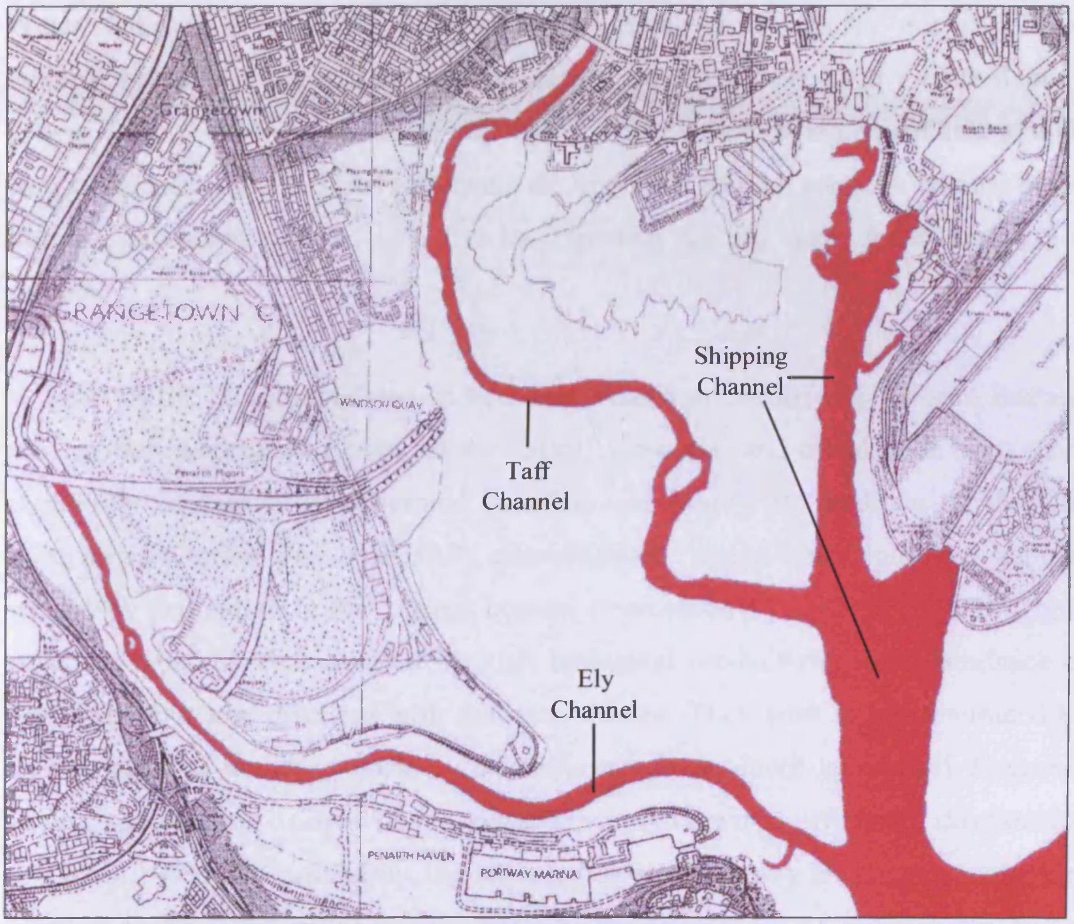


Figure 3.2: Location of pre-barrage 'Sub-tidal Estuarine Habitats' as highlighted in red. Classification of these habitats is based upon Cowardin *et al.* (1979)



(b). Inter-tidal

The inter-tidal habitats of estuaries are those areas in which the sediments are subject to regular flooding (and subsequent exposure) on the ebb (and flow) of the tides. They also include the associated splash zones (those areas which are influenced by saline conditions indirectly through spray). Of all the habitats in Cardiff Bay before Barrage construction, the inter-tidal areas were of the most conservation importance, and were the primary habitats for which the Taff/Ely 'Site of Special Scientific Interest' (SSSI) designation was made.

Using the classification system of Cowardin *et al.* (1979), the inter-tidal estuarine habitat systems of Cardiff Bay can be divided further into two habitat classes – 'Unconsolidated Shore' and 'Emergent Wetland'. Again, I would argue that 'Open Water' habitats should also be considered on equal terms with the unconsolidated mud shores. Open water habitats very rarely appear as part of any classification system, even though they form an important component of the inter-tidal area in their own right; just as the exposed sediments are important feeding areas for wading birds, flooded sediments are also likely to be important feeding areas for estuarine fish species.

Most of the 'Unconsolidated shores' that existed in Cardiff Bay prior to Barrage construction were most typical of the 'Mud' sub-class, and could have been more commonly referred to as 'Intertidal Mudflats', or simply as 'mudflats' in the U.K Biodiversity Action Plan (UKBAP) classification: "sedimentary intertidal habitats created by deposition in low energy coastal environments" (UKBAP, 1999). These areas are typically characterised by high biological productivity and abundance of organisms, but low diversity with few rare species. They tend to be dominated by species such as common cockle *Cerastoderma edule,* laver spire-shell *Hydrobia ulvae,* sand-hopper *Corophium volutator* and ragworm *Hediste diversicolor* (UKBAP, 1999). In Cardiff Bay, the latter two species were by far the most common, together making up approximately 84% of the total mass of invertebrate fauna, although *Hydrobia ulvae*, and another species, the baltic tellin *Macoma balthica* were also present in significant numbers (Environmental Advisory Unit, 1991). This habitat occupied approximately 150 ha of the 200 ha (approximately 75%) of Cardiff Bay, and was therefore one of the most extensive habitats in pre-Barrage times (**Fig. 3.3**).

In general terms 'Emergent Wetlands' are "*characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens, where vegetation is present for most of the growing season in most years and is usually dominated by perennial plants*" (Cowardin *et al.*, 1979). In more specific terms, the 'Emergent Wetland' habitats of Cardiff Bay prior to Barrage closure could be referred to as 'Coastal

Saltmarsh' habitats - defined by the UKBAP's classification as *"the upper, vegetated portions of intertidal mudflats, lying approximately between mean high water neap tides and mean high water spring tides"* (UKBAP, 1999). In order to avoid confusion in the following text, the only difference between the two classifications is that the latter identifies salinity as the main factor affecting the type of vegetation present in the pre-barrage period, but the habitats are essentially one and the same, and any referral to saltmarsh habitat is a referral to the pre-barrage 'Emergent Wetland' habitat also.

Much research has focused on the 'Emergent Wetland' habitats of Cardiff Bay, with two main component areas (**Fig. 3.3**). The first area, which was by far the largest in extent was located in an area on the seaward side of the 'Windsor Esplanade' sea wall, extending a short distance up the eastern side of the River Taff, and, is known simply as the 'Windsor Esplanade Saltmarsh'. The second area was located on the Eastern side of the 'Ferry Road' peninsular, adjacent to the 'Redhouse' Public House, and was known as the Ferry Road or Redhouse Saltmarsh. Various estimates of the extent of these habitats have been made (e.g. Smith, 1979; Dent, 1987; Ferns, 1987; Kirby, 1988), and have been summarised by Way (1988; **Table 3.1**). At the latest estimate before Barrage closure, there were a total of 23.1 ha of saltmarsh present in the study area; these results do not, however, include the narrow bands of saltmarsh habitats that were present in several locations along the channels of the Ely and Taff Rivers (Environmental Advisory Unit, 1991). As no data on the extent of these areas are available, Way's figure (**Table 3.1**) should be taken as the most conservative. A more in depth overview of the changes in marsh extent in Cardiff Bay can be found in section **3.3.4**.

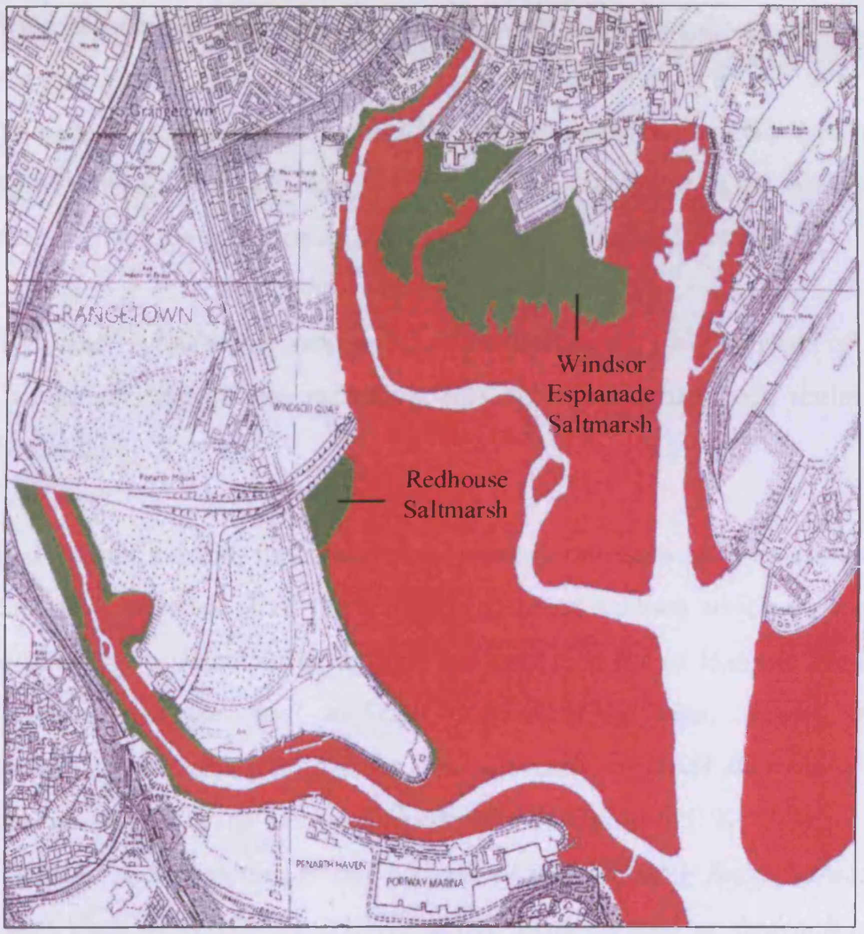
Table 3.1: Cardiff Bay saltmarsh area, as calculated from photogrammetric plots (i.e. measurement data derived from aerial photographs) from Way (1988).

Date	Ferry Road Saltmarsh (Ha)	Windsor Esplanade Saltmarsh (ha)	Total Marsh Area (ha)
1971	5.7	17.9	23.6
1981	4.5	18.5	23
1987	4.9	18.2	23.1

The saltmarsh habitats, as well as being important high tide roost areas for a variety of wading bird species (Ferns, 1987), were also of importance as winter feeding grounds for a variety of primarily passerine bird species. Kalejta (1984) noted that skylark *Alauda arvensis* and chaffinch *Fringilla coelebs* were by far the most common species inhabiting Cardiff Bay's salt-marshes, however many other species were recorded including snipe *Gallinago gallinago*, reed bunting *Emberiza schoeniclus*, and meadow pipit *Anthus pratensis*. More detailed analysis of this habitat is given in **Section 4**.

The 'Open Water' habitats of the inter-tidal estuarine habitat sub-system include all areas not thus far defined. These areas are subject to tidal influence and, therefore, vary in extent throughout the tidal cycle. It is probably because this habitat is subject to such large fluctuations in a variety of factors and conditions that it is rarely included as a habitat type in most classification systems; these fluctuations will undoubtedly cause changes in the use of the area as a habitat by a variety of organisms, resulting in a cyclic change in community types over a short period of time. For example, several species of bird use such open water areas to feed, particularly diving species such as cormorant *Phalacrocorax carbo*, but as the extent of this habitat is reduced by the outgoing tide it is likely that these birds would move off to a more suitable area. Similarly, fish species which inhabit the inter-tidal open waters would be restricted by the extent of the tide.

Figure 3.3: Location of 'Unconsolidated shore' (in red), and 'Emergent Wetland' (in green) habitat classes of the pre-barrage 'Inter-tidal Estuarine system'. NB. The 'Open Water' habitat has not been illustrated here but at full tide, occupies the entire unconsolidated shore area (in addition to the sub-tidal areas already mentioned).



3.3.2. Post-Barrage Habitats

The post-Barrage habitats of Cardiff Bay can be grouped into three main 'habitat systems' – 'Lacustrine', 'Riverine', and 'Palustrine'. The first of these, the lacustrine habitat system, makes up the vast majority of the current enclosed area of the Bay, ending where the riverine habitats begin (see Section 3.3.3) , and according to Cowardin *et al.* (1979) is defined as follows: *"The Lacustrine System includes* *wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30% area coverage; and (3) total area exceeds 8 ha (20 acres). Similar wetland and deepwater habitats totaling less than 8 ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part of the basin exceeds 2 m (6.6 feet) at low water. Lacustrine waters may be tidal or nontidal, but oceanderived salinity is always less than 0.5 ‰".* Within Cardiff Bay the 'Lacustrine Habitat' can be divided into a further two sub-systems – 'Littoral Lacustrine' and 'Limnetic Lacustrine'.

The 'Riverine' system (see section 3.2.1 for definition), only consists of one sub-system. No longer under tidal influence, this sub-system has been reclassified as 'Lower Perennial'.

The final habitat system, the 'Palustrine' system, contains no 'sub-systems'. This system, currently, includes all of the areas of emergent wetland which were classified as part of the inter-tidal estuarine habitat sub-system prior to Barrage closure. The system *"includes all non-tidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 ‰. It also includes wetlands lacking such vegetation, but with all of the following four characteristics: (1) area less than 8 ha (20 acres); (2) active wave-formed or bedrock shoreline features lacking; (3) water depth in the deepest part of basin less than 2 m at low water; and (4) salinity due to ocean-derived salts less than 0.5 ‰"* (Cowardin *et al.*, 1979).

(i). Lacustrine Habitats

(a). Limnetic Lacustrine Habitats

The Limnetic subsystem is essentially any area within the Lacustrine habitat which is typified by deep open waters (over 2 m), with no emergent vegetation

(Cowardin *et al.*, 1979). Currently (and ever since freshwater impoundment in 2001) this is the Bay's most extensive habitat, covering the vast majority of the whole of the enclosed studied area, and totalling approximately 200 ha in extent.

The Limnetic subsystem can be divided into three main habitat classes – 'Open Water', 'Unconsolidated Bottom' and 'Aquatic Bed'. The first of these classes, would probably fall under the 'Eutrophic Standing Waters' category of the UKBAP's (1999) classification, but to maintain synonymy will be referred to as 'Open Water' throughout the report. In terms of area coverage and sheer volume this habitat class is by far the largest of those currently present. In general terms, 'Open Water' habitats are deemed to have high biodiversity, planktonic algae and zooplankton being abundant in the water column, submerged vegetation is diverse and numerous species of invertebrate and fish are present (UKBAP, 1999). In addition, in the Bay these deeper areas provide open water habitats that are also important feeding areas for diving birds, particularly cormorant *Phalacrocorax carbo*, and great crested grebe *Podiceps cristatus*, which prey upon on the huge numbers of fish inhabiting these areas.

The 'Unconsolidated Bottom' class includes all of the benthic habitats within the limnetic lacustrine system, and is likely to be most important habitat to invertebrates such as chironomid midge larvae, and tubificid worms. These can occur at extremely high densities and provide an important food resource for the numerous fish species inhabiting the open waters.

The 'Aquatic Bed' habitat includes "*wetlands and deepwater habitats dominated by plants that grow principally on or below the surface of the water for most of the growing season in most years. Water regimes include sub-tidal, irregularly exposed, regularly flooded, permanently flooded, intermittently exposed, semi-permanently flooded, and seasonally flooded*" (Cowardin *et al.*, 1979). In Cardiff Bay this habitat consists primarily of areas of floating (e.g. common duckweed *Lemna minor*) and rooted (e.g. Canadian pondweed *Elodea Canadensis)* vascular vegetation, which are often present during the summer months to such an extent that removal becomes necessary to maintain access to boats. This habitat not only provides an important refuge for many invertebrate species but is also an important food resource to a wide variety of organisms, including birds such as coot *Fulica atra*, and mute swan *Cygnus olor*. Both bird species show population increases at times of high aquatic macrophyte abundance, although the accessibility of this food resource in the limnetic sub-system is likely to be restricted due to the depth of the water (although this is of no effect where the vegetation grows tall enough to be near to the surface).

(b). Littoral Lacustrine Habitats

'Littoral Lacustrine' habitats are defined as "*all wetland habitats in the Lacustrine System. Extending from the shoreward boundary of the system to a depth of 2 m (6.6 feet) below low water or to the maximum extent of non-persistent emergents, if these grow at depths of greater than 2 metres*" (Cowardin *et al.*, 1979). Within Cardiff Bay this subsystem forms a border of varying extent (dependent on the steepness of the land/water transition) around the perimeter of the Bay in all areas where a natural transition remains but not where docks and other hard standings exist (because water is generally deeper than 2 m and no gradual transition occurs) (**Fig. 3.3**). The sub-system can be further divided into 'Unconsolidated Shore', 'Unconsolidated Bottom', 'Aquatic Bed' and 'Open Water' habitat classes.

The 'Open Water' habitats, which, as a result of the reduced depth, tend to be more sheltered than the limnetic open waters, form important habitats for a number of aquatic invertebrates, and make particularly valuable fish 'nursery' sites, as can be observed throughout the summer months. It is also within these habitats that many species of wildfowl feed by upending to take both aquatic vegetation and invertebrates.

The 'Aquatic Bed' habitats tend to make up a greater proportion of the total area in the littoral than the limnetic subsystem. This again, is partly because of the increased shelter of the shallower waters but is also a consequence of plants being better able to photosynthesise in shallower areas where light does not have to penetrate so far. This habitat is likely to have similar conservation value to the limnetic aquatic bed habitats, however its more favourable conditions and easier accessibility makes the proportion of organisms utilising this specific habitat likely to be much higher. Within the littoral system this is also likely to be the most important habitat class for fish breeding and the subsequent sheltering of the fry until they move out into deeper waters as their size increases.

The importance of the littoral areas with regards to fish, has been highlighted recently (2004) by the results of a hydro-acoustic fisheries monitoring programme within the Bay, which found that "fish density was significantly higher in the Bay margins than in the Bay centre (Clabburn & Coley, 2004).

(ii). Riverine Habitats

(a). Lower Perennial Riverine Habitats

The 'Lower Perennial habitat sub-system' is defined as an area in which:
"The gradient is low and water velocity is slow. There is no tidal influence, and some water flows throughout the year. The substrate consists mainly of sand and mud. Oxygen deficits may sometimes occur, the fauna is composed mostly of species that reach their maximum abundance in still water, and true planktonic organisms are common. The gradient is lower than that of the Upper Perennial Subsystem and the floodplain is well developed" (Cowardin *et al.*, 1979).

In Cardiff Bay, this habitat is restricted to two locations; the lower portion of the River Taff, and in the lower portion of the River Ely (**Fig. 3.4**). In this present report, the upper limit of the habitat class is defined by that of the study area - that is, up to the 'Clarence River Bridge' on the Taff, and the 'A4232 Grangetown Link Road' on the Ely. Although the exact limits of the lower perennial subsystem is likely to be further upstream, it is difficult to confirm without detailed measurement of the water velocity and gradient. As a whole the upper limit of the 'riverine habitat system' is where the tributary stream or streams originate.

The lower limit of the lower perennial subsystem is much easier to define. It is simply where the rivers enter the lacustrine habitats of the Bay and can be defined by drawing an imaginary line approximating to an extension of the lacustrine shoreline (**Fig. 3.4**). The 'lower perennial' riverine sub-system can be further divided into 'Open Water', 'Aquatic Bed' and 'Unconsolidated Bottom' habitat types (as in the 'limnetic lacustrine' sub-system above), as well as an 'Unconsolidated Shore' habitat type.

Because the marginal areas of the lower perennial riverine habitats are relatively shallow and sheltered, they have proved to be amongst the most attractive habitats to fish within the Cardiff Bay Study area, especially at the point where the rivers enter the Bay itself (Clabburn & Coley, 2004).

Figure 3.4: Location of the post-barrage 'Riverine' (in red) and 'Lacustrine' (in blue) habitat systems. The 'Limnetic Lacustrine' sub-system, which is not illustrated here, would form a boundary around the perimeter of the Bay, in all areas less than 2 m in depth.

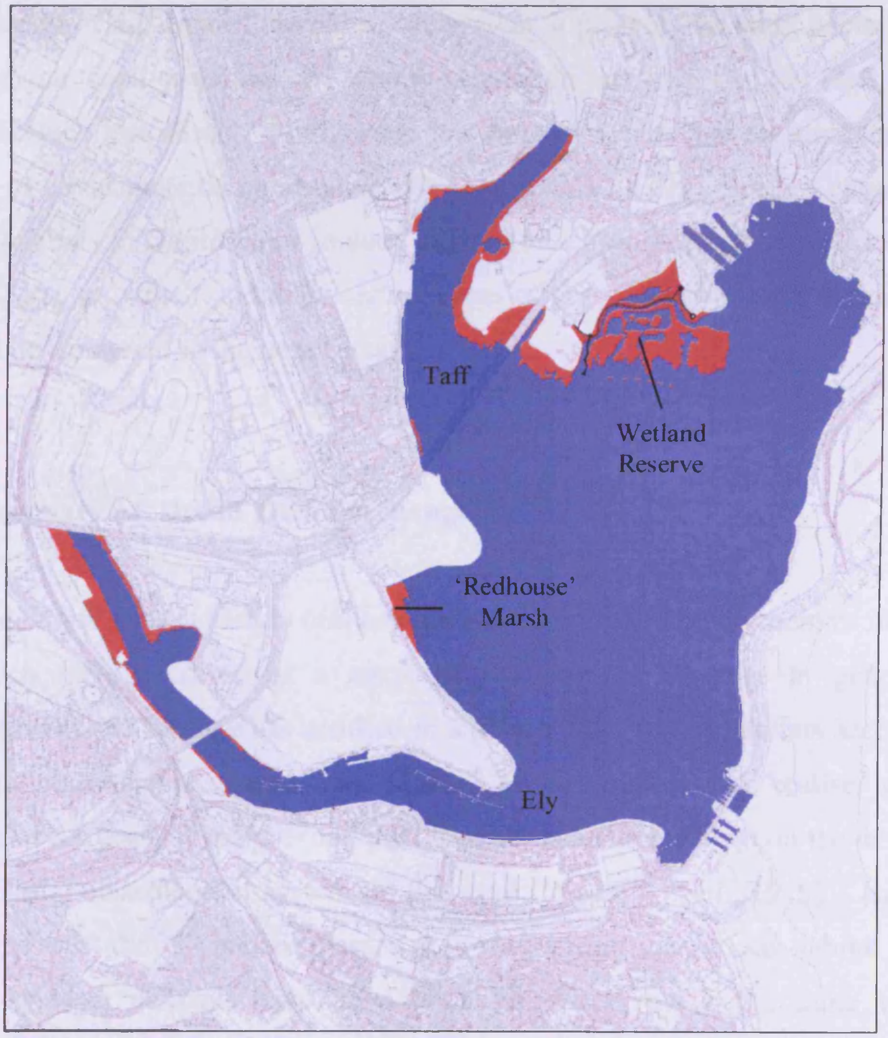
(iii). Palustrine Habitats

Of all the post-Barrage habitat systems present in Cardiff Bay, palustrine habitats are perhaps the most important, because they include a wide variety of habitat classes, which in turn provide food and shelter for a wide diversity of flora and fauna. Palustrine habitats have been defined previously (See **Page 44**). According to this definition, all significant areas of wetland habitats along the foreshore of Cardiff Bay are palustrine – including the few marsh areas (and their associated water bodies) that remain, namely the Cardiff Bay Wetlands Reserve, the small marsh area adjacent to the former 'Red House' pub, as well as all the much smaller areas fringing the Rivers Taff and Ely (**Fig. 3.5**). These habitats are directly comparable with the 'Emergent Wetland' habitats of pre-Barrage times.

A total of 6 main habitat classes are contained within the palustrine system; 'Open Water', 'Unconsolidated Bottom', 'Unconsolidated Shore', 'Aquatic Bed', 'Emergent Wetland' and 'Scrub-Shrub Wetland'. The main 'Open Water' habitats of the palustrine systems in Cardiff Bay are restricted to the Wetland Reserve area (with the exception of a few small channels in some other areas). They consist primarily of a variety of man-made scrapes, reens, ditches and ponds of various depths, with a broad spectrum of nature conservation value. They are important habitats for many invertebrate species, in addition to being important feeding and breeding areas for fish, and important feeding areas for a variety of waders and wildfowl.

'Unconsolidated Bottom' habitat refers to the benthic areas of the 'Open Water' habitats. These, as we would expect, are important habitats for a variety of benthic invertebrates, particularly chironomid larvae, and tubificid worms. The extent of 'Unconsolidated Shore' is very restricted in the post-Barrage habitat. In most areas the transition from land to water is steep and 'Emergent Wetland' tends to be present right up to (and occasionally into) the water. There are, however, a few areas, which have remained vegetation free; as the nominal water level is approximately equal to ground level these areas are frequently flooded. The very few areas of 'Unconsolidated Shore' habitat which do exist have proved to be important habitats to a variety of invertebrates, and hence make an attractive feeding area for wading birds such as snipe, *Gallinago gallinago*; high numbers of this species have been observed using the areas extensively during the winter months during my own surveys.

Figure 3.5: Location of post-Barrage 'Palustrine' habitats as highlighted in red. Note the much smaller areas which are present along the river channels of the Taff and Ely.



The 'Aquatic Bed' habitats are very similar to those already discussed as components of post-Barrage lacustrine and riverine habitats. Species which characterise this habitat class (namely *Elodea* and *Lemna* sp) are likely to have spread into the more recently created palustrine system from the lacustrine and riverine systems. This is a hypothesis that is supported by the fact that the initial occurrence of the 'Aquatic Bed' class was restricted to areas which were freely connected to the 'open Waters' of the Bay.

The final two habitat classes, 'Emergent Wetland' and 'Scrub-shrub Wetland' are considered in greater detail in the next section. It is, however, the presence of these two classes in particular that define the palustrine system. The former makes up the vast majority of the area of the palustrine system at present; the latter habitat class is defined as an "area dominated by woody vegetation less than 6 m (20 feet) tall. The species include true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions" (Cowardin *et al.*, 1979). Species characteristic of such habitats in Cardiff Bay include alder, *Alnus glutinosa*, and to a lesser extent willow, *Salix sp*, which dominate certain areas of the wetland reserve at present and thus will be discussed in the next section.

3.3.3. Summary of 'Broad Habitat' change

The previous section clearly outlines the major 'Broad Habitat' changes in Cardiff Bay which have occurred as a result of the Barrage Closure. In general, the construction of the Barrage has resulted in a greater diversity of habitats according to the habitat classification system used (**Tab. 3.2**). It is important to realise, however, that the classification of the pre- and post-Barrage habitats is reliant on the definitions of a particular classification system (in this case Cowardin *et al.*, 1979) – and hence we have to trust that all habitat classes occurring within the various habitat systems and sub-systems defined, have been classified fairly, using the same types of parameters. One possible failure of the system in classifying the present data can be seen with the palustrine system of the post-barrage period, which, in the pre-barrage period, is only represented by a habitat class (emergent wetland) rather than a whole system.

Table 3.2: Summary of Pre- and Post-Barrage Habitats.

Pre-Barrage Habitats	Post-Barrage Habitats
1. Estuarine inter-tidal open water	1. Lacustrine limnetic open water
2. Estuarine inter-tidal unconsolidated bottom	2. Lacustrine limnetic unconsolidated bottom
3. Estuarine inter-tidal unconsolidated shore	3. Lacustrine limnetic aquatic bed
4. Estuarine inter-tidal emergent wetland	4. Lacustrine littoral open water
5. Estuarine sub-tidal open water	5. Lacustrine littoral unconsolidated bottom
6. Estuarine sub-tidal unconsolidated Bottom	6. Lacustrine littoral unconsolidated shore
	7. Lacustrine littoral aquatic bed
	8. Lower-perennial riverine open water
	9. Lower-perennial riverine unconsolidated bottom
	10. Lower-perennial riverine unconsolidated shore
	11. Palustrine open water
	12. Palustrine unconsolidated bottom
	13. Palustrine unconsolidated shore
	14. Palustrine emergent wetland
	15. Palustrine aquatic bed
	16. Palustrine scrub-shrub wetland

3.3.4. Change in Extent of 'Marsh' Habitats in Cardiff Bay (1885-2005)

Analysis of marsh habitat extent using historical maps of Cardiff Bay revealed the significant changes which have occurred since 1885 as a result of both natural and anthropogenic actions. The changes are summarised graphically in **Fig. 3.6** and are illustrated in the 8 maps prepared using 'Mapmaker Pro' **(Fig. 3.7)**. The two aerial photographs of the area adjacent to 'Windsor Esplanade' **(Fig. 3.8)** reveal just how much the extent marsh changed in this area alone, with none present in the photograph taken during 1947. In the earliest records examined here, the majority of marsh area was concentrated on the river Ely – consisting of the significant 'saltings' of the Penarth moors. Obviously, being an estuarine environment these habitats were typical of various types of saltmarsh, though the communities present are unknown due to lack of historical records. There is a general decline in the extent of all marsh areas between 1885 and 1947 - primarily due to a steady rate of reclamation of the habitat in the Taff Estuary. The subsequent sharp increase in the extent of total marsh habitat was primarily due to the success of the invasive species, *Spartina anglica,* in the area adjacent to Windsor Esplanade. At the same time vast amounts of marsh from the former Penarth Moors were reclaimed, and the River Ely itself was diverted in the early 1970s – a process which further reduced the extent of marsh because new river banks with flood defence in mind featured boulders and thus were largely unsuitable for growth of vegetation.

Figure 3.6: Changes in 'marsh' extent in Cardiff Bay (1885-2005).

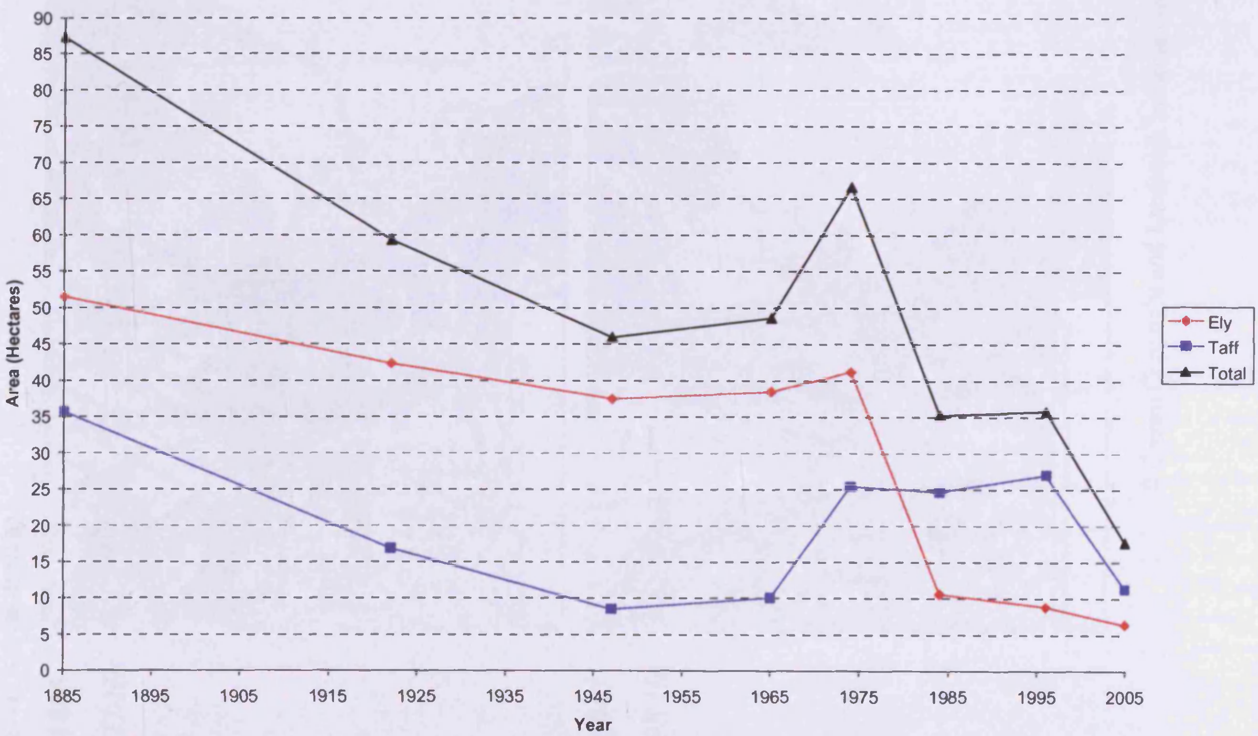
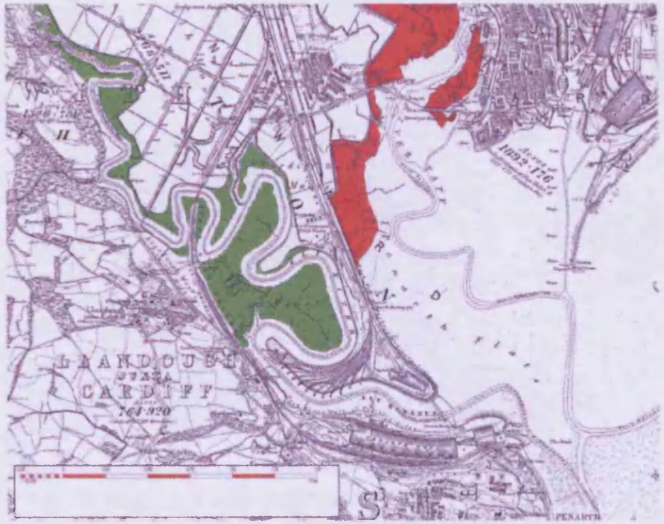


Figure 3.7: Changes in the extent of 'marsh' habitat in Cardiff Bay in; *A) 1885; B) 1922; C) 1947; D) 1965; E) 1974; F) 1984; G) 1996; F) 2005*. Red coloration indicates marsh of the Taff Estuary, Green indicates marsh of the Ely Estuary. Total marsh area is given for each map.

A) 1885

87.27 Ha

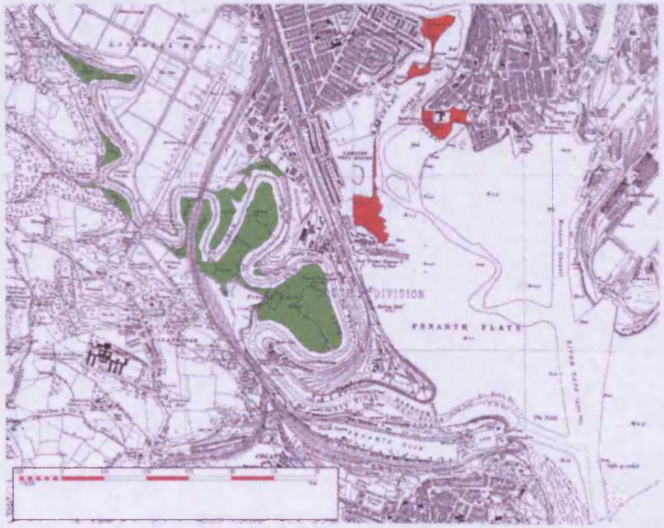


B) 1922

59.32 Ha

C) 1947

45.98 Ha



D) 1965

48.59 Ha

E) 1974

66.66 Ha

F) 1984

35.25 Ha

G) 1996

35.81 Ha

H) 2005

17.69 Ha

Figure 3.8: Aerial photographs of the area adjacent to Windsor Esplanade from A) 1947; and B) 2005. Notice the lack of much marsh habitat in the earlier photograph.

A)

Image from Cities Revealed® aerial photography, © The GeoInformation Group, 2001.

B)

© Cardiff County Council, 2005.

The effects upon the Bay's habitats, of the closure of the Barrage in 1999, have been discussed previously, and the extent of change instigated by the development is obvious from the preceding figures. Most notably, large amounts of the marsh, particularly at Windsor Esplanade, were permanently submerged due to the higher average water levels. Furthermore, development of the remaining habitats by the creation of various scrapes and other water features, as well as further reclamation (i.e. at the site of the Cardiff Yacht Club) has further reduced the extent of marsh habitat to the current total of around 17.69 ha – some 69.58 ha less than in 1885. Thus the extent of marsh habitats present in Cardiff Bay today, is far lower than at any point in the recorded history available.

Previous measurements undertaken by Smith (1979), Dent (1987), Ferns (1988) and Way (1988) have all focussed upon the extent of saltmarsh habitat in the Taff Estuary alone. The values derived from these past studies are compared to those obtained from the current study in **Tab. 3.3.**

It is worth remembering when comparing the values from the present study with those collected previously, that the present study uses very different methodology that is dependent on the accuracy of, and the ease of interpretation of the original maps used.

Previous studies have all used aerial photographs as base images to trace the extent of marsh, and thus are subject to their own errors in interpretation, thus the accuracy of all measurements should be treated with a degree of caution. It is obvious however, that the majority of measurements are comparable for the relevant time periods.

Table 3.3: Comparison of current derived measurements of marsh area with existing data from Way (1988), Dent (1987), Ferns (1988), Smith (1979).

Year	Estimated Marsh Area (Ha)				
	Current Study	Way (1988)	Dent (1987)	Ferns (1988)	Smith (1979)
1885	35.71	-	-	-	-
1922	16.9	-	-	-	-
1947	8.5	-	-	-	-
1948	-	-	5.7	-	-
1960	-	-	15.5	-	-
1962	-	-	-	20	-
1965	10.07	-	-	-	-
1971	-	23.6	25	26	-
1974	25.45	-	-	-	-
1977/1978	-	-	-	-	29.4
1981	-	23	22.7	23	-
1984	24.66	-	-	-	-
1987	-	23.1	24.7	-	-
1996	27.02	-	-	-	-
2005	11.28	-	-	-	-

3.4. Conclusions

Cardiff Bay has undergone a series of both anthropogenic and natural changes that have resulted in the habitats which exist at present. With regards to the broad habitats of Cardiff Bay, there have been two major changes which have influenced the types of habitat present today – both of which are related to the hydrology of the area. The first of these, being the most obvious, was the change from brackish/saline waters to freshwater. The second, having an equally strong effect on the whole ecology of the area, was the cessation of tidal conditions, and the presence of a relatively stable water level.

At first sight, we may expect these changes to result in a reduction in the number of habitat types, though, the results presented in this report prove the opposite – although some caution has to be taken in interpreting this outcome, particularly because the number of habitats classified depends entirely on the accuracy of the classification system as already discussed. When we consider the precise definition of a 'Habitat' it may become clearer as to why more habitats may be available in the post-Barrage environment. Many such definitions exist, however, the U.S Environmental Protection Agency defines a habitat clearly as; *"a place where the physical and biological elements of ecosystems provide a suitable environment including the food, cover, and space resources needed for plant and animal livelihood"* (E.P.A, 2005).

It is well known that the estuarine environment is a harsh one, and, as a result, all estuaries are characterised by having abundant populations of organisms (high productivity), but with relatively few species (low biodiversity) present (McLusky, 1981) – not least because of the problems of adapting to the continually fluctuating salinity, but also due to a whole host of other problems which face estuarine dwellers including fluctuating temperature, sediment loads, and the hydrological regime itself. Hence, if an estuary has low biodiversity, and a habitat is defined by the species which can inhabit it, it is of no real surprise that the much less harsh freshwater environment can contain many more habitats (as many more organisms are able to inhabit it).

In addition, it is likely that the post-Barrage environment will further diversify over time, to provide further habitats for a larger number of organisms. It is important to remember that all the habitats in the Bay at present are in a relatively early stage of succession, with only six years of development at the most, and it may be some time before the patterns of high productivity of relatively few species (for instance chironomid midge inhabiting the 'Unconsolidated Bottom' habitats at present), give way to much more diverse ecosystem.

The marsh habitats of Cardiff Bay (examined in section **3.3.4**) have suffered a drastic reduction in extent over the last 120 or so years. However, the marsh habitats present in Cardiff Bay now, are likely to be far more diverse, in terms of both species and structure, than those which occurred prior to the closure of the barrage.

In addition the marsh habitats are also likely to be less contaminated now, due to significant improvements in the levels of pollutants as a result of the reduction in industry in the area, and the stricter legislation on discharges of all types into the Taff and Ely, some of which came about as a result of the barrage scheme itself.

Whether the habitat change in Cardiff Bay has significantly affected the communities of the inhabiting macrophytes, aquatic macroinvertebrates and birds, will form the basis for the remainder of this thesis.

4. Macrophyte Ecology of Cardiff Bay

4.1 Introduction

4.1.1. General

Macrophytes, commonly defined as any plants that are readily identified with the naked eye, are perhaps the most important component of any wetland ecosystem - often helping define wetland habitat types (e.g. on the basis of species composition and growth forms present), and also playing a key role in many of the important ecological services that are provided by these ecosystems (as outlined in the introductory section). For instance, it is the macrophyte vegetation which considerably slows flood waters, and subsequently returns significant quantities of water to the atmosphere via evapotranspiration, and is therefore important in the flood attenuation value of wetlands. Similarly, the roots of macrophytes can provide a valuable defence against bank erosion by stabilizing the soil – and therefore have an important role in coastal protection (e.g. on saltmarshes) - approximately 50 per cent of wave energy can be dissipated within the first 2.5 m of a marsh, and virtually all of this destructive energy is absorbed within 30 m (Knutson, 1978).

In an analogous manner, the sediment deposition known to occur in wetlands, is most noticeable in areas where water moves most slowly – and this is predominantly in vegetated areas of marshland. Man has taken advantage of this process in some areas by the deliberate introduction of Spartina grasses which accelerate the process of marsh accretion. For example, Common Cordgrass *Spartina anglica* was introduced to Strangford Lough in Northern Ireland during the 1940s to increase sediment accretion in coastal protection schemes (Bleakly, 1979 as cited in Hammond *et al.*, 2002).

It is the vegetation of wetlands that is also responsible for many of the chemical services for which wetlands are exploited. A good example is the role of plants in the removal of various pollutants from the aquatic habitats – perhaps the best known plant with regards to this process is Common Reed *Phragmites australis* which is used extensively for its ability to remove excess nutrients, as well as toxic residues (heavy metals, pesticides, herbicides etc.) from water, in a process commonly known as biofiltration.

Most importantly, however, macrophytes are the reason for the extremely high productivity of many wetland ecosystems. Many wetland macrophytes are perennial and have a high leaf to stem ratio, and as such, constantly and efficiently convert solar energy to fix carbon and create the huge levels of biomass typical of such ecosystems (Williams, 1993) – thus supporting a diversity of species in turn. Because of their important role at the very base of food chains, and because of their role in the structuring of habitats (which will be covered in the subsequent section), macrophytes are critical in any review of the ecological changes which have occurred in Cardiff Bay.

4.1.2. The Importance of Macrophytic Vegetation to Waterfowl

The macrophytes of Cardiff Bay are important in attracting a diverse community of wetland bird species. They constitute a valuable resource to birds in a number of ways. Perhaps most obvious is the importance of plants as a direct source of nutrition – providing a readily available source of fruit, seeds, stems and leaves which are eaten by a wide variety of species. Macrophytes also provide the food resources for a range of invertebrate species that are in turn important in the diet of wetland birds. Macrophytes also provide materials for nest building and nest platform construction, sites in which to locate nests, sites with defensive cover from predators, and even as perches for singing and other territorial displays.

As mentioned in the previous section, macrophytes also play an important role in the structuring of habitats - a subject which has been briefly outlined in the previous chapter. Particularly important, in relation to its effect on wetland bird usage, is the vertical structure of the vegetation present, with such variables as plant height, number of vegetation layers, foliage volume, and leaf form affecting habitat choice (Macarthur & Wilson, 1967 as cited in Weller, 2004). The horizontal diversity or patchiness of vegetated habitats has also been shown to have a significant effect upon bird diversity. For example, Roth (1976) found that bird species diversity increased faster than the degree of species overlap in a series of increasingly complex habitats from grasslands to forests.

4.1.3. The effects of transition from a brackish to a freshwater environment on macrophyte vegetation

The effects of desalination on vegetated habitats (particularly on areas of saltmarsh) have only been studied and documented on a very few occasions and the results are limited in that much of the research has focused on the effects of a few major developments. Perhaps the most well known of these developments occurred in an area known as the Ijsselmeer (translated as Lake Ijssel), located in the north-west of the Netherlands. This lake was created in 1932 by the enclosure of the Zuiderzee (Zuider Sea), and is now essentially a shallow lake some 1,217 km^2 in area that has been entirely fresh water since 1944. Numerous research projects were set up to look at the effects of the closing of the Zuiderzee on the surrounding landscapes and habitats. The most notable of these studies were long-term projects involving permanent plot vegetation research resulting in over 30 years of data outlining the transition of halophytic to glycophytic vegetation (Kruseman & Vlieger, 1940a; Kruseman & Vlieger, 1940b; Westhoff, 1969; Westhoff & Sykora, 1979, all as cited in Smits *et al.*, 2002). More recently, similar studies into the succession of former saltmarshes in parts of Meldorf Bay, Germany (an area which was partly diked in 1978) have also been undertaken (FTZ Westcoast, 2005).

In both of these study areas, research has documented a relatively rapid colonisation by many freshwater species after the change from estuarine/marine environments; they have also noted the survival of several halophytic species for relatively long periods of time (over 30 years in the case of the Ijsselmeer (EAU, 1991)). Westhoff & Sykora (1979, as cited in Smits *et al.*, 2002), in a Dutch study, also noted the effect of disturbance via grazing and mowing on the rate of desalination, and found that, the disappearance of the halophytic communities dominated by sea aster *Aster tripolium* occurred far more rapidly in an unmanaged experimental plot than in a continually managed area.

4.2. Methods

4.2.1. Data Collection

(i). *Historical Data Collection*

A number of detailed surveys of the vegetated saltmarsh habitats within the confines of Cardiff Bay have been undertaken at various times throughout its development. The first detailed survey available was that undertaken by P.F. Randerson in 1979, as part of a survey of the saltmarshes of the Severn Estuary on behalf of the Nature Conservancy Council (Smith, 1979). Various other surveys were undertaken between this assessment, and the closure of the Barrage in 1999, (for example Kalejta, 1984; and WAS, 1998). These surveys focused on the primary area of saltmarsh in Cardiff Bay, namely the Windsor Esplanade Saltmarsh, located on the Eastern side of the Taff mouth (now known as Cardiff Bay Wetland Reserve). Using these surveys data were collated and literature reviewed, in order to outline the changes in extent of the vegetated habitats and the species composition of their macrophyte communities. Where relevant, classification of the communities was undertaken with the use of the 'Modular Analysis of Vegetation Information System' (MAVIS), a computer program which automatically classifies vegetation groups according to the National Vegetation Classification (NVC; Rodwell, 1991a, 1991b, 1992, 1995, 2000). MAVIS computes matching coefficients between the published synoptic tables, and the new field data using the 'Czekanowski coefficient' (Smart, 2000).

While the aforementioned surveys provided information on pre-Barrage aspects, it must be realised that this current project did not begin until three and a half years after the initial barrage closure in November 1999. This is almost two years after the Bay was impounded with fresh water (April 2001). To explore and assess the changes that occurred when the habitats of Cardiff Bay were initially subjected to the new freshwater regime it was therefore necessary to collect background information from mainly personal communication with ecologists that had been involved with the development of the area from its onset. Although from reliable sources, the details of these observations are however limited and simply serve to provide an insight into the major changes that occurred during the period. Fortunately, a post-Barrage habitat survey of the Wetland Reserve, which mapped the major vegetation types and major species present in a walkover survey undertaken by the Cardiff Naturalists Society (on behalf of Cardiff Harbour Authority) in June and July of 2001 - just after freshwater impoundment was available for study (Cardiff Naturalists' Society, 2001; Highways & Parks, 2003).

(ii). *Field Data Collection (May 2003-May 2006)*

The present project has, since May 2003, involved carrying out more detailed surveys of the habitat types and in particular the vegetation types, including their distributions and extents. Initially, in the summer of 2003, the major areas of marginal macrophyte vegetation were mapped approximately whilst walking the entire foreshore of Cardiff Bay. For the purpose of presentation and analysis, maps were drawn using the mapping software 'Map Maker Pro'. Additionally, the major species dominating various areas were recorded for five major areas of the Bay (i.e. separate lists were compiled for the 'Cardiff Bay Wetland Reserve'; the 'River Taff'; the 'River Ely'; the 'Redhouse Marsh/Prospect Place'; and the 'Associated British Ports (ABP) land/Barrage')) as illustrated in **Fig. 4.1**. The primary aims of this initial survey were simply to provide an insight into likely important habitats (for birds in particular), and also to provide some indication of the variation in vegetation type and therefore community composition within the Cardiff Bay study area. Additional 'dominant' species were added to the whole bay species lists as and when they were observed during subsequent visits to the respective areas.

To identify exact species composition, and community types, a second phase of more detailed surveys was started. Time constraints made it impossible to conduct such surveys throughout the whole Bay; it was therefore decided that survey work would be undertaken in what has been identified as the most important and extensive area of vegetated habitat within Cardiff Bay - the Cardiff Bay Wetland Reserve (**Fig. 4.1**). This site was chosen on the basis of its ease of access, its obvious environmental gradient (from former sea wall to marsh edge), and also its conservation value which makes it one of the obvious core areas for research into the successional changes that have occurred post-Barrage (particularly with regards to its value as a habitat and food resource for birds).

Although a number of different survey methods were considered, because of the obvious environmental gradient from dry land to open freshwater it was decided that plots should be taken along fixed transects. This method allows the same linear area of land to be sampled over a period of time thus giving an insight into changes occurring in any particular plot. Samples were taken using 2 m^2 quadrats constructed using three garden canes, each measuring 2 m in length (using a 2 m length of a 30 m surveyor's tape measure as the fourth side). Two transects were marked out; each running approximately north to south from the old sea wall to the farthest edge of the reserve **(See Figs. 4.2, 4.3 and 4.4)**, one of 184 m in length ('Transect 1' – **Fig. 4.3**), and the other of 272 m ('Transect 2' – **Fig. 4.4**). The precise coordinates for the start and end of each transects are as follows:

Transect	**Start Location**		**End Location**	
	Easting	***Northing***	***Easting***	***Northing***
Transect 1	318767.6	174172.6	318759.7	173982.7
Transect 2	318854.8	174213.8	318928.2	173954.3

The exact location of each of the two transects was chosen after considering various orientations aimed at covering the maximum number of different habitat types, whilst continuing to follow the environmental gradient. Although the two are obviously linked the landform is not completely natural and therefore other factors had to be taken into consideration, for example, the inclusion of at least one of the areas of recently created (Autumn 2003) high level ground (which were reduced back to bare soil during their creation, and therefore represented early-stage succession) and the avoidance of deep channels (which made access difficult). In an attempt at permanently marking the locations of each transect short lengths of garden cane (c. 50 cm) were pushed into the ground at 10 m intervals and flagged with red tape to improve visibility. These also provided convenient anchor points for the tape measure in subsequent surveys. Quadrats were positioned on the marked out transect, starting at the sea wall (0 m), always aligning the quadrat on the right hand side of the tape measure, which together with the precise coordinates above, enabled precise relocation of the quadrats in subsequent surveys (**Fig. 4.5**).

To gain a quantitative measure of the abundance of species present, the Domin Scale (**Tab. 4.1**) was utilised to simplify the recording process. In this approach, the cover is assessed by eye as a vertical projection on to the ground (i.e. each species is viewed as if it were a flat image viewed from above) of all the live, above-ground plant parts inside the quadrat (Dahl & Hadac, as cited in Rodwell, 1995). The visualisation method used here, sometimes results in the total percentage cover far exceeding the expected 100 % maximum, simply because several different layers of vegetation may exist.

Figure 4.1: Areas surveyed during a preliminary walkover marginal macrophyte survey of Cardiff Bay during the summer of 2003.

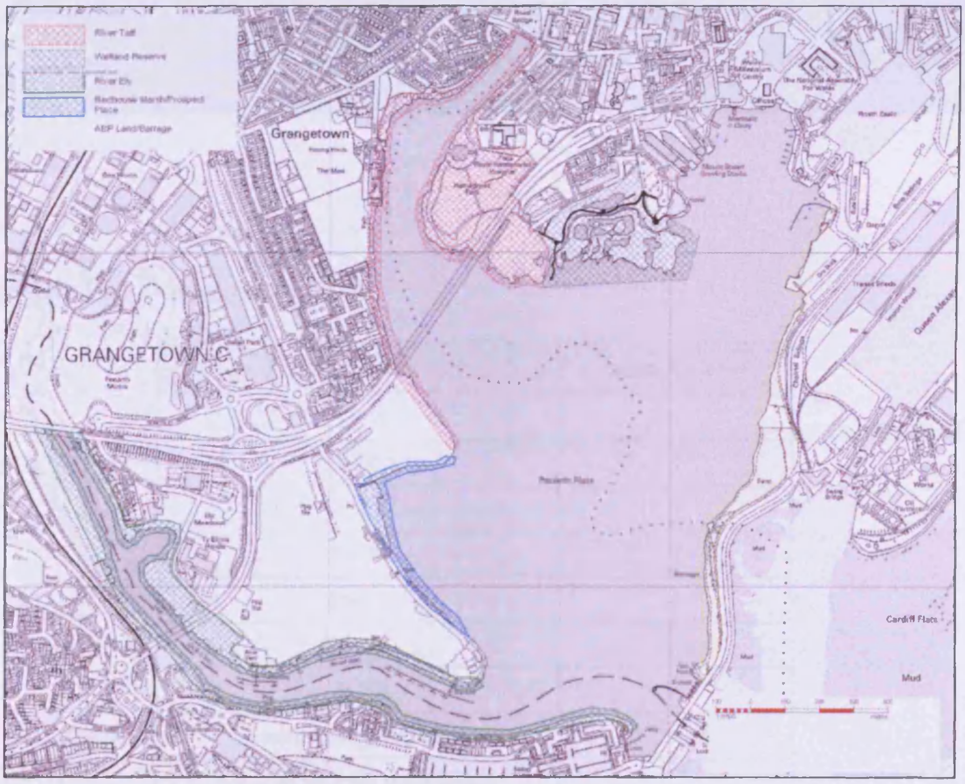


Figure 4.2: Approximate location of transects used for detailed macrophyte surveys of Cardiff Bay Wetland Reserve. The extent of Common Reed *Phragmites australis* is shown in red.

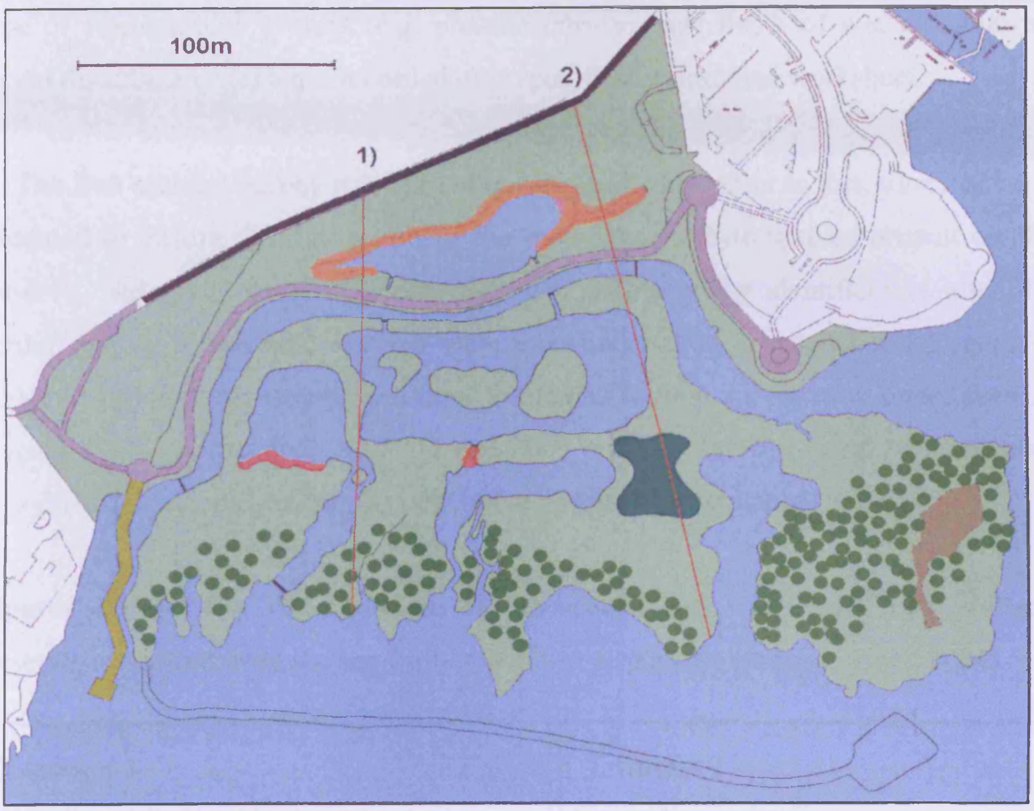


Table 4.1: The Domin Scale

% Cover	Domin Value
91-100	*10*
76-90	*9*
51-75	*8*
34-50	*7*
26-33	*6*
11-25	*5*
4-10	*4*
<4 with many individuals	*3*
<4 with several individuals	*2*
<4 with few individuals	*1*

Quadrat location (meters from the sea wall) the species name along with its Domin value, the maximum height for that species (except the April 2004 survey), the total percentage cover, and any notes about factors which may have affected the type of communities present (e.g. presence/absence and depth of water, landform, recent disturbance etc) were recorded on a specifically-designed worksheet.

The first transect survey was carried out in April 2004. Prior to this, time had been allocated to ensure familiarization of the major macrophyte species present on the Reserve, and also allow sufficient re-growth of plants for identification after the winter period. Subsequent surveys were then undertaken in August and December 2004, in order to investigate seasonal variation. A final survey was undertaken in August 2005 in order that the 2004 and 2005 summer surveys could be compared, thus providing an insight into the vegetative change over an annual period.

Figures 4.3 and **4.4:** The Locations of Transects 1 and 2 at Cardiff Bay Wetland Reserve, as viewed from the sea wall at Windsor Esplanade (taken in April 2004).

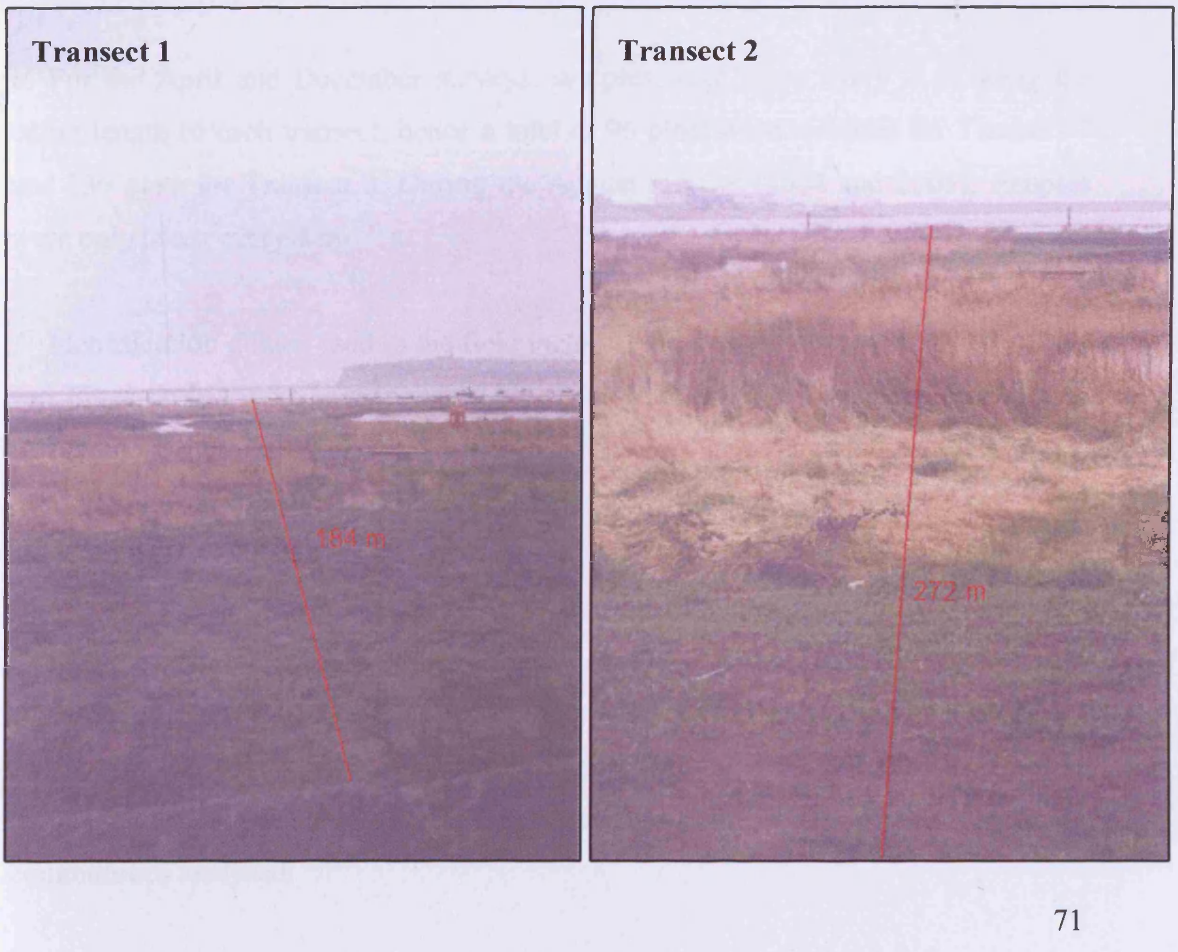


Figure 4.5: Quadrat alignment on vegetation transects (as marked out by the tape measure and canes).

For the April and December surveys, samples were taken every 2 m along the entire length of each transect, hence a total of 96 plots were recorded for Transect 1 and 136 plots for Transect 2. During the August surveys (2004 and 2005), samples were only taken every 4 m.

Identification guides used in the field included Fitter & Fitter (1984), Stace (1999) and Fitter (2003), with nomenclature based on Stace (1999). Together these proved sufficient for the identification of the majority of species whilst in the field; occasionally more difficult taxa (particularly where flowers were absent) had to be photographed and identified later.

Later in the study, spot height maps of the Wetland Reserve, along with construction plans, were used to collate approximate land height measurements for each of the quadrat samples. This allowed investigation of the effect of land height (above the nominal water level of the Bay - 4.5 m AOD) on the vegetation communities analysed.

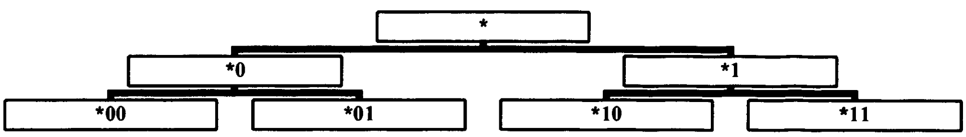
4.2.2. Data Analysis

(i). *General*

All raw data arising from the eight transect surveys were initially entered into Microsoft Excel Spreadsheets, in order to aid intial data manipulation and analysis. Because the total numbers of quadrats sampled in April and December 2004, and August 2004 and August 2005 were different, only the data from every 4 m (i.e. 0-2 m, 4-6 m etc) along each transect were used for comparison of each individual transect with surveys undertaken at different times. Using these data, the transects were analysed by comparing the frequency of occurrence of plant species for each transect on each sampling occasion – this being simply the number of quadrats in which a species was recorded (within each transect) expressed as a percentage.

(ii). *Community Classification*

As well as graphical analysis, the species abundance data from August 2004 and 2005 were also examined with the use of TWINSPAN (**T**wo-way **I**ndicator **S**pecies **An**alysis). This program constructs an ordered two-way table by first classifying samples (samples = quadrats in this case) according to their similarity, and then using this classification to obtain a classification of the species according to their ecological preferences – a method best described as "dichotomized ordination analysis" (Hill, 1979). Only the data from the August transects were included in this particular analysis; deemed the most suitable and reliable set of results on the basis of timing of data collection (i.e. during the summer 'flowering season' when most species could be accurately identified). In order to obtain the classifications, a series of divisions are made successively by the software (the number of which is user defined), each time dividing the new 'group' into two further groups. These groups or TWINSPAN classes, which are represented by a decimal and binary number, are divided as follows:



Because of the complicated format of the TWINSPAN output, data were presented in a simplified table based upon Odland (1997). The species occurrences and abundances (SOA) in the different TWINSPAN classes were calculated according to a formula by Odland (1997), which uses the cover abundance values, and number of occurrences of a species in a specific site class, to give a value of importance, on a 0-100 scale. This formula, which has been modified to suit the data analysed in this report, is as followed:

$$\text{SOA} = \frac{\sum Yij}{7n} \times 100$$

Where y_{ij} is the cover value (cut-level) of species '*i*' in quadrat '*j*', and '*n*' is the number of quadrats in the site class. In this illustrative case a species which occurs at the arbitrary level of 7 in all quadrats within a particular site class will receive an SOA value of 100 whereas a species which occurs at lower arbitrary levels in all quadrats will receive a lower SOA, and so on. The value 7 relates to the maximum number of cut levels utilised in the analysis. The cut levels used in this analysis are illustrated as follows (**Table 4.2**) – note that the low Domin Values (1, 2, and 3) and high values (9 and 10) have been combined in order to down-weight the influence of less common and dominant species.

Table 4.2: Cut levels used in Twinspan analysis and their relevance

Arbitrary Value*	Cut Level	Domin Value	% Cover
1	0	1,2 & 3	0-4
2	4	4	4-10
3	5	5	11-25
4	6	6	26-33
5	7	7	34-50
6	8	8	51-75
7	9	9 & 10	76-100

* As used in TWINSPAN output

Additionally, the 'Twinspan' program was set to make a maximum of five divisions (although level 4 was chosen for analysis here), with the minimum group size for division being 3. The maximum number of indicator species per division was set to 7.

4.3 Results

4.3.1. Pre-study (Historical) Macrophyte Ecology of Cardiff Bay

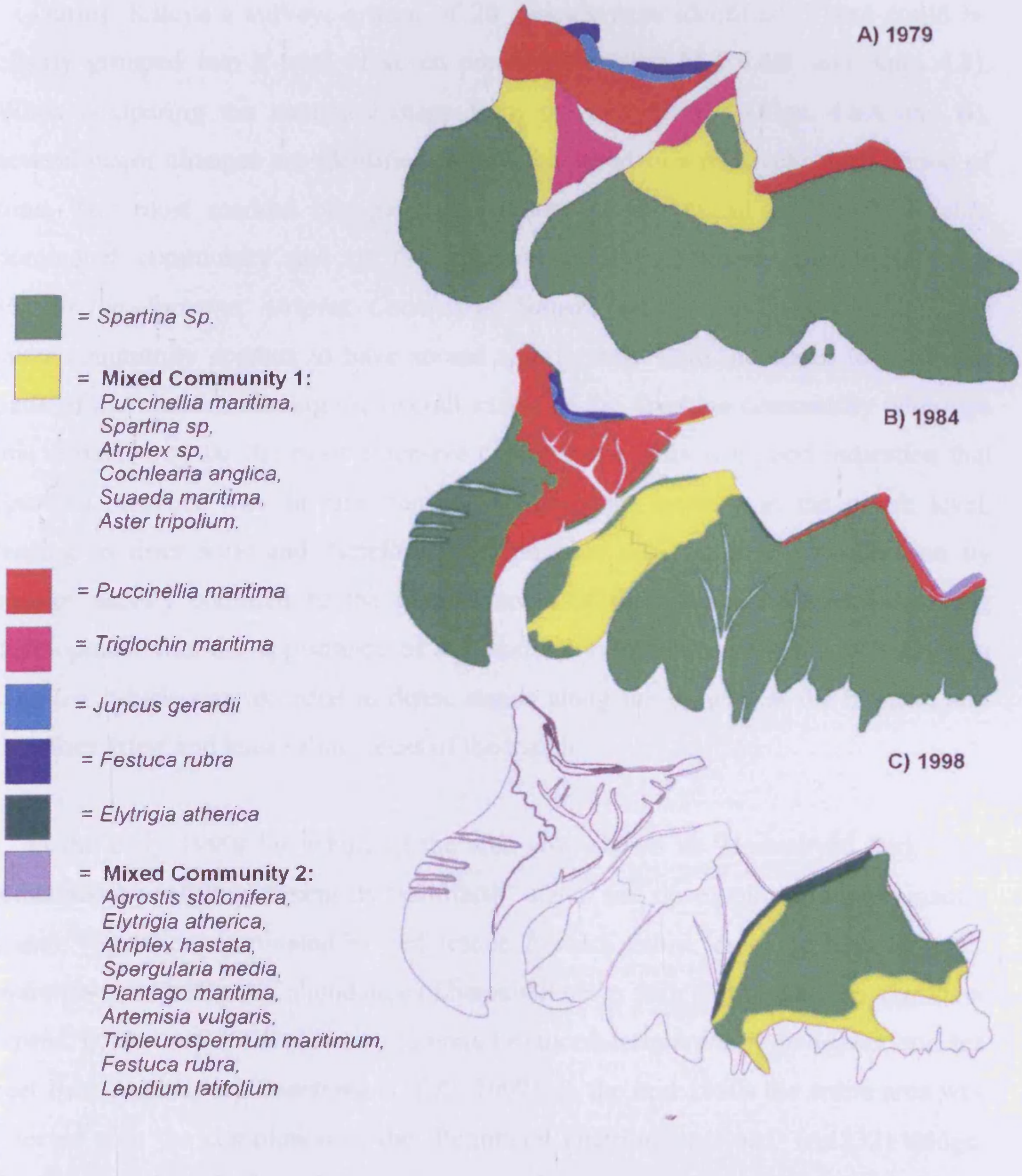
(i). Pre-Barrage Macrophyte Ecology (1979-1999)

The development of Cardiff Bay is a relatively recent occurrence, and the same is true of the 'Emergent Wetland' habitats within. These were classified as saltmarsh habitats before barrage construction. Ferns (1987) noted that the Windsor Esplanade saltmarsh, which was to become the most substantial area of such habitat in more recent times, was not present to any degree only 124 years ago (as illustrated in an Ordnance Survey Map of 1881).

The deliberate introduction of *Spartina anglica* into the Severn Estuary, and its subsequent spread into Cardiff Bay some time in the 1930s or 1940s (Dent, 1987; Ferns, 1987) caused a much more rapid expansion in the extent of all the emergent wetland habitats in Cardiff Bay. By the 1960s it was the dominant species in all saltmarsh areas (Ferns, 1987). This is of no real surprise, as it was because of the stabilising properties of *S. anglica* that the species was introduced into areas such as the Severn Estuary; with the aim of preventing bank erosion and to aid in land reclamation (Rodwell, 2000). *Spartina anglica* has been introduced throughout the world for this purpose, and according to the Global Invasive Species Database, is now classified as one of the of the worlds' worst invasive alien species (ISSG, 2005).

By 1979, when P.F. Randerson surveyed the area (Smith, 1979), the overall dominance of *Spartina* had decreased significantly, and six distinct community types could be identified, with a total of 14 different halophytic species (see **App. 4.1** and **Fig. 4.6a**). At this time *Spartina* communities were still the most prevalent, however, new communities dominated by *Puccinellia maritima* and *Triglochin maritima,* had begun to colonise the area. A mixed community with *Spartina anglica, Atriplex sp, Cochlearia anglica, Suaeda maritima* and *Aster tripolium* as co-dominants also made up an area of significant extent and, together with the *Spartina* community was estimated to cover approximately 87% of the entire area (Smith, 1979; Ferns, 1987). Comparatively small areas of *Festuca rubra*, and *Juncus gerardii* existed at the most northerly point of the marsh in the area now known as 'Hamadryad Park' (Smith, 1979).

Figure 4.6: Changes in the extent of various plant communities on the Windsor Esplanade /Hamadryad Salt-marsh area as identified by their dominant species. Maps shown are in ascending order with data from A) Randerson's 1979 survey (Smith, 1979); B) Kalejta's 1983/84 survey (Kalejta, 1984), and C) Wetland Advisory Service's 1998 survey (WAS, 1998).



A significant amount of erosion of the southern edge of the Windsor Esplanade area of the saltmarsh, which resulted in a reduction in the extent of the area, occurred some time between 1981 and 1987 (Way, 1988). During this period the next detailed macrophyte survey was undertaken (Kalejta, 1984); some 5 years after P.F Randerson's data were collected.

During Kalejta's survey, a total of 26 species were identified. These could be clearly grouped into a total of seven communities (see **Fig. 4.6B**. and **App. 4.2**). When comparing the summary maps from the two surveys (**Figs. 4.6A** and **B**), several major changes are identified to have occurred in a relatively short period of time. The most marked changes can be seen in the extent of the *Puccinellia* dominated community and of the appearance of the mixed community (with *Puccinellia, Spartina, Atriplex, Cochlearia, Suaeda* and *Aster* as co-dominants). This latter community appears to have spread significantly from the upper to the lower parts of the marsh, reducing the overall extent of the *Spartina* community (although this remained by far the most extensive community). This is a good indication that *Spartina* presence was, in fact, causing a significant increase in the marsh level, leading to drier soils and therefore more suitable conditions for colonisation by species usually confined to the highest areas of the marsh. Another interesting development was the appearance of a strandline community of sea couch *Elytigia atherica,* which was recorded in dense stands along the seawall at the highest, and therefore driest and least saline, areas of the marsh.

In the early 1990s the whole of the area now known as 'Hamadryad Park' was reclaimed by infilling, losing its 'saltmarsh' status and developing a predominantly grassy vegetation dominated by red fescue *Festuca rubra*, creeping bent *Agrostis stolonifera,* as well as an abundance of herbs/tall herbs such as white clover *Trifolium repens*, golden melilot *Melilotus altissima*, bristly ox-tongue *Picris echioides*, and sea beet *Beta vulgaris* ssp. *maritima* (L.E.C, 1997). In the mid 1990s the entire area was bisected with the completion of the 'Peripheral Distribution Road' (A4232) bridge. By the time of the final pre-Barrage survey in September 1998 - just over a year prior to the closure of the Barrage in November 1999 (and just over 2.5 years prior to the official freshwater impoundment), the extent of emergent wetland vegetation in the area had been vastly reduced (as illustrated in **Fig. 4.6C.**) This final pre-Barrage survey, which was undertaken by the Wetland Advisory Service on behalf of the Cardiff Bay Development Corporation (WAS, 1998), identified a total of 20 species on the reserve, and divided these into four main communities: 'Edge', 'Middle', 'Mud' and 'Top' (see **App. 4.3**). The 'Edge' community located along the southernmost shoreline of the marsh was characterised by several species including *Aster tripolium, Cochlearia anglica* and *Spartina sp.* The 'Middle' community, which was by far the largest in extent, was dominated by *Spartina*, while the 'Mud' community was characterized by the presence of a large number of species at much lower densities. Finally, the 'Top' community, present along the length of the sea wall, consisted of a strandline community dominated by sea couch *Elytrigia atherica*, as first identified by Kalejta (1984). An attempt was made at reclassifying these informally named communities into NVC communities with the use of 'MAVIS' – the results of which are listed in **Table 4.3.**

Table 4.3: Results of 'MAVIS' analysis of communities recorded by the 'Wetland Advisory Service' survey of the Windsor Esplanade salt-marsh in 1998. The abbreviated NVC community names (See Rodwell, 1991a, 1991b, 1992, 1995, 2000) are given under column heading 'NVC type', and the corresponding Czekanowski's coefficients (on a scale of 0-100; 100 being an exact match) are given under the heading 'Similarity Value'. Values are provided for each of the 4 previously defined communities. The 10 NVC communities which corresponded most closely with the communities previously defined by the WAS (1998) are listed in descending order of likeness.

'Edge' Community		**'Middle' Community**		**'Mud' Community**		**'Top' Community**	
NVC	*Similarity*	*NVC Type*	*Similarity*	*NVC*	*Similarity*	*NVC*	*Similarity*
SM6	56.99	**SM12**	57.47	**SM12**	52.37	**SM24**	54.64
SM12	51.79	**SM6**	54.19	**SM13a**	45.16	**S21b**	41.99
S21a	34.68	**SM13a**	44.44	**S21b**	43.91	**SM25a**	38.05
SM13a	34.62	**SM14a**	42.22	**SM13**	40.61	**SM12**	36.66
SM14a	34.29	**SM14c**	41.83	**SM14c**	39.6	**S21**	36.36
S21b	34.15	**SM14**	40.09	**SM13d**	39.22	**SM25**	36.2
SM8	34.09	**SM13**	39.14	**SM13c**	39.01	**MC1c**	35.5
SM13	32.59	**SM10**	38.79	**SM16d**	37.8	**SM23**	33.03
SM10	32.18	**S21a**	37.33	**SM10**	37.38	**SM13a**	32.59
SM14c	31.62	**S21b**	37.21	**SM16b**	36.93	**SM14b**	32.26

N.B All source data from WAS (1998). All communities are based on the results of 8 random quadrat samples except the 'Mud' community which was based on only 4 samples.

As can be seen from **Table 4.3**, a total of 10 equivalent NVC vegetation communities (along with their similarity values) have been provided for each of the 4 communities; previously defined by the Wetland Advisory Service in their 1998 survey as 'Edge', 'Mud', 'Middle' and 'Top' (WAS, 1998). Only those communities which matched at a similarity of over 50 will be considered as follows – as these can be used with a certain degree of confidence.

The most closely-matching NVC community for 'Edge' group of samples was NVC type 'SM6: *Spartina anglica* salt-marsh community' (Rodwell, 2000) with a similarity value (Czekanowski's coefficient) of 56.99. The second most closely matching NVC type for this group was 'SM12: Rayed *Aster tripolium* on salt-marshes' with a similarity value of 51.79. Because both of these communities have a similarity value to the 'Edge' community of over 50, and because there is only a difference of 5.2 between them, it is probable that this area was in a state of succession somewhere in between the two. I hypothesise that, at this point in the development of the Taff-Ely salt-marsh, the community was in the process of changing from the *Spartina* dominated (SM6) to the predominantly *Aster* (SM12) dominated community; probably as a result of new colonisation of the latter species from higher (and therefore drier and less saline) regions of the marsh, as accretion of substrate by the presence of *Spartina* itself created similar conditions in the formerly lower lying areas of the marsh. This type of succession, whereby *Spartina* essentially causes its own demise by making conditions more suitable for other species, has been documented on several occasions (Ranwell, 1964a, as cited in Rodwell, 2000).

For the 'Middle' community, grouping of the samples in MAVIS resulted in a highest similarity value of 57.47 for NVC type 'SM12: Rayed *Aster tripolium* on salt-marshes'. NVC type 'SM6' - '*Spartina anglica* salt-marsh community' also matched with a coefficient of 54.19. If we compare this community to the 'Edge' community we can see that the two most similar NVC types are the same, but have switched places – thus reinforcing the above hypothesis that the drier and less saline conditions caused by *Spartina,* were allowing the *Aster* community to spread further down the marsh to previously uninhabitable areas for the associated species.

The 'Mud' community, located at the North Eastern upper limit of the marsh, again, was most closely matched to NVC type 'SM12: Rayed *Aster tripolium* on salt-marshes'; although this community is less accurately represented (as fewer samples were used to identify the community during data collection). This is further indication that the *Aster* dominated community was indeed in the process of spreading from higher to lower-lying areas of the marsh. It is worth noting that there is also a much larger difference (of 7.21) between the first and second (SM13A) most closely matching NVC communities, indicating that this was likely to be the origin of the *Aster* dominated communities found in the other areas of the marsh. This larger difference in the similarity value means that there is less chance that the community is in a state of succession between the two (as is probable in the 'Edge' and 'Middle' communities), although the similarity value is not as high as in the other two cases, the reason for which is unclear.

The final community is most similar to 'SM24: *Elymus pycnanthus* (*since renamed *Elytrigia atherica*) salt-marsh community', at a similarity value of 54.64 and a relatively large difference of 12.65 between the top two matches. This indicates a good correlation, and also means that this community was probably not undergoing any major succession into another community at the time. This is perhaps one of the most notable of the pre-barrage habitats in terms of its importance after barrage closure (see below).

(ii). *Post-barrage/Pre-present Study Macophyte Ecology (1999-2003)*

In addition to the obvious natural transitional changes associated with the desalination of Cardiff Bay's habitats, the closure of the Barrage also resulted in the initiation of several developments, which served to alter further, the extent and type of habitat present in the former saltmarsh area. These developments included a new housing development of some 1.3 ha, a new clubhouse for the 'Cardiff Yacht Club' in the southwest corner of the former saltmarsh covering some 1.7 ha, associated 'linear open space' of 1.2 ha, as well as further development of approximately 7.1 ha of the Hamadryad Park area, north of the bridge (L.E.C., 1997). In addition, the new nominal level of the bay waters of 4.5 m above ordnance datum (AOD) resulted in a further reduction in the area of emergent wetland with communities previously lying at the lowest points of the marsh area (i.e. the 'Edge' community in WAS, 1998), which would have been submerged only for very brief periods, now being subject to permanent inundation.

Although there are wetland habitats fringing each of the aforementioned 'developed' areas, the only significant wetland habitat that remained post-Barrage closure in this specific area of the Bay was a relatively small area of approximately 8.15 ha (Highways & Parks, 2003). This area was earmarked for development as an area of nature conservation in 1998 (WAS, 1998) and was later to become known as the Cardiff Bay Wetland Reserve, the primary focus of this present study.

Development of the Cardiff Bay Wetland Reserve did not begin until over 2 years after the initial barrage closure, and just under a year from the freshwater impoundment. During this period the site remained relatively undisturbed with successional changes more likely to be due to changing biotic conditions rather than human interference. The very first of the observed 'natural' changes in the remaining wetland area was the gradual die-back of the majority of the halophytic vegetation. This process appeared to have initiated fairly rapidly, and was well underway by early 2001, when the former saltmarsh areas were recorded to be dominated by dead and dying saltmarsh species (V. Grantham, personal communication). This suggests that desalination of the saltmarsh area was already well underway by this point, even though the Bay was not yet 'officially' closed and not therefore fully freshwater (this did not happen until April 2001).

The first detailed macrophyte surveys after Barrage closure came from the Cardiff Naturalists' Society, who undertook two walkover surveys of the Windsor Esplanade Saltmarsh on behalf of Cardiff Harbour Authority in June and July 2001 (Cardiff Naturalists Society, 2001). During the surveys, a total of 91 species were recorded (**Appendix 4.4**), mostly of newly colonising freshwater ruderal communities (72 species). A much smaller number of individuals of many halophytic species (19 species) remained in certain areas, and thus had not been entirely replaced at this time.

During January and February 2002 the first phase of construction work to form the Wetland Reserve area caused widespread ground disturbance. This same period also saw several significant floods of the majority of the land area of the Reserve, bringing with it large amounts of plant debris which were highly visible as a strandline of some 200 meters long, 5 meters wide and up to 50 cm deep (V. Grantham, Pers. Comm). A combination of these factors may have led to the next major phase of succession, observed in the summer of the same year, when the salt-tolerant but predominantly freshwater species hemlock-water dropwort *Oenanthe crocata* became very abundant (even dominant) across the whole area. That this process occurred is backed by previous records of the relatively common occurrence of this species along the channels of the Rivers Taff and Ely (EAU, 1991); it is likely that this species became dominant through water-carried dispersal of the seeds from upstream areas. Similar phenomena occurred with *Alnus glutinosa* and Willow *Salix sp*, both of which had also colonised the lower lying, and most regularly flooded areas of the marsh by this time.

No further records of vegetation succession in the area were made until the present study began in the summer of 2003 when a casual walkover survey was undertaken of the entire foreshore of Cardiff Bay – with a particular focus on the Wetland Reserve area. The results of this preliminary survey, and the results of the subsequent transect surveys are covered in **Section 4.3.2**.

During autumn 2003, construction work began on the final phase of development of the wetland reserve. This work concentrated on the creation of various new aquatic habitats, and the expansion of existing ones, as well as the creation of four raised areas/islands, which were aimed at providing areas above the maximum flood levels for breeding birds to nest without egg loss occurring. This had been a problem in times of high river flow in the past. This construction work was notable in that it reduced many of the vegetated areas of the Reserve to bare soil, particularly in the case of the raised areas which were formed from soil unearthed during the digging of the new aquatic habitats. When the next stage of fieldwork in the present study was begun, different areas of the reserve represented different stages of ecological development, and therefore were significantly different in species composition (and therefore general appearance). The recording of such areas of disturbance was therefore, important, in order to identify the separate communities present and to explain their distribution during the transect surveys.

4.3.2. Post-barrage Macrophyte Ecology (Results of the Present Study May 2003-2006)

(i). *General*

A total of 134 macrophyte species were recorded within the Cardiff Bay study area over the period of the study, using a combination of both casual and quantitative survey techniques (See **Table 4.4**). The casual surveys of the Bay revealed a total of 100 species when all sampled areas were taken into account, the largest percentage of which (85%) were recorded at the Wetland Reserve site. The Taff and Ely were the second and third most speciose with 43% and 33% of the total species respectively. The remaining areas (the ABP land/Barrage and the Redhouse Marsh) revealed relatively fewer species (18% and 11 % of the total) – a fact that can be attributed to the much smaller extent of vegetation within each of the sampling areas. Because of the casual nature of these surveys the results should only be used as a general outline of the most ubiquitous species present, and there are undoubtedly many more species present than recorded. In addition, the large difference in the number of species recorded at the Wetland Reserve and the other areas is likely to be partly due to the additional time spent in the area, as it was the primary study site within Cardiff Bay throughout the study period. The transect survey recorded a total of 96 species at the wetland reserve site alone (the only site that was surveyed using this methodology, this figure included 33 species which were not recorded during the casual survey of the reserve. However, 22 species recorded during the casual survey were not recorded during the transect surveys of the reserve – these being primarily obvious species that existed in isolated patches, for instance Reedmace *Typha latifolia.*

A total of 9 halophytic species were noted, and, with the exception of *Elytrigia atherica*, they were present in small numbers and only occured in small 'relict' communities. This indicates a noticeable decrease in the number of salt marsh species and a slight increase in the number of freshwater species since the Cardiff Naturalists' Society survey in 2001. One such 'relict' community, dominated by *Spartina anglica,* remained in several of the many former 'tidal' ditches, particularly in the south-eastern corner of the Wetland Reserve.

By the time of the initial walkover survey in the summer of 2003, the major species dominant over the vast majority of the Wetland Reserve was *Elytigia atherica.* In addition, *Alnus glutinosa* and *Epilobium hirsutum* were dominant, both along the marsh edge, and adjacent to the numerous ditches dissecting the marsh; most probably an indication that presence was due to seed dispersal from upstream of the River Taff at times of high river flow/high waters (in addition to a habitat preference for wetter soils). In addition, *Oenanthe crocata* remained common; although most individuals of this species became unidentifiable by the summer as a result of a sizeable infestation of the oecophorid moth larvae, *Depressaria daucella,* which feeds in late spring/early summer, and reduces the plants to bare stems. Notable ruderal species (in terms of their abundance) present on the reserve included *Picris echioides, Tripleurospermum inodorum, Lactuca serriola, Sonchus oleraceus* and *Senecio jacobaea,* the former two species being by far the most common. Of the ruderal grass species *Holcus lanatus* was the most common, often replacing *Elytrigia atherica* in distinct swathes where disturbance had allowed its colonisation.

Species more characteristic of the wetter (lower lying) areas of the reserve included *Mentha aquatica, Ranunculus sceleratus, Lycopus europaeus and Lythrum salicaria,* in addition to several natural colonisations of *Phragmites australis*, and other monocotyledons such as *Phalaris arundinacea*, *Typha latifolia*, and several *Carex* spp.

A number of species recorded on the Reserve were in fact, not a result of natural colonisation, and are a consequence of deliberate introduction into the area as part of the Reserve's management (in an attempt at improving the nature conservation value of the site). Species introduced via this method were primarily marginal aquatic vascular plants including *Phragmites australis*, *Iris pseudoacorus* and *Ranunculus aquatilis,* which were planted around the various aquatic habitats found at the site.

Table 4.4: Species recorded during all macrophyte surveys (using both casual (A) and quantitative (B) methods) of Cardiff Bay (May 2003-May 2006). Those species highlighted in red are examples of halophytic species which have survived the freshwater transition. Areas are defined as follows: **1)** Wetland Reserve; **2)** Taff; **3)** Redhouse; **4)** Ely; **5)** Other.

Species		Method		Casual Survey Area				
		A	B*	1	2	3	4	5
Sycamore	*Acer pseudoplatanus*	*	*	*	*			
Creeping Bent	*Agrostis stolonifera*		*					
Water Plantain	*Alisma plantago-aquatica*	*	*	*				
Alder	*Alnus glutinosa*	*	*	*	*	*	*	
Meadow Foxtail	*Alopecurus pratensis*	*		*				
Bugloss	*Anchusa arvensis*		*					
Wild Angelica	*Angelica sylvestris*		*					
Lesser Burdock	*Arctium minus*	*		*	*			
False Oat-grass	*Arrhenatherum elatius*		*					
Mugwort	*Artemisia vulgaris*	*	*	*	*		*	
Sea Aster	*Aster tripolium*		*					
Common Orache	*Atriplex patula*	*	*	*				
Spear-leaved Orache	*Atriplex prostrata*	*	*	*				
Wild Oat Grass	*Avena fatua*	*		*				
Sea Beet	*Beta vulgaris maritima*	*	*	*				
Trifid Burr Marigold	*Bidens tripartina*	*		*			*	
Black Mustard	*Brassica nigra*		*					
Butterfly Bush	*Buddleja davidii*	*	*	*	*	*	*	*
Flowering Rush	*Butomus umbellatus*	*	*	*				
Hedge Bindweed	*Calystegia sepium*	*	*	*	*			
Common Yellow Sedge	*Carex demissa*	*	*	*				
Long Bracted Sedge	*Carex extensa*	*		*				
False Fox Sedge	*Carex otrubae*	*		*				
Greater Tussock Sedge	*Carex paniculata*	*		*				
Pendulous Sedge	*Carex pendula*	*	*	*			*	
Hop Sedge	*Carex pseudocyperus*	*		*				
True Fox Sedge	*Carex vulpina*	*		*				
Rosebay Willowherb	*Chamerion angustifolium*	*	*	*	*	*		
Chicory	*Cichorium intybus*	*			*			
Creeping Thistle	*Cirsium arvense*	*	*	*	*	*		*
Spear Thistle	*Cirsium vulgare*	*	*	*	*			
Travellers Joy	*Clematis vitalba*	*					*	
Common Scurvygrass	*Cochlearia officinalis*	*	*	*				
Field Bindweed	*Convolvulus arvensis*	*			*			
Canadian Fleabane	*Conyza canadensis*		*					
Sea Kale	*Crambe maritima*		*					
Crested Dogstail	*Cynosurus cristatus*	*	*	*	*			
Cocksfoot	*Dactylis glomerata*		*					
Wild Carrot	*Daucus carota*	*	*	*	*		*	
Wild Teasel	*Dipsacus fullonum*	*		*	*		*	
Canadian Waterweed	*Elodea Canadensis*	*	*	*				
Nuttall's Waterweed	*Elodea nuttallii*	*	*	*				
Bearded Couch	*Elymus caninus*		*					
Sea Couch	*Elytrigia atherica*	*	*	*				*
Common Couch Grass	*Elytrigia repens*	*		*	*	*	*	
Great Willowherb	*Epilobium hirsutum*	*	*	*	*	*	*	*
Marsh Willowherb	*Epilobium palustre*	*	*	*		*		

Species		Method		Casual Survey Area				
		A	B*	1	2	3	4	5
Hoary Willowherb	*Epilobium parviflorum*	*	*	*				
Square-stemmed Willowherb	*Epilobium tetragonum*		*					
Sun Spurge	*Euphorbia helioscopia*	*		*				
Japanese Knotweed	*Fallopia japonica*	*		*	*		*	
Giant Fescue	*Festuca gigantea*		*					
Meadowsweet	*Filipendula ulmaria*	*	*	*			*	
Fennel	*Foeniculum vulgare*	*				*		*
Mountain ash	*Fraxinus excelsior*	*			*			
Goat's Rue	*Galega officinalis*	*		*				
Cleavers	*Galium aparine*	*	*	*				
Marsh Bedstraw	*Galium palustre*		*					
Cut-leaved Cranesbill	*Geranium dissectum*		*					
Floating Sweet Grass	*Glyceria fluitans*	*			*			
Ivy	*Hedera helix*		*					
Meadow Oat-grass	*Helictotrichon pratense*		*					
Hogweed	*Heracleum sphondylium*	*	*	*	*	*		*
Yorkshire Fog	*Holcus lanatus*	*	*	*	*		*	
Marsh Pennywort	*Hydrocotyle vulgaris*		*					
Imperforate St.Johns Wort	*Hypericum maculatum*	*	*	*				
Perforate St. Johns Wort	*Hypericum perforatum*	*		*				
Himalayan Balsam	*Impatiens glandulifera*	*		*	*			
Soft Rush	*Juncus effusus*	*	*	*			*	
Hard Rush	*Juncus inflexus*	*	*	*				
Prickly Lettuce	*Lactuca serriola*	*	*	*				
Fat Duckweed	*Lemna gibba*	*						
Common Duckweed	*Lemna minor*	*						
Dittander	*Lepidium latifolium*	*		*	*			
Ox-eye Daisy	*Leucanthemum vulgare*	*	*	*				
Purple Toadflax	*Linaria purpurea*		*					
Common Toadflax	*Linaria vulgaris*	*		*				
Birdsfoot Trefoil	*Lotus corniculatus*		*					
Gypsywort	*Lycopus europaeus*	*	*	*				
Purple Loosestrife	*Lythrum salicaria*	*		*				
Cultivated Apple	*Malus domestica*	*			*			
Common Mallow	*Malva sylvestris*	*			*			
Black Medick	*Medicago lupulina*		*					
White Melilot	*Melilotus albus*	*				*		
Golden Melilot	*Melilotus altissima*	*	*	*	*		*	
Water Mint	*Mentha aquatica*	*	*	*				
Spear Mint	*Mentha spicata*		*					
Round-leaved Mint	*Mentha suaveolens*		*					
Spiked Water Milfoil	*Myriophyllum spicatum*		*					
Hemlock Water Dropwort	*Oenanthe crocata*	*	*	*				
Common Evening Primrose	*Oenothera biennis*	*					*	
Hard Grass	*Parapholis strigosa*		*					
Wild Parsnip	*Pastinaca sativa*	*	*	*			*	
Water Pepper	*Persicaria hydropiper*	*	*	*				
Redleg	*Persicaria maculosa*	*	*	*				
Reed Canary Grass	*Phalaris arundinacea*	*	*	*	*		*	
Common Reed	*Phragmites australis*	*	*	*	*	*	*	
Bristly Oxtongue	*Picris echioides*	*	*	*	*	*	*	*
Ribwort Plantain	*Plantago lanceolata*	*	*	*	*		*	
Greater Plantain	*Plantago major*		*					
Black Poplar	*Populus nigra*	*			*			
Common Fleabane	*Pulicaria dysenterica*	*	*	*		*	*	*
Common Water Crowfoot	*Ranunculus aquatilis*		*					
Creeping Buttercup	*Ranunculus repens*		*					
Celery-leaved Buttercup	*Ranunculus sceleratus*	*	*	*				

Species		Method		Casual Survey Area				
		A	B*	1	2	3	4	5
Bramble	*Rubus fruticosus*	*	*	*	*		*	
Curled Dock	*Rumex crispus*	*	*	*			*	
White Willow	*Salix alba*		*					
Goat Willow	*Salix caprea*		*					
Willow	*Salix fragilis*	*		*	*	*	*	
Osier	*Salix viminalis*		*	*				
Elder	*Sambucus nigra*	*			*		*	
Water Figwort	*Scrophularia auriculata*	*		*				
Common Figwort	*Scrophularia nodosa*		*					
Common Ragwort	*Senecio jacobaea*	*	*	*	*	*	*	*
Charlock	*Sinapis arvensis*	*	*	*				
Hedge Mustard	*Sisymbrium officinale*	*	*	*	*			
Bittersweet	*Solanum dulcamara*	*	*	*				
Smooth Sow Thistle	*Sonchus oleraceus*	*	*	*				
Branched Bur-Reed	*Sparganium erectum*	*	*	*				
Common Cord Grass	*Spartina anglica*	*	*	*	*	*	*	
Greater Duckweed	*Spirodela polyrhiza*	*						
Dandelion	*Taraxacum officinale*	*	*	*	*			
Haresfoot Clover	*Trifolium arvense*	*	*	*				
Lesser Trefoil	*Trifolium dubium*	*						
Red Clover	*Trifolium pratense*	*	*	*	*		*	
White Clover	*Trifolium repens*	*	*	*	*		*	
Sea Arrow-grass	*Triglochin maritima*		*					
Scentless Mayweed	*Tripleurospermum inodorum*	*	*	*	*	*	*	*
Coltsfoot	*Tussilago farfara*	*	*	*	*		*	
Bulrush	*Typha latifolia*	*		*				
Stinging Nettle	*Urtica dioica*	*	*	*	*	*	*	*
Fen Nettle	*Urtica galeopsifolia*		*					
Small Nettle	*Urtica urens*		*					
Species Totals:		**100**	**96**	**85**	**43**	**18**	**33**	**11**
Total Number of Species = 134								

* Used to survey Wetland Reserve Only

(ii). *Transect Survey Results (General)*

As mentioned previously, the transect surveys undertaken in 2004 and 2005 recorded a total of 96 species, occurring across the area surveyed (from the old sea wall on Windsor Esplanade to the southern edge of the Reserve). 88.5% of all the species so far recorded across the entire Reserve area during casual surveys (**Table 4.4**) were also recorded during the transect surveys of the same area, implying that the data from the transects are fairly representative of the whole area, even though a relatively small proportion of the marsh area was surveyed.

As expected from prior observations, *Elytrigia atherica* was by far the most frequently occurring species along both transects (**Tables 4.5** and **4.6** and **App. 4.5**) in all surveys, with frequency of occurrence (FO) ranging between 64.1% on Transect 1, (Apr 04) and 76.1% on Transect 2 (Aug 04). This species often occurred more than twice as frequently as the next most frequently recorded species – these being *Holcus lanatus* (mean of 35.3% FO) on Transect 1, and *Picris echioides* (mean of 42.7% FO) on Transect 2.

Other commonly encountered species included *Oenanthe crocata*, *Epilobium hirsutum*, *Tripleurospermum inodorum*, *Alnus glutinosa*, *Agrostis stolonifera*, *Rumex crispus* and *Sonchus oleraceus*. The vast majority of species on both transects were recorded at less than 10% FO - in the case of Transect 1, 85.3% of species occurred at less than 10% FO; and 87.7% of species occurred at less than 10% FO on Transect 2. This indicates that the relatively few opportunistic species mentioned above have dominated the terrestrial areas of the reserve.

Table 4.5: Percentage Frequency of Occurrence (% F.O)* of Species along 'Transect 1' in April, August and December of 2004, and August 2005.

Species	% Frequency of Occurrence*				
	Apr-04	***Aug-04***	***Dec-04***	***Aug-05***	**Mean**
	(92 samples)	***(46 Samples)***	***(92 samples)***	***(46 Samples)***	-
Elytrigia atherica	64.1	76.1	71.7	73.9	71.5
Holcus lanatus	23.9	28.3	34.8	54.3	35.3
Picris echioides	22.8	30.4	22.8	28.3	26.1
Agrostis stolonifera	0	37	4.3	52.2	23.4
Epilobium hirsutum	7.6	39.1	5.4	37	22.3
Oenanthe crocata	41.3	2.2	15.2	19.6	19.6
Alnus glutinosa	5.4	21.7	19.6	19.6	16.6
Phragmites australis	7.6	8.7	13	28.3	14.4
Lycopus europaeus	0	21.7	6.5	26.1	13.6
Rumex crispus	13	4.3	14.1	21.7	13.3
Tripleurospermum inodorum	10.9	17.4	5.4	2.2	9.0
Elodea sp.	0	8.7	8.7	10.9	7.1
Filipendula ulmaria	0	0	7.6	15.2	5.7
Carex sp.	1.1	0	1.1	19.6	5.5
Calystegia sepium	0	8.7	0	8.7	4.4
Galium palustre	2.2	8.7	0	6.5	4.4
Plantago lanceolata	4.3	0	6.5	6.5	4.3
Mentha aquatica	0	2.2	2.2	10.9	3.8
Dactylis glomerata	0	0	4.3	10.9	3.8
Senecio jacobaea	0	4.3	0	10.9	3.8
Phalaris arundinacea	0	4.3	4.3	6.5	3.8
Alisma plantago-aquatica	0	4.3	0	8.7	3.3
Epilobium tetragonum	0	13	0	0	3.3
Tussilago farfara	0	4.3	2.2	6.5	3.3
Salix sp	0	4.3	4.3	4.3	3.2
Arrhenatherum elatius	0	0	0	10.9	2.7
Atriplex patula	0	10.9	0	0	2.7
Sonchus oleraceus	2.2	6.5	1.1	0	2.5
Myriophyllum spicatum	0	0	0	8.7	2.2
Daucus carota	0	4.3	0	4.3	2.2
Atriplex prostrata	0	2.2	3.3	2.2	1.9
Urtica dioica	3.3	0	0	4.3	1.9
Melilotus altissima	0	2.2	2.2	2.2	1.7
Medicago lupulina	0	0	0	6.5	1.6
Ranunculus aquatilis	0	4.3	1.1	0	1.4
Epilobium parviflorum	0	2.2	0	2.2	1.1
Triglochin maritima	0	2.2	0	2.2	1.1
Brassica nigra	0	4.3	0	0	1.1
Juncus effusus	1.1	0	2.2	0	0.8
Linaria purpurea	0	2.2	1.1	0	0.8
Taraxacum sp	3.3	0	0	0	0.8
Acer pseudoplatanus	0	2.2	0	0	0.6
Artemisia vulgaris	0	0	0	2.2	0.6
Butomus umbellatus	0	0	0	2.2	0.6
Cirsium arvense	0	0	0	2.2	0.6
Cirsium vulgaris	0	0	0	2.2	0.6
Cynosurus cristatus	0	2.2	0	0	0.6
Elymus caninus	0	2.2	0	0	0.6
Galium aparine	0	0	0	2.2	0.6
Hydrocotyle vulgaris	0	0	2.2	0	0.6
Hypericum maculatum	0	0	0	2.2	0.6
Iris pseudacorus	0	2.2	0	0	0.6

Species	% Frequency of Occurrence*				
	Apr-04	***Aug-04***	***Dec-04***	***Aug-05***	**Mean**
	(92 samples)	***(46 Samples)***	***(92 samples)***	***(46 Samples)***	-
Juncus inflexus	0	0	0	2.2	0.6
Leucanthemum vulgare	0	2.2	0	0	0.6
Persicaria maculosa	0	2.2	0	0	0.6
Persicaria hydropiper	0	0	0	2.2	0.6
Plantago major	0	0	0	2.2	0.6
Pulicaria dysenterica	0	0	0	2.2	0.6
Ranunculus sceleratus	0	2.2	0	0	0.6
Rubus fruticosa	1.1	0	1.1	0	0.6
Sinapis arvensis	0	0	0	2.2	0.6
Sparganium erectum	0	0	0	2.2	0.6
Spartina anglica	0	0	2.2	0	0.6
Spartina maritima	0	0	0	2.2	0.6
Trifolium dubium	0	2.2	0	0	0.6
Trifolium repens	2.2	0	0	0	0.6
Crambe maritima	1.1	0	0	0	0.3
Festuca gigantea	0	0	1.1	0	0.3
Total Number of Species	**19**	**39**	**30**	**46**	

Table 4.6: Percentage Frequency of Occurrence (% F.O)* of Species along 'Transect 2' in April, August and December of 2004, and August 2005.

Species	% Frequency of Occurrence*				
	Apr-04	Aug-04	Dec-04	Aug-05	Mean
	(136 samples)	(68 Samples)	(136 samples)	(68 Samples)	-
Elytrigia atherica	70.6	86.8	83.8	88.2	82.4
Picris echioides	41.2	52.9	39.7	36.8	42.7
Holcus lanatus	46.3	17.6	55.9	33.8	38.4
Tripleurospermum inodorum	38.2	48.5	34.6	8.8	32.5
Epilobium hirsutum	18.4	29.4	29.4	48.5	31.4
Agrostis stolonifera	0	23.5	2.2	57.4	20.8
Oenanthe crocata	42.6	0	27.2	8.8	19.7
Rumex crispus	19.9	4.4	25.7	23.5	18.4
Phragmites australis	2.9	10.3	10.3	17.6	10.3
Sonchus oleraceus	31.6	1.5	2.9	0	9.0
Atriplex prostrata	0	20.6	2.9	8.8	8.1
Plantago lanceolata	1.5	1.5	14	14.7	7.9
Alnus glutinosa	6.6	7.4	7.4	8.8	7.6
Lycopus europaeus	0	11.8	0.7	17.6	7.5
Dactylis glomerata	0	5.9	2.9	20.6	7.4
Phalaris arundinacea	1.5	5.9	4.4	11.8	5.9
Calystegia sepium	0	5.9	0	16.2	5.5
Cirsium vulgare	0	2.9	4.4	14.7	5.5
Epilobium parviflorum	0	16.2	0	4.4	5.2
Arrhenatherum elatius	0	0	0	19.1	4.8
Senecio jacobaea	0.7	2.9	0	14.7	4.6
Urtica dioica	5.1	2.9	0	8.8	4.2
Epilobium tetragonum	0	0	0	16.2	4.1
Lactuca serriola	0	13.2	0	2.9	4.0
Cirsium arvense	2.9	1.5	2.2	8.8	3.9
Carex sp.	0	0	5.1	10.3	3.9
Ranunculus repens	0	0	8.8	2.9	2.9
Melilotus altissima	0	7.4	0.7	1.5	2.4
Filipendula ulmaria	0.7	0	2.2	5.9	2.2
Taraxacum sp	5.9	0	0.7	1.5	2.0
Alisma plantago-aquatica	0	0	0	7.4	1.9
Mentha aquatica	0	0	0	7.4	1.9
Artemesia vulgaris	0	1.5	1.5	2.9	1.5
Medicago lupulina	0	1.5	0	4.4	1.5
Triglochin maritima	0	0	0	5.9	1.5
Galium palustre	2.2	1.5	0	1.5	1.3
Angelica sylvestris	0	2.9	0	1.5	1.1
Daucus carota	0	0	0	4.4	1.1
Brassica nigra	1.5	0	2.2	0	0.9
Atriplex patula	0	0	1.5	1.5	0.8
Conyza canadensis	0	0	1.5	1.5	0.8
Trifolium pratense	0	0	1.5	1.5	0.8
Buddleja davidii	0.7	1.5	0.7	0	0.7
Anchusa arvensis	0	0	2.9	0	0.7
Geranium dissectum	0	0	0	2.9	0.7
Leucanthemum vulgare	0	2.9	0	0	0.7
Lotus corniculatus	0	0	0	2.9	0.7
Pastinaca sativa	0	0	0	2.9	0.7
Urtica urens	0	0	2.9	0	0.7
Crambe maritima	2.2	0	0	0	0.6
Tussilago farfara	0	0	0.7	1.5	0.6
Aster tripolium	0	0	0	1.5	0.4

Species	% Frequency of Occurrence*				
	Apr-04	*Aug-04*	*Dec-04*	*Aug-05*	Mean
	(136 samples)	*(68 Samples)*	*(136 samples)*	*(68 Samples)*	-
Beta vulgaris maritima	0	1.5	0	0	0.4
Chamerion angustifolium	0	1.5	0	0	0.4
Cochlearia officinalis	1.5	0	0	0	0.4
Heracleum sphondylium	0	0	0	1.5	0.4
Linaria purpurea	0	0	0	1.5	0.4
Myriophyllum spicatum	0	0	0	1.5	0.4
Parapholis strigosa	0	1.5	0	0	0.4
Persicaria hydropiper	0	0	0	1.5	0.4
Rubus fruticosa	0	0	0	1.5	0.4
Scrophularia nodosa	0	0	0	1.5	0.4
Acer pseudoplatanus	0.7	0	0	0	0.2
unidentified grass sp	0	0	0.7	0	0.2
*Hedera helix**	0	0	0.7	0	0.2
Helictotrichon pratense	0	0	0.7	0	0.2
Juncus effusus	0	0	0.7	0	0.2
Mentha spicata	0	0	0.7	0	0.2
Mentha suaveolens	0	0	0.7	0	0.2
Salix sp	0	0	0.7	0	0.2
*Sisymbrium officinale**	0	0	0.7	0	0.2
Trifolium repens	0.7	0	0	0	0.2
Urtica galeopsifolia	0	0	0.7	0	0.2
Total no. of Species	**24**	**32**	**41**	**51**	**37**

*Percentage Frequency of Occurrence is based upon the number of occurrences of a species (at a Domin cover level of at least 1) in all quadrats. I.e. if a species occurred in all 92 quadrats (irrelevant of degree of cover) in April, then it would receive an FO value of 100%.

(iii). *Community Analysis of Transect Data*

The following section outlines the results of a Twinspan analysis of the transect survey macrophyte data collected in August of 2004 and 2005. This analysis was undertaken with the aim of separating the main macrophyte communities found along the entire length of both transects, and therefore supporting conclusions drawn from casual observation (and vice-versa). Using the data resulting from the four transects, the first division (level 2) separated out a group of 8 quadrats dominated by *Elodea canadensis* with *Butomus umbellatus* and *Myriophyllum spicatum* also present, and a group containing all other samples and species (see **App. 4.6** and **Tab. 4.7**). Because of the small number of samples representative of the *Elodea canadensis* community (Twinspan site class *1) this initial separation was chosen for analysis. Similarly, a site class containing only *Phragmites australis* (class *011) was separated off at level 3 of the Twinspan analysis. The remainder of the samples, however, could be divided several times further before becoming too small for further division. On the basis of all groups in the 'second' group being further divisible, the fourth level of divisions was chosen as an appropriate overview of the communities present (i.e. after the fourth level of divisions some groups became too small to divide further). As a result, a total of 8 individual site classes were derived – a figure deemed adequate to describe the communities present (**Table 4.7**). The following flow chart illustrates where in the division process each site class was derived.

Figure 4.7: Flow Chart illustrating the origin of derived site class within the Twinspan division hierarchy (chosen sites are in green).

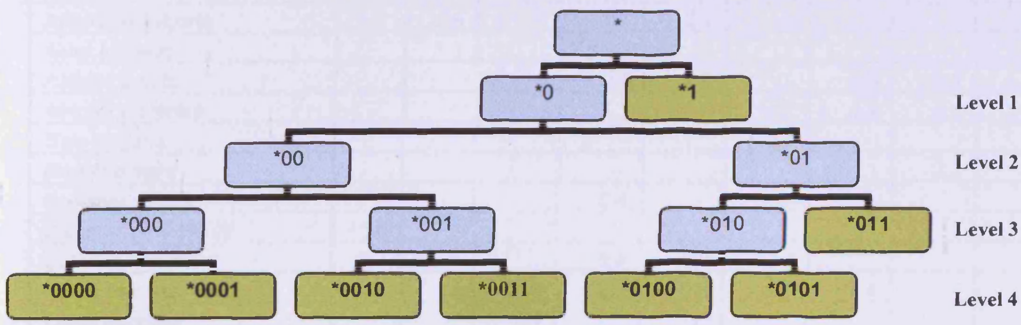


Table 4.7: 'Species Occurrence and Abundance' (SOA) values of species within derived Twinspan classes. Also shown are the division level of each site class, the number of samples and species within each class. Additionally, the origin of the samples (with regards to each of the two transects undertaken in 2004 and 2005) is expressed as a percentage of the total number of samples in each site class. Indicator species for each site class are shown in red.

Site Class	*1	*011	*0101	*0100	*0011	*0010	*0001	*0000	* (all samples)
Samples in Site Class	8	26	12	38	72	37	12	13	218
Acer pseudoacorus					0.2				0.1
Agrostis stolonifera	1.8	11.0	2.4	9.4	23.2	5.4	60.7	3.3	15.3
Alisma plantago-aquatica		0.5	4.8	1.1	0.8	0.4			0.9
Alnus glutinosa			56.0	21.8					6.9
Angelica sylvestris				1.9					0.3
Arrhenatherum elatius			2.4	1.5	3.4	0.4	9.5		2.1
Artemisia vulgaris		0.5		1.1	0.2				0.3
Aster tripolium		1.1							0.1
Atriplex patula				0.8	0.6		3.6	1.1	0.6
Atriplex prostrata				1.1	0.4	14.7	1.2	1.1	2.9
Beta vulgaris						0.8			0.1
Brassica nigra								2.2	0.1
Buddleja davidii				0.4					0.1
Butomus umbellatus	3.6								0.1
Calystegia sepium		3.3		5.3	5.0				2.9
Carex demissa			22.6	5.6	0.8		2.4		2.6
Carex pendula			2.4						0.1
Chamerion angustifolium				0.8					0.1
Cirsium arvense				1.1	0.6	3.9			1.0
Cirsium vulgare					3.4	6.2	1.2		2.2
Conyza canadensis						0.4			0.1
Cynosaurus cristatus					0.4				0.1
Dactylis glomerata			1.2	2.6	4.2	2.3		4.4	2.6
Daucus carota					0.6		6.0	2.2	0.7
Elodea canadensis	53.6			1.1					2.2
Elymus caninus				0.4					0.1
Elytrigia atherica	3.6	63.7	25.0	72.9	79.8	61.8	27.4	16.5	61.1
Epilobium hirsutum		7.1	16.7	33.1	7.9	5.8	2.4		11.3
Epilobium palustre					0.2				0.1
Epilobium parviflorum				1.1	1.6	1.5		2.2	1.1
Epilobium tetragonum				3.8	1.4	0.8	1.2		1.3
Filipendula ulmaria			8.3	3.4	1.2				1.4
Galium aparine					0.2				0.1
Galium palustre			2.4	4.5					0.9
Geranium dissectum					0.4				0.1
Heracleum sphondylium				1.1					0.2
Holcus lanatus		2.7	4.8	6.4	10.7	5.0	53.6	79.1	13.8
Hypericum maculatum				0.8					0.1
Juncus inflexus				1.5					0.3
Lactuca serriola				0.4	0.6	2.3		2.2	0.8
Leucanthemum vulgare					0.2	0.8		1.1	0.3
Linaria purpurea							1.2	2.2	0.2
Lotus corniculata							4.8		0.3
Lycopus europaeus		0.5	14.3	10.5	2.4	0.8	3.6	1.1	3.9

Site Class	*1	*011	*0101	*0100	*0011	*0010	*0001	*0000	* (all samples)
Samples in Site Class	8	26	12	38	72	37	12	13	218
Medicago lupulina					0.2		13.1	2.2	0.9
Melilotus altissima		1.1			0.8	1.9	2.4	2.2	1.0
Mentha aquatica				4.1	0.8				1.0
Myriophyllum spicatum	12.5				0.2				0.5
Oenanthe crocata			19.0	4.5	0.4		1.2		2.0
Parapholis strigosa								4.4	0.3
Pastinaca sativa				0.8	0.6				0.3
Persicaria hydropiper			2.4	0.4					0.2
Persicaria maculosa					0.4				0.1
Phalaris arundinacea		1.1	27.4	3.4	0.4	2.7			2.8
Phragmites australis	3.6	51.1		1.1	2.0			1.1	7.1
Picris echioides			1.2	0.8	11.5	37.1	26.2	34.1	13.8
Plantago lanceolatum			1.2	1.1	0.8	0.8	4.8	1.1	1.0
Plantago major					0.4				0.1
Pulicaria dysenterica							2.4		0.1
Ranunculus aquatilis						0.4		1.1	0.1
Ranunculus repens			2.4			0.8			0.3
Ranunculus sceleratus					0.2				0.1
Rubus fruticosa					0.2				0.1
Rumex crispus		1.1	2.4	4.9	1.8	3.1	3.6		2.4
Salix alba				0.4					0.1
Salix caprea					0.6				0.2
Salix viminalis			3.6	1.1					0.4
Scrophularia nodosa				0.4					0.1
Senecio jacobaea			1.2	2.3	4.8		2.4		2.2
Sinapis arvensis					0.2				0.1
Solanum dulcamara			1.2						0.1
Sonchus oleraceus					0.8	0.4		1.1	0.4
Spartina anglica			2.4						0.1
Sparganium erectum							3.6	1.1	0.3
Taraxacum officinale							2.4		0.1
Trifolium dubium								1.1	0.1
Trifolium pretense							2.4		0.1
Triglochin maritime		1.1		1.1	0.8				0.6
Tripleurospermum inodorum				0.8	1.8	32.0	3.6	17.6	7.4
Tussilago farfara				2.3	0.4	0.8			0.7
Urtica dioica			4.8	0.8	0.4	0.4	1.2		0.7
Number of Species	**6**	**14**	**25**	**45**	**49**	**28**	**27**	**24**	**81**
% Origin of Samples:									
Transect 1 2004	**37.5**	**11.5**	**8.3**	**34.2**	**15.3**	**10.8**	**16.7**	**30.8**	
Transect 2 2004	**0.0**	**23.1**	**16.7**	**13.2**	**27.8**	**70.3**	**0.0**	**46.2**	
Transect 1 2005	**62.5**	**23.1**	**41.7**	**23.7**	**16.7**	**2.7**	**33.3**	**15.4**	
Transect 2 2005	**0.0**	**42.3**	**33.3**	**28.9**	**40.3**	**16.2**	**50.0**	**7.7**	

The classes, in the above table (**Table 4.7**) can be summarised as follows:

- ***Site Class *1***

Derived after the first level of divisions, this class represents an aquatic community with the indicator species *Elodea canadensis* being the dominant species present with an SOA of 53.6. Also present were *Butomus umbellatus* and *Myriophyllum spicatum* though at far lower values of SOA. This community was restricted to 'Transect 1', in the locations where the transect crosses open water habitats – primarily where these habitats were in the form of relatively deep channels (<1 m).

- ***Site Class *011***

This site class, separated at the third level of Twinspan divisions, is characterized by the presence of *Phragmites australis* - its sole indicator species, with an SOA of 51.1. Present on both transects (though more extensive on Transect 2 in both years) the main distribution of this community is where the transects cross the main reservoir at the highest point of the reserve (the area shown in red in **Fig. 4.2**) – an area which was purposefully planted with the species in order to aid bio-filtration of the water entering the reserve from run-off sources. *Elytrigia atherica* was the most abundant and widespread of the 14 species found in this site class, though *Agrostis stolonifera* was also fairly common.

- ***Site Class *0101***

Located primarily in the wetter, lower-lying areas of the reserve towards the southern edge and adjacent to the ditches which dissect the reserve, this site class is characterized by fairly high abundance and distribution of two indicator species - *Alnus glutinosa* with an SOA of 56.0, and *Phalaris arundinacea* with an SOA of 27.4. Other species present at significant SOA values included *Carex demissa* (SOA=22.6), *Oenanthe crocata* (SOA=19), *Epilobium hirsutum* (SOA=16.7), and *Lycopus europeaus* (SOA=14.3). Notably these are all species which are typical of 'wetter' ground usually at the margins of various water bodies.

• ***Site Class *0100***

The indicator species for this site class were *Elytrigia atherica* (SOA = 72.9) and *Epilobium hirsutum* (SOA = 33.1), both of which were distributed regularly throughout the quadrats making up the site class. The site class was the second most speciose of those identified during the Twinspan analysis with a total of 45 species included within, although the majority of these were present at relatively low values of SOA. The quadrats in this site class represent those in transitional areas between the higher terrestrial habitats of the reserve and the lower lying, wetter ones – hence the inclusion of many marginal aquatic species.

• ***Site Class *0011***

By far the largest site-class being made up of a total of 72 samples, and also the most speciose community containing 49 species, it is dominated by the most common and abundant species found at the wetland reserve - *Elytrigia atherica* with an SOA of 79.8. A relatively high occurrence of *Agrostis stolonifera* at an SOA of 23.2 is also indicative of the community. The class appears to be characteristic of areas which have suffered very little disturbance, or at the very least received very little disturbance during the final phase of construction work. Thus this community is probably the most established community of all, but is likely to be fragile in its existence, with other grass species being able to out-compete where *E. atherica* is not the dominant species. Its continued success in these areas is most likely due to its relatively large size and dense growth, enabling little space for new species to colonize under 'natural' circumstances.

• ***Site Class *0010***

The indicator species for this community were *Atriplex prostrata* (SOA = 14.7), *Picris echioides* (SOA = 37.1), and *Tripleurospermum inodorum* (SOA = 32.0), although *Elytrigia atherica* remained the most widespread and abundant species. Interestingly, the site class was dominated by samples from Transect 2 undertaken in 2004. More specifically the samples are mainly from the large raised area present on this transect. It is obvious when we examine the species typical of this site class that the vast majority are ruderal in nature, and this is a result of the significant disturbance to which certain areas of the reserve were subject to during a phase of construction work during the summer/autumn of 2003 – when the aforementioned 'raised area' was constructed. This explains the significant presence of the halophytic *Atriplex prostrata* – it is likely that the excavation of earth to create the raised areas unearthed seed stock of this species as well as unlocking salt trapped within the sediments, thus allowing the species to thrive temporarily.

- ***Site Class *0001***

Dominated by *Agrostis stolonifera* (the indicator for the site class with an SOA of 60.7), *Holcus lanatus* (SOA = 53.6), *Elytigia atherica* (SOA = 27.4) and *Picris echioides* (SOA = 26.2), this site class is most typical of disturbed areas, however it differs from the previous site class in that it contains lower numbers of halophytic species. It is likely that the site class exists where salinity has not been increased through mixing of sediments, but where disturbance has occurred nonetheless, even dominating as such areas desalinate. This idea is enforced by the fact that far fewer quadrats represented the site class in the summer of 2004 (less than a year after construction work) than in the summer of 2005.

- ***Site Class *0000***

The indicators for this site class are *Tripleurospermum inodorum* (SOA = 17.6), and *Holcus lanatus* (SOA = 79.1) – the latter of which was by far the most dominant species within the site class. As with the previous class, this site is thought to represent formerly disturbed sites, but at a slightly later stage in their succession, hence the increase in the dominance of *Holcus lanatus*. The majority of the quadrats which were classified into this site class originated from the former track used by construction traffic during the 2003 phase of construction, an area which lies at the most northerly and highest point of the reserve.

4.4. Conclusions

The emergent wetland habitats of Cardiff Bay have undergone a drastic and rapid change from the halophytic communities of pre-Barrage times. As highlighted in the previous section, the biodiversity of the pre-Barrage environment was far lower than at present – and this includes the macrophyte species, which are equally subjected to the many harsh conditions of an estuarine environment.

At present, the 'Emergent Wetland' habitats are the result of a combination of natural colonisation by ruderal species, and human interference via planting of certain species. Perhaps one of the most noticeable patterns of vegetation development at present is the spread of the upper-saltmarsh species *Elytrigia atherica*, across the vast majority of many of the emergent wetland habitats present around the Bay. This is particularly surprising, because the species was present in only small areas pre-barrage – at the very upper limit of the saltmarsh. The most plausible explanation for the subsequent spread of the species post-Barrage is that the lowering salinities in the marsh allowed the species to gradually spread from the upper to the lower parts of the marsh, before any glycophytic plants were able to colonise. This dominance would be helped by the fact that *Elytrigia* grows in extremely dense and relatively tall (>1.3 m) stands, thus causing difficulty for new species to establish. This explanation is backed up by the fact that subsequent disturbance of the *Elytrigia*, with bare ground being uncovered, was observed to result in the rapid colonisation by ruderal species such as *Picris echioides, Tripleurospermum inodorum* and *Holcus lanatus.*

What has been observed, with regards to the pattern of post-Barrage vegetation development, can be seen as an accelerated model of the possible end result of the natural succession occurring on the saltmarsh prior to the freshwater impoundment. We have seen from the results presented in this report that accretion of the saltmarsh was leading the spread of upper saltmarsh dominants to lower regions of the marsh (particularly in the case of *Aster tripolium*). Although it is difficult to predict the full extent to which the marsh would have 'dried out' as a result of accretion under normal circumstances, it is likely that we would have seen a substantial spread of *Elytrigia* at some point in the saltmarsh's development.

From observations of the current macrophyte species present within Cardiff Bay, it is likely that future development, will result in many more varied sub-habitats for a greater diversity of organisms, however, without management certain species, such as *Alnus glutinosa*, do threaten to reduce habitat diversity by creating a monotypic vegetation, because of aggressive growth and colonisation.

In summary, the emergent wetland habitats are developing as could be expected from looking at the dominance of past and present communities, however, the communities are not likely to be completely typical of a freshwater marsh for many years to come, primarily because of the continued existence of halophytic species from the pre-Barrage era. The exact length of time in which halophytic species continue to survive is difficult to predict, although as mentioned previously, in a similar situation in the Netherlands certain halophytic species (including *Elytrigia atherica*) survived for over 30 years after the change from saline to freshwater. Perhaps one of the most influential factors on the length of time in this situation, as outlined by the current research, will be the level of disturbance the area is subjected to, which, contrary to the results of Westhoff & Sykora (1979, as cited in Smits *et al.*, 2002), appears to increase the rate of colonisation by other species (and therefore increases the rate of loss of the halophytic species).

5. Invertebrate Ecology of Cardiff Bay

5.1. Introduction

5.1.1. General

As well as being an important part of the diet of many wetland bird species, aquatic and terrestrial wetland macroinvertebrates have important roles in the functioning of wetland ecosystems, providing a vital link between wetland primary production and higher trophic levels. Some of their most important functions (in relation to benthic aquatic invertebrates) are summarized by Covich *et al.* (1999). These include acceleration of detrital decomposition and the subsequent release of bound nutrients into solution by their feeding activities, excretion, and movement through sediments – thus enabling such organisms as bacteria, fungi, algae, and aquatic angiosperms to utilize the formerly inaccessible nutrients, which in turn are essential to support organisms from higher trophic levels. In these ways they are essential contributors to ecosystem services.

In addition, predatory invertebrate species are essential for the control of the numbers, locations and size distributions of prey species (Crowl & Covich, 1990 and 1994, as cited in Covich *et al.,* 1999). Finally, as already mentioned with regards to birds, they are also important in the direct provision of food for other aquatic and terrestrial vertebrate consumers. With these details in mind, a series of field studies were undertaken between May 2004 and September 2005 with the aim of investigating the aquatic macroinvertebrate ecology of the developing freshwater wetlands of Cardiff Bay.

Sampling of invertebrates was undertaken with the aim of accomplishing four key objectives. The first and foremost of these was to investigate the distribution and abundance of invertebrate food resources available to birds which feed amongst the various aquatic habitats of the Cardiff Bay Wetland Reserve. The second objective was to investigate, by comparison with past data, the changes in macroinvertebrate communities which have occurred as a result of the transition of Cardiff Bay from a saline to a freshwater environment. The third objective was to assess the variability in water quality between the various aquatic habitats distributed across the reserve, using the revised Biological Monitoring Working Party (BMWP) scoring system (Walley & Hawkes, 1996, 1997). The final objective was to investigate the predatory effect of the abundant fish populations of Cardiff Bay on the abundance of invertebrates (specifically of benthic invertebrates such as larval chironomids and oligochaete worms). A small-scale, field-based experiment was undertaken as part of the latter. The choice of each of the aforementioned research objectives was derived from the following brief literature review on each subject area.

5.1.2. The Importance of Aquatic Invertebrates to Waterfowl

The abundance of wetland birds is often correlated with the availability of their aquatic invertebrate prey (Goss-Custard, 1970; Murkin *et al.*, 1982; Puttick, 1984; Phillips, 1991; Hockey *et al.*, 1992; Velasquez, 1992; Yates *et al.*, 1993; Sanders, 1999; Sanders, 2000). Therefore it is logical that identification of invertebrate communities is of utmost importance for the successful management of the main waterfowl feeding habitats in Cardiff Bay.

The importance of aquatic invertebrates in the diet of waders is well documented as they form the predominant part of the diet of the majority of species, thus the subject has formed the focus of many detailed scientific studies over the years. A great deal of this research has focused on prey type, size selection, and availability to both individual wader species, and wader communities as a whole (Goss-Custard, 1970 & 1977; Bryant, 1979; Beukema *et al.,* 1993; Zwarts & Wanink, 1993; and Dierschke, 1994). Other areas which have received considerable attention with regard to wader-invertebrate relationships include the effects (or possible effects) of habitat change (usually anthropogenic) upon prey availability, and the effects of habitat manipulations on the abundance of prey invertebrates (Evans *et al.*, 1979; Street, 1983; Goss-Custard *et al.*, 1991; Rehfisch, 1994; Green & Hilton, 1998; and Sanders, 2000), as well as studies on the correlation between invertebrate and wader distribution (Yates *et al.,* 1993). However, it is important to note that much of the research on relationships between waders and invertebrates in the UK (and elsewhere), has focused on estuarine (namely inter-tidal) habitats, because, as discussed in the introductory chapters, they are the preferred and most important winter feeding habitats for the majority of wading bird species – a fact that can be attributed to the high productivity and relatively mild winters that are typical of these habitats (Austin & Rehfisch, 2003).

Although Cardiff Bay now represents a freshwater environment, studies undertaken over the research period have revealed that certain habitats (namely the Wetland Reserve) have continued to provide valuable winter feeding habitats to a number of wading bird species – the most notable of which (particularly in terms of abundance) has been the Common Snipe *Gallinago gallinago* - the wintering populations of which have increased in the post-barrage environment. Other wader species which have used the bay as a feeding habitat include Redshank *Tringa totanus*, Lapwing *Vanellus vanellus*, Turnstone *Arenaria interpres*, and Ringed Plover *Charadrius hiaticula*, as well as several Gull and Tern species (see the 'birds' chapter for additional species and further details).

In contrast to waders however, it is only relatively recently that the importance of aquatic invertebrates as a dietary component of wildfowl has been realised (particularly with regards to duck species). In fact, prior to the late 1960's wildfowl were thought to persist primarily on plant foods (Cottam, 1939; Martin & Uhler, 1939 as cited by Eulis *et al.*, 1992; Glasgow & Bardwell, 1962; McGilvrey, 1966 as cited in Eulis *et al.*, 1987). The importance of invertebrate resources to wildfowl throughout the year was first demonstrated by several detailed studies of their food habits in the late 1970's and 1980's (Swanson *et al.,* 1979; Reinecke & Owen, 1980; Euliss & Harris, 1987). Invertebrates have since been shown to be particularly important in the diet of female ducks prior to reproduction, with much of the calcium needed for egg production being sequestered from the shells of molluscs (Krapu & Reinecke, 1992). In addition, a number of studies have also identified the importance of invertebrates to duckling survival in a number of species. For instance, Hill *et al.* (1987) reported that mallard ducklings *Anas platyrhynchos* feeding in lakes with high densities of fish and low densities of aquatic macroinvertebrates survived at lower rates than those feeding in riverine habitats with low densities of fish. Similarly, in a study by Giles (1994) the importance of aquatic invertebrates to juvenile wildfowl was identified by experimental removal of fish (a subject that will be covered subsequently) from a gravel pit lake. After this management procedure (which substantially increased chironomid and gastropod densities), tufted duckling *Aythya fuligula* brood use of the lake increased greatly, and their subsequent survival also appeared to increase. In addition, Shoveler *Anas clypeata* and Pochard *Aythya ferina* nested successfully for the first time at the site.

It is obvious from the findings of such research, that a diverse and abundant supply of aquatic macroinvertebrate prey is beneficial to the majority of waterfowl (both waders and wildfowl) present within Cardiff Bay, and that they are important in the conservation of present waterfowl communities, and the promotion of Cardiff Bay as a feeding habitat. As a result it was important in the present study, to quantify the taxa present in terms of their approximate densities, and to note their distribution across various habitat types, in order that future waterfowl conservation efforts can be targeted at the most important feeding habitats present.

5.1.3. Effects of the Ttransition from a Brackish to a Freshwater Environment on Aquatic Invertebrates

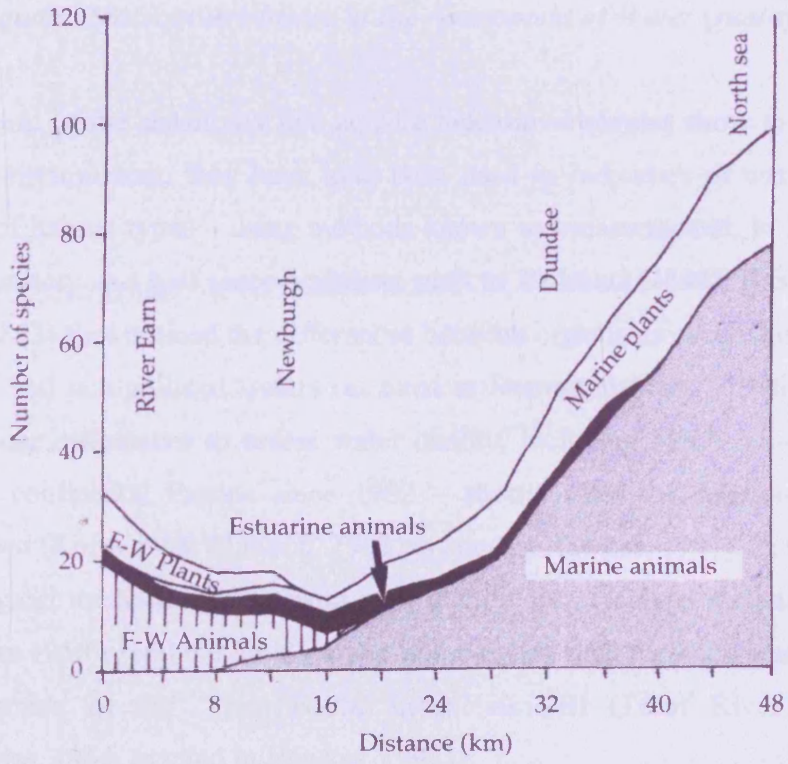
Despite being an area of huge interest, and with many developments in the pipeline which would result in the desalinisation of estuarine habitats (as discussed in the introduction), there have been very few studies of the effect of this drastic habitat change upon invertebrate communities. Although many studies, particularly in relation to birds, hypothesize upon the effect of changing invertebrate communities on the habitat quality and food resources available to birds and other dependant predators (often in relation to the Environmental Impact Assessments of such developments), there have been few opportunities to study specific successional changes of invertebrate as they actually occur. The small amount of research that has been done on this subject comes largely from the Netherlands (as is the case with this type of ecological change in general). As with the other subjects covered thus far, this research has resulted largely from studies of the numerous Dutch reclamation schemes which have served to create numerous freshwater lake systems from previously saline water bodies. The first major example of such a scheme (which has been mentioned previously with regards to macrophytes), was the closure of the Zuider Zee in 1932 to create a freshwater lake (known as the Ijsselmeer) of some 3000 km^2. Ecological changes were studied by a large team of biologists, the early results of which were published by Redeke (1922, 1936 as cited in Vaas, 1966) and de Beaufort (1954, as cited in Vaas, 1966). Noteworthy observations relating to invertebrate populations, included a population explosion of a rare, brackish water crab *Rhithropanopeus harrisi tridentatus* during the early transitional years as salinity began to decline, although the species subsequently became extinct in the lake as salinity continued to decrease further (Vaas, 1966). Additionally, there was a notable population explosion of Chironomidae (non-biting midges) in 1935 (in the middle of the transition period to freshwater) which was so severe that roads in the area were impassable to traffic – a trend that continued until sufficiently large populations of fish (of which Ruff *Acerina cernua* were the most important) built up to control the midges (Vaas, 1966).

Because of cross-language barriers, and because the research arising from the Netherlands is now relatively dated (much of it having been undertaken prior to 1970), very little of the original data are available for comparison with the current study – hence it is only the very few examples of the most notable of these ecological changes which are highlighted. The usefulness of such comparisons may be questioned in any case as these are likely to be specific to geographic location, and site specific biotic and abiotic factors, for example the observed increase of the brackish water crab in the Ijsselmeer could not occur in Cardiff Bay as the species was never present in the area. However, broad comparisons of most examples can still be made, as will be highlighted in the results and discussion sections following.

Generally, invertebrate communities of freshwater habitats are relatively diverse, and often occur at lower densities than those of estuarine habitats, though this is largely dependent on habitat type, habitat heterogeneity and water quality, the latter of which is discussed in the subsequent section. Other environmental variables which have been found to have significant effects on the community composition of invertebrates in freshwater habitats include permanence, depth, flow and altitude (Williams *et al*., 2003).

In contrast, estuarine habitats are typified by relatively low invertebrate diversity, but high invertebrate density, as a result of the high productivity of such environments. The most widespread macroinvertebrates found within UK estuaries include polychaete worms such as the ragworm *Hediste diversicolor*, molluscs such as *Macoma balthica* and *Hydrobia ulvae*, and crustaceans including the amphipod *Corophium volutator* (Davidson *et al.*, 1991). It is generally accepted that there is a clear generalised pattern of declining diversity of all species of flora and fauna as one enters the estuary from either end with a relatively few estuarine species occurring within this range (McLusky & Elliott, 2004), as illustrated in **Fig. 5.1** (after Alexander, Southgate & Bassindale, 1935).

Figure 5.1: Composition of the flora and fauna along the Tay Estuary (Scotland) ranging from the River Earn at 0 km to the North Sea at 48 km (After Alexander, Southgate & Bassindale, 1935 as cited in McLusky & Elliott, 2004).



More recently however, it has even been suggested that estuaries are representative of a two-ecocline model, where fauna inhabiting the mid-estuary are either freshwater or marine species at the very edge of their inhabitable range – with the major controlling environmental variable being the salinity gradient within the estuary (Attrill & Rundle, 2002; Attrill, 2002). This is a significant distinction as it essentially suggests that truly estuarine species do not exist. Moreover, several other studies have also come to the same conclusion (e.g. Odum, 1988; Barnes, 1989; as cited in Attrill & Rundle, 2002). Either way, taking these facts into account, we would expect fairly rapid changes in diversity to have taken place after Barrage closure, with a general increase in invertebrate diversity though this is obviously dependent on the limiting factors of freshwater environments – particularly water quality (see following section). As with other aspects of the ecological change in Cardiff Bay, we would expect the changes in invertebrate diversity over a temporal scale to roughly follow the pattern observed over a spatial scale, as one moved upstream from the bay in its pre-Barrage state – as both effectively represent a reduction in salinity.

5.1.4. Aquatic Macroinvertebrates in the Assessment of Water Quality

Because of the sensitivity that aquatic macroinvertebrates show to small changes in their environment, they have long been used as indicators of water quality in a variety of habitat types – using methods known as bioassessment. In fact, it is more than a century and half since scientists such as Kolenati (1848), Hassal (1850) and Cohn (1853) first noticed the differences between organisms occurring in organically polluted and non-polluted waters (as cited in Sharma & Moog, 1996). Methods for using these differences to assess water quality, including biotic indices, have been used in continental Europe since 1902 – shortly after the relationship was first discovered (Kolkwitz & Marsson, 1902, as cited in Hawkes, 1997). In Britain, the use of biological methods for assessing river quality only received serious consideration in the late 1950's, and the rapid growth in the use of such methods was fuelled by the establishment of the 'Trent Biotic Index' or TBI (Trent River Board, 1960; Woodiwiss, 1964, as cited in Hawkes, 1997).

Over the years at least 100 biotic indices have been developed internationally, and of these around 60% have been based on macroinvertebrates alone, thus highlighting the importance of water quality in determining invertebrate communities (De Pauw & Hawkes, 1993). The majority of these biotic indices rely on two main principles, firstly that the invertebrate taxa Plecoptera, Ephemeroptera, Trichoptera, Gammaridae, Asellidae, Chironomidae and Tubificidae disappear in this order as the level of organic pollution rises; and secondly, that the number of taxonomic groups (or taxon diversity) is reduced under the same conditions (Hellawell, 1986 as cited in Czerniawska-Kusza, 2005).

The Biological Monitoring Working Party (BMWP, 1978 as cited in Walley & Hawkes, 1997), which is based on exactly the aforementioned principles, has been used extensively in the U.K and is the basis for nationwide monitoring schemes such as the Environment Agency's 'General Quality Assessment' (GQA) of rivers and canals. Because of its ease of use, and value as a rapid bioassesment tool the BMWP scoring system has also been modified and successfully employed in a number of other countries including Spain, Holland, India, and Ecuador, as summarised by Mustow (2002) who himself used a revised version of the BMWP system to assess water quality in Thai rivers.

The original BMWP scoring system relied on the allocation to each family of a score between 1 and 10 based upon the family's perceived sensitivity to organic pollutants (1 being low, and 10 being high sensitivity), and these scores were irrespective of the family's level of abundance in the sample or the type of site from which the sample was taken (Walley & Hawkes, 1997). However, this changed in 1996, when Walley & Hawkes (1997) undertook a computer-based reappraisal of the BMWP family scores based upon biological data from the 1990 River Quality Survey of England and Wales. As a result of the reappraisal, overall, site-related and site-abundance-related derived scores, and indicator values of 34 selected families were published, as well as revised formulae for calculating the ASPT (Average Score Per Taxon). Being the chosen method for assessing water quality in the sampled aquatic habitats in Cardiff Bay, this scoring system will be covered in more detail in the following section (see methods). By using such techniques to assess water quality, I was able to identify habitats which may require more specific management in order to improve their utilisation by organisms which are higher in the food chain (namely birds in this case), and to create a more diverse ecology than polluted waters would allow.

5.1.5. Predation of Invertebrates by Fish

The effects of fish predation on invertebrate communities have been investigated in a number of large, and small scale experiments in a range of established aquatic habitats (both marine and freshwater). With regards to Cardiff Bay this theme can be divided into two particular areas of interest – firstly, and most importantly with regards to the current study, are the effects of interspecific competition between fish and waterfowl – namely the reduction by fish of the invertebrate resources available to waterfowl. The second area of interest is the potential contribution of fish predators towards reduction in larval chironomid densities, which has both positive consequences (ameliorating the public nuisance that midges cause) and negative consequences (reduction in prey density for other consumers) in the case of Cardiff Bay. There have been a number of studies undertaken, both in the UK and abroad into the effect of both interspecific competition between fish and waterfowl for invertebrate food resources, and more directly on the effect of fish predation upon invertebrate community ecology.

In a study of the effects of both waterfowl and fish on macroinvertebrates in a shallow eutrophic lake in Sweden undertaken by Marklund *et al.* (2002), it was concluded that macroinvertebrates in such lakes rarely become severely reduced by waterfowl, whereas benthivorous fish, even at relatively low densities, are able to reduce macroinvertebrates. In the same paper, an analysis of 10 literature sources found there to be a reduced macroinvertebrate density at relatively low fish densities, whilst it was common for a severe reduction to occur at high fish densities.

Studies which have focused more directly on interspecific competition between fish and waterfowl, have illustrated significant benefits of reduced fish densities on waterfowl populations. In addition to the results of the studies by Giles (1994) and

Hill *et al.* (1987) mentioned earlier, several other studies have focused on the effect of fish removal from lakes. Hanson & Butler (1994) found that macroinvertebrate density increased during the first three years after fish removal from a shallow eutrophic lake, as did usage of the habitat by migratory diving ducks. There is also evidence to suggest that some waterfowl species choose breeding sites with lower fish abundance, for instance Wagner (1997) found that breeding red-necked grebes *Podiceps grisegena* in Sweden occurred at sites which had low relative fish abundance. Additionally the dry-weight biomass of macrozoans (larger invertebrates and small vertebrates in this case) at breeding sites was up to 16 times greater than at non-breeding sites even though physical and chemical conditions did not differ significantly.

In another interesting study undertaken at Lough Neagh in Northern Ireland (Winfield *et al.*, 1992), a drastic reduction in the number of tufted ducks *Aythya fuligula* was thought to be primarily a result of competition with roach *Rutilus rutilus,* whilst in contrast, the number of great crested grebes increased in parallel with increased fish availability. A decrease in the roach population in the mid 1980s changed the trend back towards more tufted ducks and fewer great crested grebes wintering on the lake. This study is of particular relevance in the case of Cardiff Bay as roach have likewise been amongst the most abundant fish species occurring in its waters since barrage closure – a single sample collected via seine netting in 2004 contained an estimated 182,000 individuals (Greest, 2004 - see results section for further details).

In addition to affecting the community structure and abundance of invertebrate taxa, fish predation is also thought to affect size structure of invertebrate communities – for example Blumenshine *et al.* (2000), in a study of three temperate lakes, found that benthos size structure responded to a gradient of fish consumption, where higher predation rates resulted in invertebrate communities with smaller sized individuals. This fact is also of importance with regards to the current study, as larger-sized more profitable individual invertebrates are likely to be of greater importance in the diet of waterfowl.

In addition to the direct predatory effects already mentioned, invertebrate colonisation studies undertaken by Abjornsson *et al.* (2002), showed that predatory invertebrate species (including *Gerris* sp., *Notonecta glauca* and *Hydroporus* sp. amongst others) occured at lower densities in pools where fish presence could be detected, even though no direct predation took place. The findings of this research thus suggests that predatory aquatic invertebrates (namely the winged adult stages) use chemical cues to assess the quality of a site with regards to predation risk, and thus select those sites with the lowest inherent risks. Although this only applies to a select group of invertebrates, the predatory invertebrates have been shown to have significant direct (Cooper *et al.,* 1990; McPeek, 1990; Nystrom & Abjornsson, 2000) and indirect (Peacor & Werner, 1997) effects upon prey (namely non-predatory invertebrates), and so any reduction in the abundance of these predators will obviously further influence invertebrate communities regardless of the direct effects of any fish present.

The second area of interest in relation to the Cardiff Bay Barrage project is the contribution of fish predation specifically towards reduction in larval chironomid abundance within the benthic habitats of the bay. Upon adult emergence, chironomid midges are regarded as pestiferous when they occur at extremely high densities – for example, Edwards (1957, 1962 as cited in Edwards *et al.,* 1964) found densities of *Chironomus riparius* at densities in excess of 100,000/m^2 in two organically polluted rivers. High chironomid densities are typical of newly created or damaged aquatic habitats throughout the world, because they are typically the earliest colonisers due to the efficiency of the adult flight period in allowing quick dispersal over large areas, their ability to build up large populations quickly, and their tolerance of eutrophic conditions (Solimini *et al.*, 2003). In addition, Chironomidae are able to tolerate the sudden changes in habitat conditions which can be present in newly-created shallow lakes (Danell & Sjoberg, 1982). Research has shown that these periods of high density at initial colonisation are relatively short lived, and abundance is drastically reduced upon establishment of natural predators and competitors. In one such study by Danell & Sjoberg (1982), autumnal larval biomass of Chironomidae in a shallow lake of 35 ha (created by flooding a sedge meadow) reduced from 55 g per m^2 to less than 10 g per m^2 between the third and eighth years after the creation of the habitat.

As expected, bearing in mind the aforementioned, and as predicted by the Cardiff Bay Barrage Environmental Statement (EAU, 1991), Chironomidae rapidly colonised the newly created freshwater habitats of the Bay after impoundment, and have been present in significant densities ever since. As a result, considerable effort has gone into measures designed to reduce their populations whilst the ecosystem develops to a point where predation keeps the numbers to an acceptable level. Such measures have included the use of high intensity lamp based traps, and the use of the larvicide *Bacillus thuringiensis israelensis*, more commonly known by its abbreviated name of Bti. In addition several attempts have been made at encouraging natural predators of the midges into the bay (including bird, fish, and bat species), in the hope that they will actively decrease both the larval and adult populations.

It is important to remember, however, that chironomid larvae are widely considered to be a particularly valuable food resource for wetland birds (Holmes & Pitelka, 1968; Danell & Sjoberg, 1977, 1982; Eldridge, 1990; Rehfisch, 1994; & Sanders, 1999a; as cited in Sanders, 2000) and thus although fish predation may have positive effects on controlling midge populations initially, their continued presence, particularly in bird 'targeted' habitats is likely to reduce the availability of the valuable and abundant chironomid food resource to bird populations. Indirectly, this is also likely to reduce the abundance of other invertebrate taxa (particularly predatory species) which form an important part of the aquatic food web, and thus waterfowl diet.

5.2 Methods

5.2.1. Data Collection

(i). *Historical Data*

Historical data for the pre-barrage situation were collected from the Ecological Appraisal Team of Environment Agency Wales which undertook several studies of the macro-invertebrate populations of the Bay – primarily from the benthos of the deeper water areas of the Bay which were inter-tidal mudflats prior to impoundment. Because different methods and locations were used for the present study (primarily because of different research objectives) the pre-barrage data presented here is not subject to any detailed statistical analysis and any comparison with present findings should be treated with caution – the data are only presented so as to outline the major differences between the past and present communities.

(ii). *Casual Surveys*

Casual surveys of the invertebrates of the wetland reserve site were undertaken from the beginning of the current study in May 2003, thus representing the state of freshwater macro-invertebrate colonisation some three and a half years after Barrage closure. All invertebrate species, both terrestrial and aquatic, observed during visits to the site were noted, giving a general (non-exhaustive) list of the most abundant species present at the reserve. Aquatic macro-invertebrates were sampled along the shallow marginal areas of several of the reserves water bodies using a standard long-handled pond net. The majority of terrestrial invertebrates were identified in the field from prior experience, though some specimens were photographed and identified using relevant field guides. Although these preliminary surveys give a general insight into types of invertebrates present, they would have been biased towards recording only the most common and obvious species (for example Lepidoptera, Odonata, and Orthoptera), and are of limited value in providing quantitative data, hence are not subject to any detailed analysis and are provided for purpose of interest only.

(iii). *Quantitative Surveys*

Quantitative surveys of macro-invertebrates were undertaken in a total of 6 separate aquatic habitats at Cardiff Bay Wetland Reserve during May and September 2004, and September 2005. No quantitative surveys of the reserve were undertaken during 2003 due to substantial construction work for what was to be the final phase of habitat creation, which took place throughout the targeted sampling period. As well as affecting invertebrate communities directly through habitat disturbance, the construction traffic would have proved too hazardous for sampling at this time. The quantitative surveys which took place as part of the study had several aims, which were as follows:

- To gain an insight into the colonisation of the formerly aquatic habitats by freshwater macro-invertebrate species.
- To determine any variation in macro-invertebrate diversity and density between the various water bodies studied, and to attempt to explain these differences.
- To provide, based upon the findings, recommendations on the future management of the aquatic habitats in order to increase macro-invertebrate diversity and abundance.

Prior to the commencement of the first survey in May 2004, preliminary surveys of the aquatic habitats of the Wetland Reserve, and of the aquatic macro-invertebrates themselves (as mentioned previously) were undertaken. There were several aims to these preliminary studies, the first of which was to identify specific sampling sites by noting key differences in the habitat types and hydrological regimes of the various water bodies. The second aim was to gain familiarity with the type of aquatic invertebrates present. The final aim, with the help of insight gained from the previous two, was to assess the type of sampling which would work best, considering a variety of factors including substrate type, water depth, presence/absence of aquatic vegetation and accessibility.

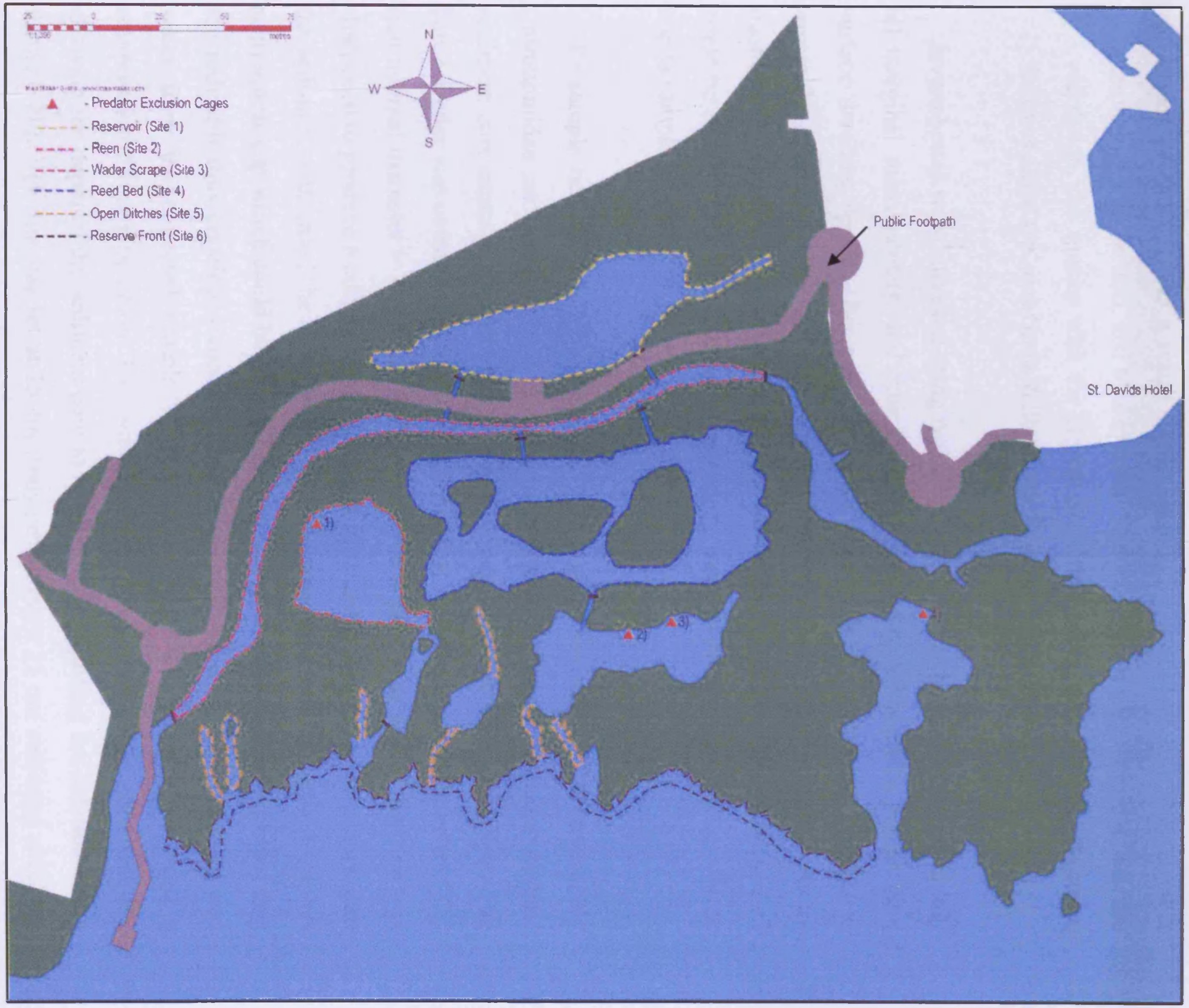
As a result of the preliminary surveys, a total of 6 distinct sampling sites were chosen to allow the maximum range of invertebrate habitats occurring on the reserve to be sampled. These sampling areas and the major differences between them, are described as follows, and are illustrated in **Figure 5.2.**

- **Site 1:-** This will be referred to henceforth as the 'Reservoir'. As its name suggests, it is the feeder reservoir for a number of other water bodies on the wetland reserve (including the 'Reen' and 'Wader Scrape'). It lies at the upper most level of the reserve, close to the former sea wall, and receives water, in the form of road/car park runoff, which is fed into the reservoir through underground pipes via a petrol filter. As a result, approximately 60% of the reservoir has been planted with Common Reed *Phragmites australis* in order to 'clean' the water of any pollutants which may be present in the urban runoff - a method that has been used widely in recent times, as *Phragmites* is capable of modifying, removing or transforming a variety of water pollutants by a combination of biological, chemical, and physical processes (Scholes *et al.*, 1998). The reservoir has a maximum depth of approximately 2 m and an enclosed area of approximately 2900 m^2.
- **Site 2**:- Also known as the 'Reen', this runs from east to west across the reserve, and is enclosed with sluices at either end, it is on a slightly lower level than the reservoir, and as previously mentioned receives water directly from it, via two channels which run underneath the public footpath. With an average width of around 2 m, and a surface area of *c.* 1400 m^2, the reen has steep banks and is fringed primarily by grass (namely Creeping Bent *Agrostis stolonifera*, and Sea Couch *Elytrigia atherica*).
- **Site 3:-** Otherwise known as the 'Wader Scrape', this is another area which is fed (indirectly) from the reservoir (by means of the 'Reen'). As its name suggests, the area was constructed primarily as a feeding habitat for waders and wildfowl. As such, the water is maintained at a shallow level (*c.* 30cm) over the majority of the area in order that the benthos is easily accessible to birds. Contained within are a series of three islands, which are aimed at providing a flood refuge and breeding area for birds. The total surface area is approximately

4500 m^2 (excluding the islands) and once again the dominant vegetation type fringing the habitat were grasses, including creeping bent, sea couch, and Yorkshire Fog *Holcus lanatus*. This area also represents a younger habitat than the previous two; since it was created during the second phase of construction during the summer/autumn of 2003 (some two years after the other habitats were created.

- **Site 4**:- Also known as the 'Reed Bed', as its name suggests, this area was intended to become dominated by Common Reed, though the planting and subsequent establishment was largely unsuccessful throughout the monitoring period, with only a small proportion being colonised along the southern edge. The major difference between this, and the other water bodies mentioned thus far, is that it does not receive a water supply from the reservoir, instead being fed by the open waters of the bay (via a connecting ditch) when at the nominal level of 4.5m AOD. A sluice, located in the connecting ditch, is aimed at preventing the water level from dropping too low in the Reed Bed area, in times of low flow, or when Bay levels are purposefully dropped for any reason. However, during extended periods when the water levels have been low in the bay, the benthos of the Reed Bed has been known to become exposed, and thus the water level across the majority of the area varies between approximately 0-30 cm. A deep channel (approximately 2 m wide) runs around the north and east of the scrape to prevent spread of Common Reed throughout the entire 1600 m^2 area. In addition to Common Reed, the same grasses predominated as in the previously mentioned sampling areas, and Branched Burr-reed *Sparganium erectum* was also common.
- **Site 5:-** The penultimate sampling area otherwise named 'Open Ditches' consisted of the numerous (formerly tidal) ditches – thus they represented naturally created habitats in an environment where they would not naturally occur (the ditches were created through erosion caused by the ebb and flow of the tide, which no longer exists). As would be expected, these ditches are open to the waters of the Bay itself, and run approximately north to south across the reserve, generally being widest at the southernmost edge of the reserve. The vegetation cover within the ditches is diverse, in terms of both aquatic and terrestrial species.

Figure 5.2: Map of the Wetland Reserve Site showing the aquatic habitats sampled during the research period.



- **Site 6: -** The final sampling area also known as the 'Reserve Front' encompasses the majority of the foreshore of the wetland reserve. Sampling was undertaken from various locations off the southernmost edge of the reserve, within the open waters of the bay. As a result of its location, it is subject to a considerable amount of wave action, and thus erosion. The site is generally devoid of aquatic vegetation, the species with the closest proximity being Alder *Alnus glutinosa*, Willows *Salix* spp, and Great Willowherb *Epilobium hirsutum*.

Invertebrates were surveyed using two clearly defined methods aimed at sampling all marginal microhabitats, and thus the maximum range of benthic, pelagic and surface dwelling species. Because one of the main objectives of sampling was to assess the specific densities of invertebrates it was necessary for the methods to be quantitative in nature, and it was decided that no single quantitative sampling method could be used to accurately survey invertebrates from all areas of the water column due to sampling biases.

To sample benthic invertebrate species with a more sedentary lifestyle (namely Chironomidae and Oligochaeta), a custom built core sampler was used to take sediment core samples from the marginal areas of the reserves aquatic habitats. The core sampler was constructed from a 1.5 m length of 110 mm external diameter (100 mm internal diameter = 78.54 cm^2 sample area) waste pipe. One end of the pipe was sharpened to produce a cutting edge, which in turn enabled the pipe to be pushed into the sediment with ease. The other end of the pipe was fitted with an airtight (rubber seal) access cap which could be screwed tight once the sampler had been pushed into the sediment thus creating a vacuum which prevented the escape of sediment and water from the collected sample. A moveable flange was constructed from a compression fitting pipe union. This was fitted near the bottom of the core sampler, allowing the depth of the sediment core to be altered by adjusting the location of the flange – although this was set at 15 cm (thus producing a 15 cm sediment core) for the entirety of the fieldwork. This depth was chosen primarily so that enough substrate filled the corer to allow a sufficient seal (and therefore a sufficient vacuum) to be created, in order that the core could be easily pulled away from the benthos when the corer was sealed and lifted.

In the field, core samples were transferred to a sample bucket by placing the core sampler over the bucket and unscrewing the access cap thus removing the vacuum. A separate, clearly labelled bucket was used for each sample. Each core was divided into two, creating two 7.5 cm depth cores, the top half of which was retained in the sample bucket, and the bottom portion (the deepest part of the core) was discarded in order that the required amount of washing of the sample in the laboratory was reduced. It was decided after preliminary investigations and a brief literature review, that this depth of core was sufficient to record the majority of the target benthic fauna, for example Olafsson (1992) noted that over 85% of the population of larval chironomids in a lake (in the South-West of the UK), inhabited the top 6 cm of the sediment.

Quantitatively sampling the pelagic and surface dwelling invertebrates proved more of a challenge in this type of habitat, because the substrate type (soft mud) and the lack of any flow prevented the use of the many standardised techniques which exist for sampling the water column and surface. As a result a new technique was developed which was deemed to be quantitative enough to reveal differences in the overall densities of invertebrates between sampling sites. This essentially involved dip net sampling along a measured length of the shoreline in a standardised way. A long handled square-framed pond dipping net, with a frame measurement of 25 cm x 25 cm, and netting size of 1 mm^2 was used to collect all of the pelagic and surface dwelling invertebrates along a 4 metre length of the shoreline as marked out by a surveyors tape measure laid out, with 2 garden canes marking the beginning and end of the transect. Thus a belt of the shoreline measuring 4 m x 0.25 m was measured – giving an approximate sample area of 1 m^2. The transect length was marked out on dry land (as close to the water as possible) in order that there was minimal disturbance to the invertebrates in the area prior to sampling. The net itself was held so that the side was exactly parallel to the substrate, and was angled slightly backwards so that the leading edge of the metal frame did not dig into the sediment but instead skimmed the surface. This not only prevented the net from becoming clogged but also prevented the collection of excess benthic invertebrate species which could not be accurately represented by this method (hence the additional core sampling).

A total of five core samples (May 2004, September 2004 and September 2005) and five 'dip net-transect' samples (September 2004 and 2005) were taken from each of the six separate sample sites. Dip net samples were also undertaken in May 2004, however these were not standardised, and thus are not comparable with data from the other two surveys. In the majority of water bodies, the margins are the most important habitats for aquatic invertebrates (Kirby, 2001), hence, at each site samples were taken from randomly chosen locations along the perimeter of the marginal shallows (within 1 m of the shore) where there was generally a water depth of between 10 and 25 cm. It was deemed that sampling the marginal habitats also provided a far more realistic representation of the invertebrate taxa which were most likely to be attainable by the majority of wader and wildfowl species (Zwarts & Wanink, 1991) in addition to providing easier access for sampling purposes as this could be undertaken from the banks surrounding the aquatic habitats. All initial sampling points were randomly chosen, with subsequent points being taken at 5 m or 10 m intervals (depending on the extent of the area being surveyed) along the shore.

In order to aid interpretation of the results, a number of chemical and physical variables were collected from each site on each sampling date. These variables included measurements of salinity and water temperature - both of which were measured with a 'YSI® combined conductivity, salinity, and temperature meter'. In addition the maximum depth (cm), and the percentage cover (estimated by eye across the entire sampling site) of aquatic vegetation and debris were all recorded for each survey site on each sampling occasion. The latter was recorded as most water bodies sampled were notably devoid of substrate other than benthic mud, and the presence of debris (mostly dead plant material washed onto the Reserve from the River Taff) was deemed to be an important possible habitat for invertebrates in its own right, providing a more complex substrate in which to live, a theory backed by various past studies, for example Street (1983) found that the addition of waste straw to pools significantly increased the availability of invertebrate food resources to waterfowl.

(iv). *Laboratory Sorting*

Because the substrate sampled consisted primarily of fine silt and mud, live 'bankside' sorting was not a feasible option (particularly in the case of the core samples due to the turbidity of the samples) and therefore all samples were transported live to the laboratory where they were washed and preserved on the day of collection, for later sorting. Each sample was washed through a series of three stacked 30 cm diameter sieves (500 μm, 5 mm, and 10 mm mesh size). The sieves were stacked in increasing size order, so that the larger pieces of debris were separated first, with the 500 μm sieve at the bottom retaining all of the macro-invertebrate fauna. In the case of the core samples, the 'cores' of silt were gently teased apart by hand into small chunks whilst in a bucket of water prior to emptying into the sieves – making the washing process more effective. A hose with a spray attachment was used to spray the samples gently, thus avoiding damaging the more delicate soft bodied invertebrates. After each sample had been thoroughly cleaned of sediment and most of the debris (vegetation etc) had been removed, the samples were emptied into sorting trays (the number depending on the size of the sample but generally a maximum of 2 trays were used), and the sieves were cleaned to avoid carryover of organisms into the subsequent sample to be washed.

All soft bodied macro-invertebrates – namely Oligochaeta, Hirudinea, and Platyhelminthes were immediately removed from the sorting tray and identified down to the lowest taxonomic level possible (to family in the case of the oligochaetes, to species for the latter two taxa), whilst alive. This was done primarily to avoid the use of the fixative formaldehyde which would have been necessary to prevent damage upon preservation of some specimens (particularly in the case of the Oligochaeta). The remainder of the samples were preserved in 80% ethyl alcohol, and stored in airtight labelled containers for later sorting. Upon sorting the remainder, each sample was first washed and then emptied into a sorting tray to which water was added in order to distribute the invertebrates more evenly. All invertebrates were initially identified to family level for the purpose of recording abundance, with further identification (to higher taxonomic levels) relying on sub-sampling of each family where further identification was practical given time constraints – as a result 'difficult' groups such as chironomid larvae, with some 588 species in the UK (Chandler 1998), were identified to family only. As a result, abundance values for individual species were not collected (except in the case where only one species was recorded per family); hence species lists given in the results section serve only as approximate indications of species diversity. The process of identification was aided by the use of a dissecting microscope, and a number of identification keys. Hammond (1983) was used for Odonata; Smaldon (1979) for the unexpected presence of a coastal prawn species. Quigley (1977) and Croft (1986) were used to identify all other taxa. Approximate length minima and maxima of invertebrates in each family were also recorded in order to give an idea of the size ranges present in each of the habitats sampled – this was done simply by choosing by eye, the smallest and largest individuals present and measuring the body length (to the nearest mm) using vernier calipers.

(v). *Fish Exclusion*

In order to investigate the effect and extent of fish predation upon benthic macro-invertebrate communities a pilot experiment was set up with the aim of comparing the densities of invertebrate fauna under predator exclusion and normal scenarios. The primary aim of this experiment was to examine the role that natural predators played in the role of reducing the densities of chironomid midge larvae. In order to exclude predators from areas of the benthos a total of four cylindrical 'exclusion cages' were installed in three separate aquatic habitats at the Wetland Reserve area - the locations of which are illustrated in **Fig. 5.2** (numbered from 1 to 4). Each cage was constructed from a wire mesh (10 mm mesh size) cylinder approximately 90 cm in diameter and 60 cm depth (see **Fig. 5.3**). The tops of the cages were constructed using a 39 inch (91.44 cm) diameter sports hoop to which a lid made from a lightweight plastic garden mesh was attached, thus creating a snug fit around the cage and creating a predator proof enclosure. As mentioned previously, the cages were installed in three locations at the Cardiff Bay Wetland Reserve (May 2005) chosen primarily with regards to minimising vandalism - thus cages were located in areas hidden from public view. The cages were pushed approximately 10 cm into the soft substrate of the pools and were subsequently checked, by netting, for any fish which may have been trapped during installation, a process which was repeated on approximately monthly basis. After a period of 4 months, the cages were sampled during September 2005 using the core sampling methodology described previously. A total of 5 cores were taken from within each exclusion cage and a further five were taken from the area immediately surrounding each of the cages (within a 30 cm reach). The core samples were subsequently sorted using the same methods as mentioned previously, with the exception that the body lengths of all individuals were recorded (as opposed to minima and maxima) in order that more detailed analysis of size differences between treatments could be undertaken.

Figure 5.3: Predator Exclusion cage in situ in the 'Reed Bed' area of Cardiff Bay Wetland Reserve.

Data relating to the fish populations of the bay, were once again obtained from Ecological Appraisal Team of Environment Agency Wales, again these data were not subject to any detailed analysis, and serve only to give an overview of the species which may have an effect on invertebrate communities. Data presented are estimated fish numbers from yearly seine netting surveys of a number of sites within Cardiff

Bay undertaken on a yearly basis between 2001 and 2006, which were kindly provided by Paul Greest (Unpublished Data, 2001-2006). Information relating to the diet type of the fish species recorded was collated from the electronic database 'FISHBASE' (www.fishbase.org).

5.2.2. Data Processing

(i). *Dip-net Sampling Data*

All raw data were entered into Microsoft Excel spreadsheets for initial manipulation and graphical data analysis. A number of diversity indices were then computed from the mean counts for each sampling site for both the 2004 and 2005 data. As abundance data was collected at the family level, the indices represent family diversity rather than species diversity. The equations for these indices are as follows:

- *Alpha Diversity (α):* $S = \alpha \log_e(1 + (N/\alpha))$
- *Margalef's Index (D_{Mg}):* $D_{Mg} = (S-1)/\log_e N$
- *Simpson's Index (D_S):* $D_S = \Sigma\{[n_i(n_i-1)]/[N(N-1)]\}$
- *Berger-Parker Index (d):* $d = 100(n_{max}/N)$
- *Shannon Index (H'):* $H' = -\Sigma\, p_i \log_e p_i$
- *Shannon Evenness (E):* $E = H'/\log_e S$

S = number of families
N = total number of individuals
n_i = total number of individuals in the ith family
p_i = proportion of individuals in the ith family
n_{max} = number of individuals of the commonest family

In order to analyse the significance of the differences in family diversity between sites within each year, a t-test was undertaken on the values of H' using the methods given by Magurran (1988). The method also includes equations for calculation of the variance of H' (VarH'), and the degrees of freedom, as follows:

$$\mathbf{VarH'} = \frac{\Sigma p_i(\log_e p_i)^2 - (\Sigma p_i \log_e p_i)^2}{N} - \frac{S-1}{2N^2}$$

$$t = \frac{H'_1 - H'_2}{\sqrt{(VarH'_1 + VarH'_2)}}$$

$$df = \frac{(VarH'_1 + VarH'_2)^2}{[(VarH'_1)^2 / N_1] + [(VarH'_2)^2 / N_2]}$$

In addition BMWP scores and the corrsponding values of ASPT (Average Score Per Taxon) were calculated for each site in each of the two years used for comparison. For the purpose of this study the pool specific BMWP scores of the revised BMWP scoring system (Walley & Hawkes, 1996 & 1997) were used as this habitat type was the most similar to those sampled. This was done by simply assigning a relevant score (See **App. 5.1**) to each family recorded, and summing the scores for each site sampled within each of the sampling years. The ASPT is the total BMWP score for a site, divided by the number of families recorded at the site. An indication of the water quality of the sampled aquatic habitats compared could then be gained by comparing the total BMWP scores to the following five point scale (Anglian Water Authority, 1986):

1. <25 = Poor
2. 26-50 = Moderate
3. 51-100 = Good
4. 101-150 = Very good
5. >150 = Exceptional

(ii). *Core Sample Data*

Although all taxa 'sampled' by the core sampling method were recorded, it was deemed that the density values would prove far too inaccurate for the non-benthic taxa which were recorded in several of the samples, primarily due to their more random distribution, and the small sampling area of the corer. As a result, only chironomid and oligochaete densities recorded using this method will be presented in the results section, however the complete results can be found in **App. 5.2**.

(iii). *Fish Exclusion Data*

Values presented in the results section relating to the fish populations in Cardiff Bay were derived by averaging the total fish catches for all sites within a particular year, giving a broad overview of fish population and community changes over the monitoring period. It is realised that this method of data presentation is not the most accurate for presentation of fish count data, as it is normal to have high variablilty in abundance between different samples, due largely to the shoaling behaviour of fish, however, for the purpose of this study the method is adequate to give a general outline of the fish communities present.

(iv). *Statistical Analysis*

Because of the large number of zero values in the collected data in all instances, the assumptions of normality were very rarely met and data transformations were unsuccessful for the purpose of the majority of parametric tests. As a result, statistical analysis of this data relies on a variety of simple χ^2 and t-tests. In the latter case, all tests were two-tailed.

5.3 Results

5.3.1. Casual Invertebrate Surveys at Cardiff Bay Wetland Reserve

Casual surveys of invertebrates undertaken during the period of monitoring (2003-2006) at Cardiff Bay Wetland Reserve revealed a fairly diverse invertebrate ecology (see **Table 5.1**) considering the survey techniques used. These surveys were aimed primarily at providing an insight into the invertebrate communities present at the Wetland Reserve which were not subject to detailed quantitative sampling (although a number of aquatic species were recorded during these surveys). A total of 58 species were recorded, the majority of these (41 species) were recorded after chance encounters during visits to the site, 12 species were recorded only via casual dip samples undertaken during preliminary surveys of the aquatic habitats, and a further 5 species were recorded by both methods. A total of 13 orders of invertebrates were recorded, the majority of species belonging to either Lepidoptera (21 species), Odonata (10 species), Hemiptera, or Gastropoda (5 species each). Orthoptera, Diptera, Coleoptera and Araneae were represented by 3 species each. The remainder of the recorded taxa (Amphipoda, Trombidiformes, Isopoda, Decapoda, and Arhynchobdellida) were represented by a single species each. As expected, the most common species recorded using these methods were generally quite conspicuous due to size, abundance or a mixture of both.

The large proportion of Lepidoptera recorded can be attributed to the diverse vegetation which provides food resources for the larvae of a number of species (e.g. Willow/Sallow *Salix* spp. was a food plant for the numerous larvae of the Eyed Hawkmoth *Smerinthus ocellata*), and a number of flowering plant species (including Butterfly Bush *Buddleja davidii*) attracted the imago of a number of nectar feeding species. The abundance and diversity of Odonata encountered at the reserve can be explained by their strong affinity with wetland habitats. The most common odonates were the Black-tailed Skimmer *Orthretum cancellatum* and Common Darter *Sympetrum stiolatum* with regards to dragonflies, though the Blue-tailed Damselfly *Ischnura elegans* and Common Blue Damselfly *Enallagma cyathigerum* were by far the most abundant adult odonates during the summer months. The large extent of sea couch *Elytrigia atherica* grassland proved to be an attractive habitat to Orthoptera – particularly the Short-winged Conehead *Conocephalus dorsalis* which has remained the most commonly encountered orthopteran species throughout the monitoring period.

Another highly abundant species at the wetland reserve is the lycosid spider *Pirata piraticus* – a marsh specialist that is able to walk and hunt on water surfaces. It is likely that the high densities of this species (estimated to be *c*. 150 per m^2 in marginal habitats (personal observations) are a result of the large numbers of chironomid midge which emerge from the surface of the aquatic habitats during the spring and summer months – providing a highly abundant and easily available food resource to the predatory spiders.

The micro-moth *Depressaria daucella* is worth mentioning here for its relationship with the host foodplant Hemlock Water-dropwort *Oenanthe crocata*. Again this species is extremely abundant in its larval stage, and it is thought that this has been a result of the high densities of the foodplant which became established early on in the macrophyte succession at the reserve due to large amount of seed stock carried down the rivers Taff and Ely. The Ditch Shrimp *Palaemonetes varians* was one of the more unusual species recorded during the casual surveys – a relic of the former saltmarsh, with viable populations in several of the freshwater aquatic habitats of the reserve (as will be covered in more detail in the following sections). A final species worth mentioning here is the Small Ranunculus *Hecatera dysodea*, a moth which became extinct in the early part of the 20th century and has since become re-established in small areas of Kent and Essex (Kimber, 2007). The larvae of this species have been recorded on a number of occasions feeding upon Prickly Lettuce *Lactuca serriola* – a ruderal species which has been fairly common in areas of the reserve which have been subject to recent disturbance through development of new habitat features (see macrophyte section).

Table 5.1: Species recorded in casual surveys of Cardiff Bay Wetland Reserve, along with method (Casual Encounter (CE) or Dip Sample (DS)), and stage of Life-cycle observed.

Order	Species		Method	Life-cycle Phase
Odonata	Banded Demoiselle	*Calopteryx splendens*	CE	Imago
	Black-tailed Skimmer	*Orthetrum cancellatum*	CE	Imago
	Blue-tailed Damselfly	*Ischnura elegans*	CE	Imago
	Broad Bodied Chaser	*Libellula depressa*	CE	Imago
	Common Blue Damselfly	*Enallagma cyathigerum*	CE/DS	Nymph, Imago
	Common Darter	*Sympetrum striolatum*	CE	Imago
	Common Hawker	*Aeshna juncea*	CE/DS	Nymph, Imago
	Emperor Dragonfly	*Anax imperator*	CE	Imago
	Migrant Hawker	*Aeshna mixta*	CE	Imago
	Red-eyed Damselfly	*Erythromma najas*	CE	Imago
Orthoptera	Common Field Grasshopper	*Chlorthippus brunneus*	CE	Imago
	Lesser Marsh-grasshopper	*Chorthippus albomarginatus*	CE	Imago
	Short-winged Conehead	*Conocephalus dorsalis*	CE	Imago
Lepidoptera	Buff-tip	*Phalera bucephala*	CE	Larvae
	Cinnabar	*Tyria jacobaeae*	CE	Larvae
	Comma	*Polygonia c-album*	CE	Imago
	Common Blue	*Polyommatus icarus*	CE	Imago
	Drinker	*Euthrix potatoria*	CE	Larvae
	Elephant Hawkmoth	*Deilephila elpenor*	CE	Larvae
	Eyed Hawkmoth	*Smerinthus ocellata*	CE	Larvae
	Knot Grass	*Acronicta rumicis*	CE	Larvae
	Large Skipper	*Ochlodes venata*	CE	Imago
	Large White	*Pieris brassicae*	CE	Imago
	Marbled White	*Melanargia galathea*	CE	Imago
	Meadow Brown	*Maniola jurtina*	CE	Imago
	N.A	*Depressaria daucella*	CE	Larvae
	Painted Lady	*Vanessa cardui*	CE	Imago
	Peacock	*Inachis io*	CE	Imago
	Red Admiral	*Vanessa atalanta*	CE	Larvae
	Sallow Kitten	*Furcula furcula*	CE	Larvae
	Six-spot Burnet	*Zygaena filipendulae*	CE	Imago
	Small Ranunculus	*Hecatera dysodea*	CE	Larvae
	Small Tortoiseshell	*Aglais urticae*	CE	Larvae, Imago
	Small White	*Pieris rapae*	CE	Imago
Diptera	Horse Fly	*Tabanus bovinus*	CE	Imago
	Hoverfly	*Volucella zonaria*	CE	Imago
	Non-biting Midge	*Chironomous spp*	CE/DS	Larvae, Imago
Decapoda	Ditch Shrimp	*Palaemonetes varians*	DS	Adult
Amphipoda	Freshwater Shrimp	*Gammarus spp.*	DS	Adult
Isopoda	Freshwater Hoglouse	*Asellus aquaticus*	DS	Adult
Gastropoda	Bladder Snail	*Physa fontinalis*	DS	Adult
	Brown Lipped Snail	*Cepea nemoralis*	CE	Adult
	Garden Snail	*Helix aspersa*	CE	Adult
	Pond Snail	*Lymnaea palustris*	DS	Adult
	Ramshorn Snail	*Anisus vortex*	DS	Adult
Arhynchobdellida	Leech	*Erpobdella octoculata*	DS	Adult
Araneae	Labyrinth Spider	*Agelena labyrinthica*	CE	Adult
	Nursery Web-Spider	*Pisaura mirabilis*	CE	Adult
	Wolf Spider	*Pirata piratica*	CE	Adult
Trombidiformes	Water Mite	*Hydrachna sp*	DS	Adult
Coleoptera	Diving Beetle	*Hydroglyphus pusillus*	DS	Adult
	Devil's Coach-horse	*Ocypus olens*	CE	Adult
	Green Dock Beetle	*Gastrophysa viridula*	CE	Adult
Hemiptera	Common Pondskater	*Gerris lacustris*	CE/DS	Adult
	Greater Water Boatman	*Notonecta glauca*	DS	Adult
	Lesser Water Boatman	*Corixa punctata*	DS	Adult
	Water Measurer	*Hydrometra stagnorum*	CE/DS	Adult
	Water Scorpion	*Nepa cinerea*	DS	Adult
CE = Casual Encounter, DS = Dip Sample				

5.3.2. Quantitative surveys

(i). *Chemical and Physical Variables*

The following presents the results of a brief survey of several chemical and physical variables, undertaken at the time of quantitative sampling in each of the six sampling sites at Cardiff Bay Wetland Reserve (See **Table 5.2** and **App. 5.3**).

According to the classification of aquatic habitats set out by Mitsch & Gosselink (1986), the aquatic habitats sampled at the Wetland Reserve vary between freshwater (<0.5 ppt) for sites 4, 5 and 6 on all sampling occasions, to slightly oligohaline, or brackish (0.5-5 ppt) for sites 1, 2 and 3 on all sampling occasions. The slight difference in salinity between sites 1-3, and 4-6 can be explained by the connectivity of the aquatic habitats to the open waters of the Bay. Unsurprisingly, site 6 (the 'Reserve Front') had the lowest salinities overall, simply because the site is part of the open waters of Cardiff Bay, and thus is subject to significant freshwater flow from the rivers Taff and Ely. 'Site 5' or the 'Open Ditches', showed only a slight variation in salinity from 'Site 6', as the habitat is also predominantly open to the waters of the Bay, although is not subject to the currents to which the marsh edge is. 'Site 4', is also partially open to the water of the Bay, although this is only true when water levels in the Bay rise above the 4.5 m AOD nominal level, as there are sluices set at the same height to maintain the water level, however, there is still some degree of flushing and thus salt leachate would be diluted somewhat. Conversely, the first three sites are all largely devoid of any direct connection to the open waters of the Bay (except during the very rare periods of extremely high water levels which have been known to cover all aquatic habitats south of the 'Reen'), and thus predominantly rely on dilution of any salts leached from the sediments by rainfall. The reason for the slight differences between the salinities of sites 1-3 is unclear, though it is likely that the disparity seen in 'Site 3' ('Wader Scrape') is due to fact that it is a newer habitat (created in 2003 as opposed to 2001) and as such the sediments were subject to more recent disturbance. Additionally 'Site 3' is much shallower than all other habitats (<35cm), and as such warms far more rapidly in hot weather (as indicated by the temperature of 20.5 °C in September 2004), and therefore is likely to be subject to significant evaporation, concentrating salts in the water. It is worth remembering however, that even the highest salinity recorded (1.0 ppt) is at the lower range of what would be considered to be brackish (oligohaline).

Table 5.2: Mean salinity and temperature, maximum depth, and the percentage cover of aquatic vegetation and debris of the six sampling sites in May and September 2004 and September 2005.

Variable	Date	Site					
		1	2	3	4	5	6
Mean Salinity (ppt)	May-04	0.7	0.6	0.9	0.4	0.2	0.2
	Sep.-04	0.7	0.5	0.7	0.2	0.2	0.1
	Sep.-05	0.6	0.7	1.0	0.3	0.2	0.1
Mean Temperature (°C)	May-04	18.0	18.0	18.2	17.8	16.5	15.9
	Sep.-04	18.2	18.3	20.5	18.1	17.6	17.2
	Sep.-05	16.8	16.8	17.2	16.7	15.8	15.3
Max. Depth (cm)	May-04	190.0	120.0	35.0	150.0	60.0	*
	Sep.-04	170.0	85.0	20.0	125.0	55.0	*
	Sep.-05	175.0	90.0	30.0	135.0	60.0	*
Aquatic Vegetation (%)	May-04	10	15.0	<5	15.0	40.0	*
	Sep.-04	15	35.0	15.0	25.0	70.0	*
	Sep.-05	25	40.0	15.0	30.0	75.0	*
Debris (%)	May-04	<5	<5	<5	10	20	*
	Sep.-04	<5	<5	<5	10	25	*
	Sep.-05	<5	<5	<5	10	20	*

* Not assessed as Site 6 (the Reserve Front) is not easily delimited, as it is not an enclosed feature

With regards to aquatic vegetation, the 'Open Ditches' (Site 5) had by far the highest percentage cover overall (between 40 % in May 2004 and 75 % in September 2005). This is largely due to the physical nature of the ditches - being narrow with marginal vegetation making up a greater proportion of the total area, in addition to the fact that they are sheltered from wind and strong currents, allowing establishment of less hardy aquatic species. In general, the habitats with the largest extent of open water (sites 1, 3, and 4) had the lowest percentage cover of aquatic macrophytes, and much of the macrophyte cover in these habitats consisted of marginal emergent species such as Common Reed *Phragmites australis*, and Branched Bur-reed *Sparganium erectum.* Where present, the most abundant submerged macrophyte species included Canadian Waterweed *Elodea canadensis*, Nuttall's Waterweed *Elodea nuttallii*, and Spiked Water-milfoil *Myriophyllum spicatum.*

Debris, which in this case refers primarily to plant material washed down the River Taff and deposited at the reserve during high flows, was only significant in the 'Open Ditches' (Site 5), and the 'Reed Bed' (Site 4), both of which are open to the waters of the Bay during periods of high flow.

(ii). *Dip-net Sampling Surveys*

Macroinvertebrates inhabiting the surface, pelagic, and benthic-pelagic interface of the aquatic habitats at Cardiff Bay Wetland Reserve were deemed to be most accurately recorded during the dip-net sampling surveys, the results of which (**Table 5.3** and **App. 5.4**) are discussed as follows.

A total of 23 families were recorded in all samples over the two year period, with 17 families recorded in 2004, and 22 families recorded in 2005. The most commonly occurring taxa were Chironomidae, Gammaridae and Physidae, as they were recorded at all sites in both 2004 and 2005. Gammaridae were also the most abundant taxa in both years with an 'all samples' average density of 34/m^2 (± 4 SE) in 2004, a density which almost doubled to 67/m^2 (± 8) in 2005.

There was no significant difference in the overall abundance of families within sites between years ($\chi^2 = 5.69$, $n = 12$, $p > 0.200$), but this is a rather general test and does not reflect the complexity of the changes in abundance within families. When the overall changes in abundance between years was examined (last two columns of **Tab. 5.3**), there was a significant increase in the abundance of gammerids ($t_8 = 3.72$, $p = 0.001$-0.010), and a significant decrease in the number chironomids ($t_8 = 3.30$, $p = 0.01$-0.02). None of the other changes were statistically significant.

A wider diversity of families was recorded in sites 1 and 4 in 2004 (see the α values at the bottom of **Tab. 5.3**), and in sites 5 and 6 in 2005, reflecting the different rates at which these sites were colonized. Overall, family diversity was higher in 2005. The water bodies on the wetland reserve (sites 1-5) were all more diverse than the adjacent waters of Cardiff Bay (site 6) in 2004, but not in 2005.

Probably the best index reflecting both diversity and abundance is MacArthur's Index (H'), and this has the advantage of being amenable to statistical testing (Magurran, 1988). The Reservoir was the site most dominated by single families in both 2004 and 2005, as reflected in the percentage d value in **Tab. 5.3**. Tubificids dominated the Reservoir in 2004 and gammerids in 2005. This coincides with a change from turbid conditions in the former year to clearer conditions in the latter.

MacArthur diversity increased significantly between 2004 and 2005 in three of the pools (site 2, $t_{17} = 4.06$, $p < 0.001$; site 3, $t_{16} = 3.94$, $p = 0.001\text{-}0.010$; site 3, $t_{19} = 4.89$, $p < .001$), and decreased in two (site 1, $t_{13} = 14.6$, $p < 0.001$; site 5, $t_{22} = 3.34$, $p = 0.001\text{-}0.010$). There was no significant change in MacArthur diversity in the adjacent Bay waters (site 6, $t_{15} = 0.40$, $p > 0.200$) which remained low in both years.

Finally, the BMWP scores, and the derived 'Average Score Per Taxon' (ASPT) values calculated for the dip-net sampling surveys give an interesting insight into the variations in water quality within the separate aquatic habitats monitored. In 2004, the water quality at the sampled sites, as indicated by the derived BMWP scores was lowest at Site 6 (16.90), and highest at Site 1 (38.30).

Table 5.3: Results of the quantitative dip net sampling surveys undertaken in September 2004 & 2005.

Family	Mean density (numbers $family^{-1}$ m^{-2}) of 5 samples per site ± SE													
	September 2004						September 2005						All Sites 2004	All Sites 2005
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6		
Asellidae				2.4 ± 0.9	13.2 ± 3.9					6.6 ± 3.0	8.4 ± 3.0		2.6 ± 1.1	2.5 ± 0.9
Chironomidae	14.2 ± 5.1	3.4 ± 1.9	2.8 ± 1.3	9.4 ± 2.3	4.8 ± 1.6	21.6 ± 3.9	1.6 ± 1.0	3.6 ± 0.7	4.0 ± 1.2	6.6 ± 1.3	1.2 ± 1.0	4.0 ± 1.0	9.4 ± 1.7	3.5 ± 0.5
Coenagrionidae	2.6 ± 1.8	35.0 ± 11.8	11.4 ± 3.4	74.6 ± 17.5	19.4 ± 3.0			25.0 ± 6.3	25.4 ± 6.5	43.6 ± 10.3	26.2 ± 9.5		23.8 ± 5.8	20.0 ± 3.8
Corixidae	11.4 ± 3.3	3.8 ± 1.5	15.4 ± 3.5	5.8 ± 2.1	21.4 ± 4.9	70.8 ± 15.6		4.0 ± 1.6	9.6 ± 1.6	26.6 ± 5.6		21.4 ± 5.3	21.4 ± 5.0	10.3 ± 2.3
Daphniidae		14.6 ± 7.0			3.0 ± 1.4					11.6 ± 2.0			2.9 ± 1.5	1.9 ± 0.9
Dytiscidae				0.8 ± 0.6						3.4 ± 1.2	6.8 ± 2.7		0.1 ± 0.1	1.7 ± 0.7
Erpobdellidae	0.2 ± 0.2							1.6 ± 0.8			0.8 ± 0.6	0.6 ± 0.4	0.0 ± 0.0	0.5 ± 0.2
Gammaridae	28.8 ± 10.5	37.2 ± 9.0	57.8 ± 19.3	30.4 ± 4.7	20.4 ± 5.6	29.6 ± 4.9	91.8 ± 12.3	39.4 ± 9.4	83.0 ± 25.1	39.6 ± 8.8	62.8 ± 20.2	83.2 ± 22.2	34.0 ± 4.4	66.6 ± 7.6
Gerridae	1.8 ± 1.1						2.6 ± 0.8	1.6 ± 0.5	1.8 ± 0.7	1.2 ± 0.6	2.2 ± 0.7	1.6 ± 0.9	0.3 ± 0.2	1.8 ± 0.3
Glossiphonidae										1.4 ± 0.5	0.8 ± 0.6	3.2 ± 1.0		0.9 ± 0.3
Hydrachnidae	1.6 ± 1.0												0.3 ± 0.2	0.0 ± 0.0
Libellulidae	0.6 ± 0.4	0.4 ± 0.2	1.6 ± 0.8	2.0 ± 1.4				0.8 ± 0.4					0.8 ± 0.3	0.1 ± 0.1
Lymnaeidae	1.8 ± 1.8			2.4 ± 0.9			18.8 ± 1.8	9.0 ± 4.1	6.8 ± 1.8	5.0 ± 1.3	12.2 ± 3.5	6.2 ± 2.1	0.7 ± 0.4	9.7 ± 1.3
Nepidae											0.8 ± 0.4			0.1 ± 0.1
Notonectidae			0.6 ± 0.4	0.4 ± 0.2							0.8 ± 0.4		0.2 ± 0.1	0.1 ± 0.1
Odontoceridae												0.8 ± 0.4		0.1 ± 0.1
Palaemonidae		1.6 ± 0.8	5.8 ± 5.8					1.2 ± 0.6	11.2 ± 3.9				1.2 ± 1.0	2.1 ± 1.0
Physidae	34.0 ± 14.2	7.8 ± 2.3	26.8 ± 4.1	26.8 ± 6.5	16.2 ± 3.5	13.4 ± 4.5	6.6 ± 2.2	18.8 ± 5.1	18.6 ± 3.6	127.8 ± 29.3	49.8 ± 14.3	12.2 ± 5.4	20.8 ± 3.1	39.0 ± 9.3
Planariidae											3.2 ± 2.3			0.5 ± 0.4
Planorbidae	1.4 ± 1.0				5.8 ± 2.4	10.6 ± 3.7	4.6 ± 2.0		7.8 ± 2.8		72.6 ± 27.5		3.0 ± 1.0	14.2 ± 6.4
Sialidae											0.2 ± 0.2			0.0 ± 0.0
Tubificidae	98.4 ± 20.3											0.4 ± 0.2	16.4 ± 7.5	0.1 ± 0.0
Valvatidae												3.0 ± 1.4		0.5 0.3
Total Numbers m^{-2}	196.8	103.8	122.2	155.0	104.2	146.0	126.0	105.0	168.2	273.4	248.8	136.6	138.0	176.3
Number of Families	12	8	8	10	8	5	6	10	9	11	15	11	17	23
BMWP Scoring:														
BMWP Score	38.30	22.60	27.00	36.70	23.40	16.90	20.50	32.70	28.20	34.90	53.60	44.20		
No. of BMWP Scoring Taxa	11	6	7	10	7	5	6	9	8	10	15	11		
ASPT	3.48	3.77	3.86	3.67	3.34	3.38	3.42	3.63	3.53	3.49	3.57	4.02		
Measures of Diversity:														
α	2.82	2.02	1.92	2.39	2.02	1.00	1.31	2.72	2.03	2.30	3.50	2.82	5.10	6.64
Dmg	2.08	1.51	1.46	1.78	1.51	0.80	1.03	1.93	1.56	1.78	2.54	2.03	3.25	4.06
Ds	0.307	0.263	0.294	0.301	0.153	0.307	0.554	0.233	0.286	0.275	0.201	0.403	0.15	0.21
d	50.00	35.84	47.30	48.13	20.54	48.49	72.86	37.52	49.35	46.74	29.18	60.91	24.70	37.80
H'	1.53	1.52	1.48	1.50	1.91	1.37	0.93	1.68	1.63	1.65	1.83	1.35	2.04	1.91
E	0.61	0.73	0.71	0.65	0.92	0.85	0.52	0.73	0.74	0.69	0.68	0.56	0.72	0.61
VarH	0.0056	0.0063	0.0063	0.0062	0.0022	0.0031	0.0092	0.0074	0.0060	0.0038	0.0034	0.0106	0.0046	0.0070

(iii). *Benthic Invertebrates*

The results shown in **Table 5.4** (also see **App. 5.2**) outline the densities of selected benthic invertebrates recorded via the core sampling methodology at each of the six sampling sites. Although a total of 18 taxa were recorded during sorting of the core samples; only chironomids, tubificids, and lumbricids are considered here as it was deemed that these interstitial benthic invertebrates would be far more accurately recorded than those less associated with the sediment itself. In addition, these families (particularly chironomidae) represent a particularly important food resource to a variety of waterfowl species, being largely sedentary (and thus are 'easy' prey), as highlighted in **Section 5.1.2.**

Chironomidae were the most commonly occurring of the three families, with significant densities recorded at all sites on all occasions. The density of tubificid worms was extremely high at Site 1 in September 2004, but they were absent from core samples from the same site in May 2004, and September 2005. Lumbricid worms were only recorded from Site 6 (the 'Reserve Front') in September 2005. Chironomid densities in all cases were far higher than those recorded during the dip-net samples discussed previously, highlighting the importance of using a specific benthos sampling technique for this family in particular.

Despite the fact that much higher numbers were recorded, the trends were very similar to those revealed by dip-netting, with tubificids only present in large numbers at site 1 in 2004 and in small numbers at site 6 in 2005. Chironomids apparently declined overall between May 2004 and September 2005, but the difference was not significant (two-tailed $t_8 = 1.78$, $p = 0.10\text{-}0.20$), no doubt due to the high variability between samples, and the fact that the trend was in the opposite direction in the adjacent Bay waters. It is rather ironic that chironomid numbers, although much lower in the dip net samples, were much more consistent, thus explaining why significant differences could be detected in the latter. No doubt this is due to fact that chironmids became more evenly distributed in the water column.

Table 5.4: Estimated Mean Densities (individuals/m^2) of selected benthic macroinvertebrates (Chironomidae, Tubificidae & Lumbricidae) recorded via the core sampling method during May/September 2004 and September 2005.

Date	Family	Mean Densities (individuals per m^2) ± SE						
		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	All Sites
May-04	Chironomidae	1680.7 ± 356.5	967.7 ± 168.9	1400.6 ± 175.5	1757.1 ± 365.5	2062.6 ± 447.3	840.3 ± 383.2	1451.5 ± 147.7
	Total Density	**1680.7**	**967.7**	**1400.6**	**1757.1**	**2062.6**	**840.3**	
Sep-04	Chironomidae	1324.2 ± 482.5	2139.0 ± 374.3	865.8 ± 181.9	1655.2 ± 402.6	611.2 ± 147.4	916.7 ± 214.6	1252.0 ± 154.8
	Tubificidae	2342.8 ± 641.2						390.5 ± 189.0
	Total Density	**3666.9**	**2139.0**	**865.8**	**1655.2**	**611.2**	**916.7**	
Sep-05	Chironomidae	152.8 ± 74.2	1451.5 ± 268.9	407.4 ± 109.5	713.0 ± 111.0	865.8 ± 190.6	2113.6 ± 634.8	950.7 ± 165.5
	Lumbricidae						25.5 ± 25.54	4.2 ± 4.2
	Tubificidae					636.6 ± 251.4	254.6 ± 120.8	148.5 ± 61.1
	Total Density	**152.8**	**1451.5**	**407.4**	**713.0**	**1502.4**	**2393.7**	

(iv). *Comparison with Pre-Barrage Invertebrate Populations*

The invertebrates shown in **Table 5.5** represent those recorded by Environment Agency Wales during sampling undertaken adjacent to the Taff/Ely Saltmarsh in 1999, representing the invertebrate communities typical of the Pre-Barrage estuarine environment (**App. 5.5**). As can be seen, the benthos in this case was dominated by Spionidae, with an extremely high estimated (by multiplying actual value per 0.05 m^2 to obtain a value per 1 m^2) mean density of 26 x 10^3 (± 2 x 10^3) individuals per m^2. Also found at very high densities in the pre-barrage situation were Tubificidae (Oligochaeta), and Nereidae (Polychaeta) worms, as well as relatively high densities of *Hydrobia* snails – all of which are typical of a productive estuarine environment.

When we compare the family diversity values, there was a dramatic increase between 1999 and 2004 (**Tab. 5.6**, $t_{17} = 41.1$, $p < 0.001$), and then a small, but still statistically significant decline between 2004 and 2005 (**Tab. 5.6**, $t_{39} = 5.25$, $p < 0.001$). The very high variability in chironomid density in the smaller number of 1999 samples is notable. This comparison should be treated with caution however, as sampling was based on different methods in very different environments.

Table 5.5: Estimated mean density (Individuals per $m^2 \pm$ SE) of all invertebrate taxa recorded near the site of Cardiff Bay Wetland Reserve in 1999 (from a total of 3 samples), along with family diversity indices. (Environment Agency Wales, Unpublished Data).

Family	**Species**	**Mean Density (m^2) ± SE**
Unknown (Nematoda)	Unknown	240 ± 92.4
Tubificidae	*Tubificoides benedeni/T. brownae*	6400 ± 3603.6
Spionidae	*Streblospio shrubsolii*	26026.7 ± 2119.3
Nereidae	*Nereis diversicolor*	3253.33 ± 519.1
Phyllodocidae	*Eteone longa*	293.333 ± 148.5
Sabellidae	*Manayunkia aestuarina*	640 ± 166.5
Tellinidae	*Macoma balthica*	540 ± 221.2
Hydrobiidae	*Hydrobia ulvae*	1680 ± 468.8
Total		**39073.3 ± 5453.6**
α		**0.74**
Dmg		**0.66**
Ds		**0.48**
d		**66.60**
H		1.10
E		0.53
VarH		0.00003

Table 5.6: Comparison of macroinvertebrate family diversity in 1999, 2004, and 2005.

Diversity Index	**1999**	**2004**	**2005**
α	0.74	5.10	6.64
Dmg	0.66	3.25	4.06
Ds	0.47	0.15	0.21
d	66.05	24.70	37.80
H	1.10	2.04	1.91
E	0.54	0.72	0.61
VarH	0.00003	0.0046	0.0070

5.3.3. Effect of Fish Exclusion on the Aquatic Invertebrate Communities of Cardiff Bay Wetland Reserve

(i). *Potential Fish Predators of Invertebrates in Cardiff Bay*

Data collated from the annual seine netting surveys undertaken by Environment Agency Wales (**App. 5.6**), revealed a total of 18 species which have been recorded over the period 2001-2006 (see **Table 5.6**). The overall trend was of a steady, 35-fold, increase in numbers between 2001 and 2006, almost all of this increase being attributable to the Roach *Rutilus rutilus*. Mean catches of this species ranged between 33 (± 21) fish in 2006, and 21 x 10^3 (± 16 x 10^3) fish in 2004. Also common were Chub *Leuciscus cephalus* and Gudgeon *Gobio gobio*, the former with mean catches of between 37 (± 24) and 9 x 10^3 (± 7 x 10^3) individuals, and the latter ranging between 42 (± 25) and 9 x 10^3 (± 8 x 10^3) individuals. Three-spined Stickleback *Gasterosteus aculeatus*, and Minnow *Phoxinus phoxinus* were also recorded during all surveys, but their abundance within catches was far lower than the previous three species.

Notably, all species recorded over the period are potential predators of invertebrates – with 39% of species having a diet consisting entirely of invertebrates, 17% feeding on a variety of fauna (vertebrates and invertebrates), with the remainder (44%) being omnivorous, with invertebrates forming part of a more varied diet. Interestingly, the two most commonly occurring species (Roach and Chub) are both omnivorous species, and it may be a result of their ability to utilise a wide variety of food resources which has enabled them to out compete other species during the period of rapid ecological change in which the surveys took place.

As can be seen from the large standard error values of the mean count data, there is considerable variation in the numbers of fish caught within each year. This is primarily a result of the significant variation between the sampling sites used, and the clumped distribution of fish caused by shoaling behaviour. Nevertheless, the results presented provide an insight into the fish species present, and thus are adequate for the purpose of this study.

Table 5.7: Mean (± SE) seine net catch of fish species Per Year in Cardiff Bay over the period 2001-2006. Diversity shown for each year are values of Fisher's alpha (α), Margalef's (DMg), Simpson's (DS), Shannon (H), and Shannon Evenness (E) index. The dietary preference of each fish species is also shown.

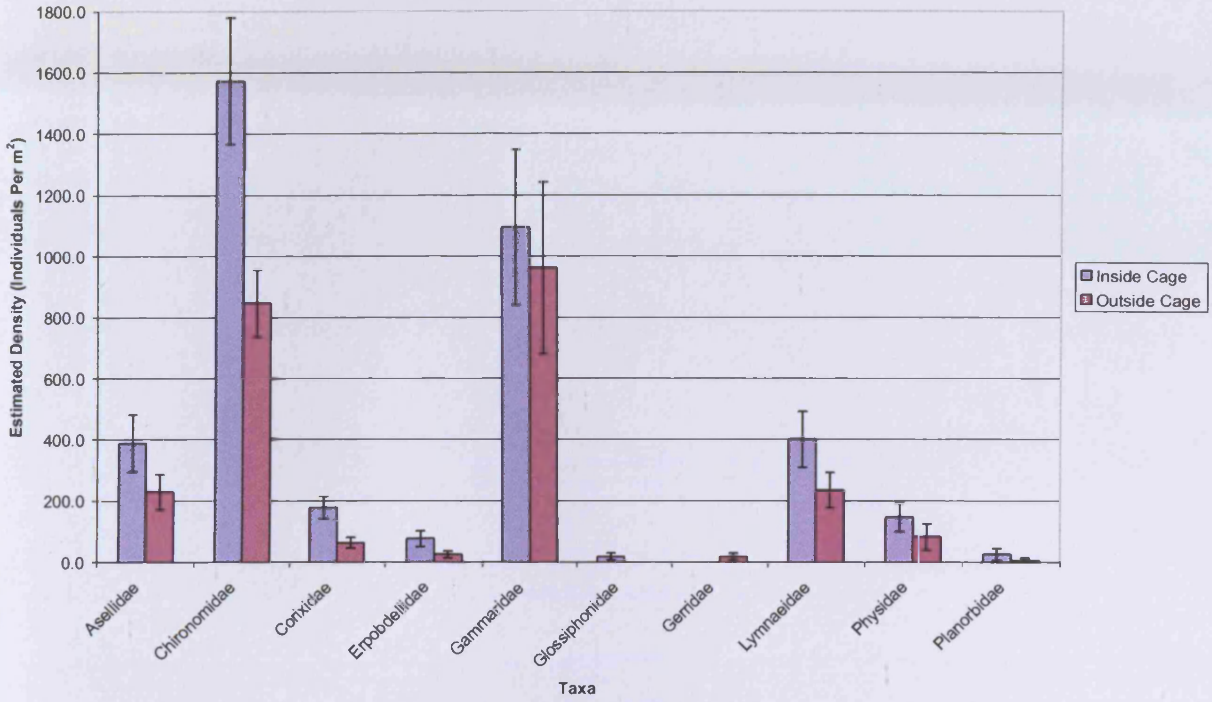
Species		2001 (*n=11*)	2002 (*n=16*)	2003 (*n=11*)	2004 (*n=11*)	2005 (*n=10*)	2006 (*n=9*)	Mean (All Years)	Dietary Preference*
Roach	*Rutilus rutilus*	179.1 ± 99.1	1008.8 ± 580.3	341.0 ± 252.0	20539.1 ± 16258.7	66.3 ± 27.2	33.2 ± 21.3	3694.6 ± 3372.1	Omnivorous
Chub	*Leuciscus cephalus*	68.2 ± 31.0	9197.3 ± 6956.4	1314.6 ± 740.0	636.4 ± 373.7	49.4 ± 39.2	37.4 ± 23.7	1883.9 ± 1476.9	Omnivorous
Gudgeon	*Gobio gobio*	89.3 ± 64.0	370.7 ± 204.9	8857.7 ± 8318.8	81.8 ± 58.5	260.8 ± 222.3	41.9 ± 25.2	1617.0 ± 1449.1	Invertivorous
3-spined Stickleback	*Gasterosteus aculeatus*	45.7 ± 22.8	3140.1 ± 2735.7	648.0 ± 340.2	20.0 ± 15.0	25.3 ± 25.0	0.2 ± 0.2	646.6 ± 509.1	Invertivorous
Minnow	*Phoxinus phoxinus*	5.5 ± 3.7	899.7 ± 626.1	290.5 ± 271.1	179.3 ± 162.3	46.6 ± 44.9	206.9 ± 127.5	271.4 ± 132.8	Invertivorous
Dace	*Leuciscus leuciscus*	-	62.3 ± 41.3	247.3 ± 183.5	232.7 ± 188.9	11.6 ± 9.6	12.2 ± 6.7	113.2 ± 52.6	Invertivorous
Eel	*Anguilla anguilla*	8.2 ± 4.00	0.6 ± 0.6	-	181.8 ± 181.8	0.1 ± 0.1	-	47.7 ± 44.8	Omnivorous
Grey Mullet	*Mugil cephalus*	217.7 ± 140.5	4.0 ± 3.2	36.4 ± 24.4	1.8 ± 1.8	8.2 ± 4.6	1.9 ± 1.3	45.0 ± 35.0	Omnivorous
Rudd	*Scardinius erythrophthalmus*	-	125.0 ± 125.0	0.9 ± 0.9	-	-	0.3 ± 0.3	42.1 ± 41.5	Omnivorous
Perch	*Perca fluviatilis*	-	-	-	40.0 ± 28.9	-	0.1 ± 0.1	20.1 ± 19.9	Omnivorous
Stone Loach	*Barbatula barbatula*	0.6 ± 0.6	36.8 ± 26.0	-	-	-	0.3 ± 0.3	12.5 ± 12.1	Invertivorous
Barbel	*Barbus barbus*	1.8 ± 1.8	40.0 ± 31.3	1.8 ± 1.8	-	5.1 ± 5.0	-	12.2 ± 9.3	Invertivorous
Smelt	*Osmerus eperlanus*	-	-	-	-	8.9 ± 8.6	1.0 ± 1.0	5.0 ± 4.0	Carnivorous
Grayling	*Thymallus thymallus*	0.7 ± 0.6	0.2 ± 0.2	-	10.9 ± 9.1	-	-	3.9 ± 3.5	Invertivorous
Flounder	*Platichthys flesus*	0.6 ± 0.5	0.1 ± 0.1	-	9.1 ± 9.1	0.4 ± 0.3	-	2.6 ± 2.2	Carnivorous
Common Carp	*Cyprinus carpio*	-	-	-	-	-	0.3 ± 0.3	0.3	Omnivorous
Sea Bass	*Dicentrarchus labrax*	-	0.2 ± 0.2	-	-	-	-	0.2	Carnivorous
Bream	*Abramis brama*	0.1 ± 0.1	-	-	-	-	-	0.1	Omnivorous
Mean Total Number of Individuals		617.45	14885.69	11738.09	21932.91	482.70	335.89		
Total Number of Species		12	14	9	11	11	12		
α		2.12	1.53	0.96	1.12	2.01	2.44		
DMg		1.71	1.35	0.85	1.00	1.62	1.89		
Ds		0.75	0.56	0.41	0.12	0.67	0.58		
H		1.58	1.17	0.91	0.34	1.51	1.23		
E		0.64	0.44	0.42	0.14	0.63	0.49		

* Dominant diet of juvenile/adult fish as stated under species summaries at www.fishbase.org

Table 5.8: Mean (± SE) invertebrate densities inside and outside of fish exclusion cages at Cardiff Bay Wetland Reserve (from a total of 5 samples per cage).

Family	**Exclusion Cage 1**		**Exclusion Cage 2**		**Exclusion Cage 3**		**Exclusion Cage 4**		**All Cages**	
	Inside	**Outside**	**Inside**	**Outside**	**Inside**	**Outside**	**Inside**	**Outside**	**Inside**	**Outside**
Asellidae			458.4 ± 137.1	203.7 ± 76.4	713.0 ± 253.4	560.2 ± 103.4	382.0 ± 133.5	152.8 ± 47.6	388.3 ± 93.5	229.2 ± 56.6
Chironomidae	2113.6 ± 294.8	891.3 ± 166.0	2342.8 ± 302.9	891.3 ± 180.1	1349.6 ± 250.2	1222.3 ± 265.9	483.8 ± 186.3	382.0 ± 106.5	1572.5 ± 206.0	846.7 ± 110.6
Corixidae	229.2 ± 74.2	50.9 ± 31.2	203.7 ± 86.4	50.9 ± 31.2	152.8 ± 74.2	50.9 ± 31.2	127.3 ± 69.7	101.9 ± 47.6	178.3 ± 36.2	63.7 ± 17.3
Erpobdellidae			76.4 ± 31.2	50.9 ± 31.2	76.4 ± 50.9	25.5 ± 25.5	152.8 ± 74.2	25.5 ± 25.5	76.4 ± 25.1	25.5 ± 11.7
Gammaridae	229.2 ± 152.8	127.3 ± 98.6	2011.7 ± 299.7	2393.7 ± 561.4	2139.0 ± 384.9	1324.2 ± 468.9			1095.0 ± 254.5	961.3 ± 280.6
Glossiphonidae	50.9 ± 31.2						25.5 ± 25.5		19.1 ± 10.4	
Gerridae				25.5 ± 25.5		50.9 ± 31.2				19.1 ± 10.4
Lymnaeidae			585.7 ± 191.4	458.4 ± 148.5	611.2 ± 194.8	178.3 ± 64.9	407.4 ± 152.8	305.6 ± 86.4	401.1 ± 91.1	235.5 ± 57.1
Physidae	280.1 ± 109.5						305.6 ± 86.4	331.0 ± 118.1	146.4 ± 46.4	82.8 ± 42.6
Planorbidae							101.9 ± 74.2	25.5 ± 25.5	25.5 ± 19.8	6.4 ± 6.4
Number of Taxa	**5**	**3**	**6**	**7**	**6**	**7**	**8**	**7**	**9**	**9**
Number of Individuals	**2903**	**1069.5**	**5678.7**	**4074.4**	**5042.0**	**3412.3**	**1986.3**	**1324.2**	**3902.5**	**2470.1**
α	**0.59**	**0.38**	**0.67**	**0.83**	**0.68**	**0.85**	**1.07**	**0.97**	**1.11**	**1.18**
Dmg	**0.50**	**0.29**	**0.58**	**0.72**	**0.59**	**0.74**	**0.92**	**0.83**	**0.97**	**1.02**
Ds	**0.55**	**0.71**	**0.31**	**0.41**	**0.29**	**0.31**	**0.17**	**0.22**	**0.27**	**0.29**
d	**72.80**	**83.30**	**41.30**	**58.80**	**42.40**	**38.80**	**24.40**	**28.80**	**40.30**	**38.90**
H'	**0.93**	**0.55**	**1.35**	**1.18**	**1.42**	**1.35**	**1.86**	**1.64**	**1.59**	**1.49**
E	**0.58**	**0.50**	**0.75**	**0.61**	**0.79**	**0.69**	**0.89**	**0.84**	**0.72**	**0.68**
VarH	**0.0004**	**0.0007**	**0.0001**	**0.0002**	**0.0001**	**0.0002**	**0.0002**	**0.0003**	**0.0002**	**0.0003**

Figure 5.4: Estimated Mean invertebrate densities (± S.E) of all samples taken from inside and outside fish exclusion cages (n=20 in each case).



(ii). *Effect of Fish Exclusion on Benthic Invertebrate Abundance*

The abundance of all invertebrates recorded both within the confines of the exclusion cages (from which avian and fish predators had been excluded for a period of 4 months) and immediately surrounding the cages are outlined in **Table 5.8** and **Figure 5.4.** Although all families recorded during the sorting process are displayed, it is likely that those which do not live within the benthic sediments (all families except the Chironomidae) are not as accurately surveyed using the core sampling methodology used during the experiment, and thus should be treated with caution.

A total of ten families were recorded during the survey, the most commonly occurring of which were Chironomidae and Corixidae – both of which were present in each treatment in each cage. Chironomidae were present at by far the highest abundance of any taxa (as can be expected by the sampling method used), with estimated mean densities ranging between 484 (± 186) and 2343 (± 303) individuals/m^2 inside exclusion cages, and 382 (± 107) to 1222 (± 266) individuals/m^2 outside of exclusion cages. Gammaridae were also recorded at high densities where present, however were absent from exclusion cage 4.

Only a single family, out of the ten recorded, occurred in greater numbers outside the cages than inside and that was the Gerridae. In the case of the two families that occurred in all four fish exclusion cages, there was a significant decline in both chironomids ($t_6 = 3.10$, $p = 0.02$-0.05) and corixids ($t_6 = 2.86$, $p = 0.02$-0.05). To avoid pseudoreplication, both of these tests use a reduced number of degrees of freedom based on the number of replicates (four exclosures and four controls), not the number of samples (which was 40).

Fish clearly exert a significant influence on invertebrate density, reducing chironomid numbers by 46% according to these trials. No doubt they have played a significant part in the decline of the huge numbers of chironomid that appeared in the years immediately after barrage closure.

(iii). *Effect of Fish Exclusion on Benthic Invertebrate Size*

All invertebrates collected during the fish exclusion experiment had measurements of body length taken and were grouped according to their origin (from inside or outside of exclusion cages. The results of a simple analysis of the effect of fish exclusion on body length are given in **Tab. 5.9.**

As can be seen, only two of the taxa show significant differences between the sizes of individuals sampled in the two 'treatment' areas. Chironomidae were significantly larger inside cages, than were individuals from immediately outside the perimeter of the exclusion cages. This may indicate a preference for larger sized chironomids by predators in the aquatic habitats of Cardiff Bay Wetland Reserve. However, because this study does not separate the taxon into species, this may actually be due to preferential predation of certain larger species.

In contrast, Lymnaeidae were significantly larger outside of the exclusion cages. This is likely to be due to the small number of particularly large individuals (up to 37 mm in length) collected outside of exclusion cages – that were in fact far too large to enter the cages due to the small mesh size. The slow rate of growth of Lymnaeid snails means that it is likely that all but the smallest individuals were able to enter the cages (since all cages were netted upon installation) with larger more mature snails confined to the non-excluded zones.

It is important to remember that (as mentioned previously), only Chironomidae are accurately represented here, due to the survey technique utilized. The raw data relating to all aspects of the fish exclusion study can be found in **Appendix 5.7.**

Table 5.9: Comparison of the body lengths of all invertebrate taxa recorded during the fish exclusion study, along with Mann-Whitney test statistic for the size difference between predator excluded and non-predator excluded individuals.

Taxa	Treatment	N.	Mean Length (mm)	Min. Length (mm)	Max. Length (mm)	Median Length (mm)	Mann-Whitney		Sig.
							u.	*p.**	
Asellidae	Inside	61	6.30	3	8	6	2975.5	0.9207	n
	Outside	36	6.28	3	8	7			
Chironomidae	Inside	247	9.96	3	22	9	50339.5	0.0012	y
	Outside	133	8.50	4	17	8			
Corixidae	Inside	28	7.29	6	9	7	567	0.4797	n
	Outside	10	7.00	6	9	7			
Erpobdellidae	Inside	12	14.58	4	20	16	105.5	0.7148	n
	Outside	4	12.75	8	23	10			
Gammaridae	Inside	172	5.41	1	9	5	26957	0.2726	n
	Outside	151	5.60	1	9	6			
Glossiphonidae	Inside	3	18.33	15	23	17	-	-	-
	Outside	-	-	-	-	-			
Gerridae	Inside	-	-	-	-	-	-	-	-
	Outside	3	10.67	9	12	11			
Lymnaeidae	Inside	63	4.40	1	9	4	2897.5	0.0412	y
	Outside	37	7.86	1	34	5			
Physidae	Inside	23	5.09	2	7	5	447	0.4826	n
	Outside	13	5.00	2	10	5			
Planorbidae	Inside	4	3.75	3	5	3.5	-	-	-
	Outside	1	5.00	5	5	-			

* adjusted for ties

5.4 Conclusions

The post-Barrage environment of Cardiff Bay provides important habitats to a diverse range of invertebrate life. It is clear that there has been a drastic decrease in the productivity of aquatic invertebrates, but at the same time the overall diversity of aquatic invertebrate taxa has increased substantially. Although data relating to the terrestrial invertebrates which occurred pre- and post-Barrage are inadequate to provide detailed analyses, it is likely that there has been a vast increase in the diversity of this important group also, with such a drastic increase in spatial heterogeneity, and plant diversity (as outlined the previous section), which in turn provides a much larger range of microhabitats and foodplants for invertebrates than saltmarsh habitats ever could.

It is also clear that fish populations in the aquatic habitats of the Wetland Reserve are likely to compete for invertebrate food resources with the avian inhabitants of the area, and thus exclusion, or removal of certain species, should be considered as part of the long-term management of the site if encouragement of feeding waterfowl in the Bay remains a key objective.

As the habitats of Cardiff Bay Wetland Reserve (both aquatic and terrestrial) continue to develop, it is likely that an even greater diversity of invertebrate life will be attracted to the site - though it is important to manage the reserve to maintain a maximum diversity of plants and habitats. If the site were allowed to develop unmanaged, it is likely that plant species diversity, will decrease as a few species become dominant (notably Alder *Alnus glutinosa*) and the pattern of increasing diversity will be reversed.

One of the major shortfalls of the design of the aquatic habitats of the Wetland Reserve is that they predominantly rely on the flow of water into the feeder reservoir from road and car-park runoff sources. The main disadvantage of this, is that water quality is likely to be of lower quality, and is likely to contain more concentrated levels of pollutants than water from other sources. The effect of this is clear from the general lack of diversity in the reservoir in comparison to the other aquatic habitats.

As mentioned previously, some parallels can be drawn with previous studies into similar types of habitat change. For example, the occurrence in the Zuiderzee, of significant numbers of the brackish water crab *Rhithropanopeus harrisi tridentatus* during the transitional period (Vaas, 1966), has been reflected in studies of Cardiff Bay with relation to the occurrence of the brackish water ditch shrimp *Palaemonetes varians* (see **Table 5.3**).

Additionally, explosions in the abundance of chironomid midge larvae inhabiting the bay were seen shortly after Barrage closure (Peter Ferns, Pers. Comm.) – a problem that has now resolved as the habitat has matured and fish numbers have risen – exactly mimicking the situation in a newly created freshwater lake in a 35 ha flooded meadow in Sweden (Danell & Sjorberg, 1982).

6. Bird Ecology of Cardiff Bay & the Gwent Levels Wetland Reserve

6.1. Introduction

As well as being the group responsible for the designation of the pre-barrage Cardiff Bay as a SSSI, birds (in particular waders and wildfowl) play a vital role in the functioning of wetland habitat systems, and as such are essential contributors to wetland ecosystem services. It is for these, and many other reasons, that birds, in particular waders and wildfowl, form the primary focus of the current project.

6.1.1. Wetland Birds in the UK

(i). *General*

With its long, embayed coastline and westerly geographic location, the UK supports a significant proportion of Europe's wetland birds. About 70 species are present in Internationally Important numbers (Ferns, 1992). In particular, the UK's estuaries are internationally important for their wintering and migrant wetland species - mainly due to UK's relatively mild climate, and particularly high tidal ranges, which ensure that the extensive mudflats rarely freeze (Clark, 2006).

(ii). *Wetland Birds in the Severn Estuary and Cardiff Bay*

The Severn Estuary is one of the UK's largest and most important sites for wetland birds. There are substantial populations of wildfowl in the upper estuary where the headquarters of the world-renowned Wildfowl & Wetlands Trust are located. The middle reaches of the estuary are Internationally Important for several species of wading birds, while the adjacent Bristol Channel supports significant breeding populations of seabirds.

Cardiff Bay forms quite a small part of the Severn Estuary, but its wetland bird populations constitute an important part of the total both before and after the construction of the Cardiff Bay Barrage. This will form the main subject of the present chapter.

6.1.2. Influences of Wetland Habitats on Wetland Birds

The importance to birds, of a number of resources and features of wetland habitats (habitat diversity, and macrophyte and invertebrate ecology) have already been discussed in the introductory sections to each of the three relevant preceding chapters. However, there are many other aspects of wetland ecology which are of importance to wetland birds, and have a significant effect on the community structure of the group.

6.1.3. Influences of Wetland Birds on Wetland Habitats

It is important to realise that, just as the wetland resources and features discussed previously can significantly affect habitat use by wetland birds, wetland birds themselves also play an important part in the functioning of such habitats, and may greatly influence ecosystem processes within wetland habitats in a number of ways.

Perhaps the most obvious way in which birds influence wetland communities is through direct predatory effects. Herbivorous species can have significant effects on plants, altering community composition by targeting preferred species, and at the same time altering the spatial habitat heterogeneity. This in turn is likely to have follow-on effects on all trophic levels above. Similarly, predatory bird species are likely to significantly affect animal communities by altering the biomass of invertebrates, fish, small mammals, and even other birds.

In addition, and perhaps more importantly, birds play a role in the initial colonisation of wetland habitats by a variety of organisms, and because of their mobility can carry such organisms over wide areas. This process, known commonly as long-distance dispersal (LDD), was first recognised by Darwin who noted the capacity of migratory waterbirds for dispersing aquatic invertebrates and plants between locations separated by hundreds of miles (Darwin, 1859; as cited in Green & Figuerola, 2005).

A variety of invertebrate ova, as well as adult amphipods, and gastropods have been recorded in the plumage of hunter-killed and live waterfowl in both Europe and North America, and plant materials such as seeds and foliage of submergent plants are commonly found in or on the plumage of herbivorous ducks and coots (Weller, 1999).

As well as transporting organisms externally, birds are also well known for transporting macrophyte seeds over long distances in the digestive tract – particularly with regards to the waders (Charadriiformes) which undergo particularly long migratory flights (Sanchez *et al.*, 2006). LDD has also been shown to enable dispersal of algae and invertebrates (including crustaceans, rotifers and gastropods) which survive digestion by waterbirds and thus are viable upon their deposit in new locations (Weller, 1999, Green *et al.*, 2002; Green & Figuerola, 2005), thus illustrating the potential for new communities to be established simply by a bird passing through an area.

Wetland birds may also contribute to nutrient cycling because of the fertilizing effects of their excreta. This is particularly true of the herbivorous ducks and geese, whose droppings can accumulate at both resting and roosting sites. In a few cases, nutrients from the excreta of wetland birds can contribute to the eutrophication of freshwater wetlands e.g. roosting gulls in parts of the Norfolk Broads.

6.2. Methods

6.2.1. Whole Bay Waterfowl Surveys

(i). Data Collection

Counts of the waders and wildfowl utilising Cardiff Bay have been made on a regular basis since 1969 via the British Trust for Ornithology's (BTO's) Wetlands Bird Survey (WeBS), formerly known as the 'Birds of Estuaries Enquiry' (BoEE). The WeBS surveys are now a joint effort between the BTO; the Wildfowl & Wetlands Trust (WWT); the Royal Society for the Protection of Birds (RSPB); and the Joint Nature Conservation Committee (JNCC) to monitor non-breeding waterfowl at around 2000 wetland sites in the UK (Collier *et al.,* 2005).

In the case of this study, the counts provide an essential window into the past ornithological interest and importance of Cardiff Bay, and continuation of comparable counts will show how the development of the Barrage has altered the species composition and species abundance of birds within the area. Therefore, monthly counts of all waders and wildfowl (collectively termed 'waterfowl') utilising the Bay between 19th May 2003 and 1st May 2006 were undertaken using the same 'WeBS' count methodology (e.g. Cranswick *et al.*, 1998), with background historical count data (3rd August 1969 - 20th April 2003), being kindly provided by P.N. Ferns who undertook the counts for the majority of the period prior to the commencement of this research (hence all results are based on personal records, not on data provided by the BTO).

Each 'WeBS core count' was undertaken on a 'priority date' (one count each month) which is pre-selected by the BTO in order to ensure optimum tidal conditions (always on a Sunday). This allows counts across the whole country to be synchronised, reducing the likelihood of birds being double-counted, or completely missed (Cranswick *et al.*, 1998). The specific method used for the observation and counting of birds present is termed the "look-see" methodology (Bibby *et al.*, 2000), whereby the observer surveys the whole of a predefined area.

Observations were undertaken from key points within the Cardiff Bay study area (**Fig. 6.1**) in order that the maximum area could be censused in the quickest time possible (thus reducing the possibility of re-counting individuals that have moved from previously counted sections). In order to aid identification and avoid missing certain individuals, a tripod-mounted spotting scope (Nikon 33x80 mm) was used at all locations, in addition to a pair of binoculars (Pentax 9-20x35 mm). In Cardiff Bay, all counts were undertaken at high tide in order to standardise tidal influences on the numbers and species of birds present. This was due to the close proximity of the Severn Estuary, the large tidal fluctuations of which may cause the movement of certain species into the count area during high tide.

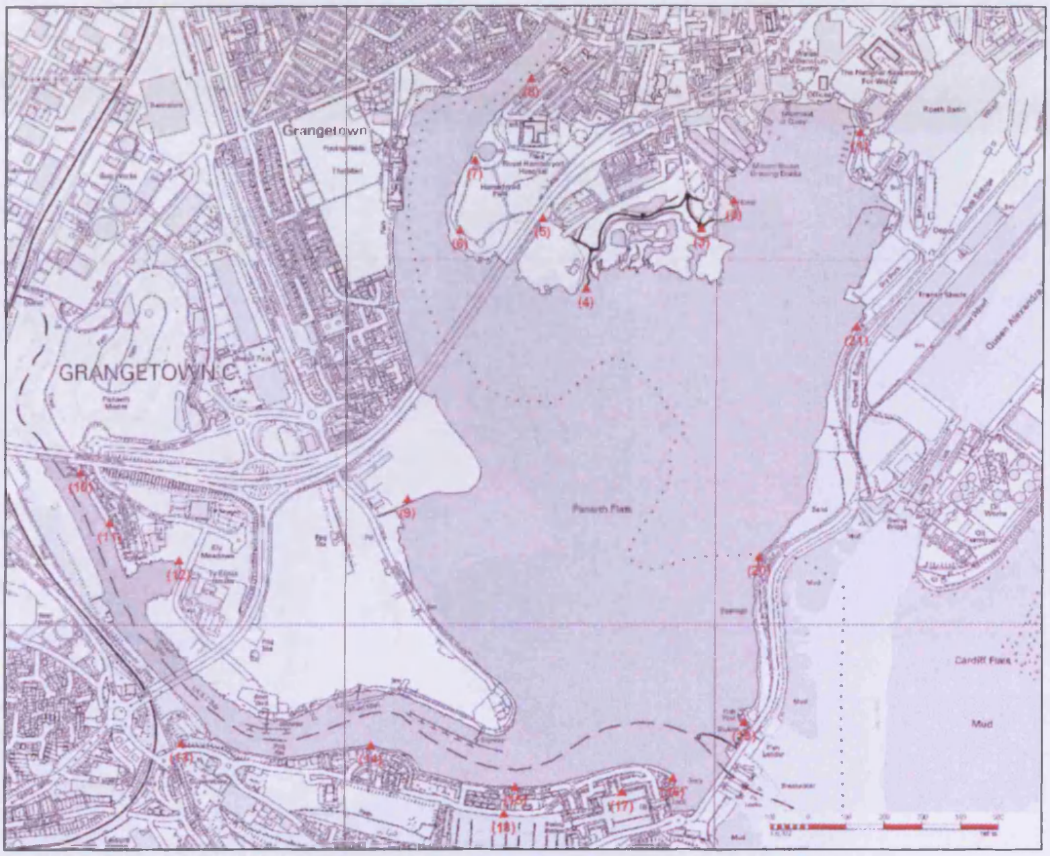
It is worth noting that counts undertaken prior to the start of my research were not undertaken every month within the year – resulting in significant gaps in the data. This is because only winter counts between the months of November and March were compulsory for 'WeBS' count volunteers, with summer counts being left to the individuals discretion. However, counts from 19th May 2003 onwards, were undertaken once per month on, or close to the recommended 'priority' dates.

In order that general area preferences of the waterfowl living within the confines of Cardiff Bay could be identified, separate data were collected for five distinctly separate areas, as illustrated in **Fig. 6.2**. In order that approximate waterfowl densities could be analysed, the areas of each of the relevant count sections were calculated using the Mapping software 'Map Maker Pro, version 3.5', the results of which are also shown in **Table 6.1**.

Table 6.1: Areas of WeBS Count Sections in Hectares.

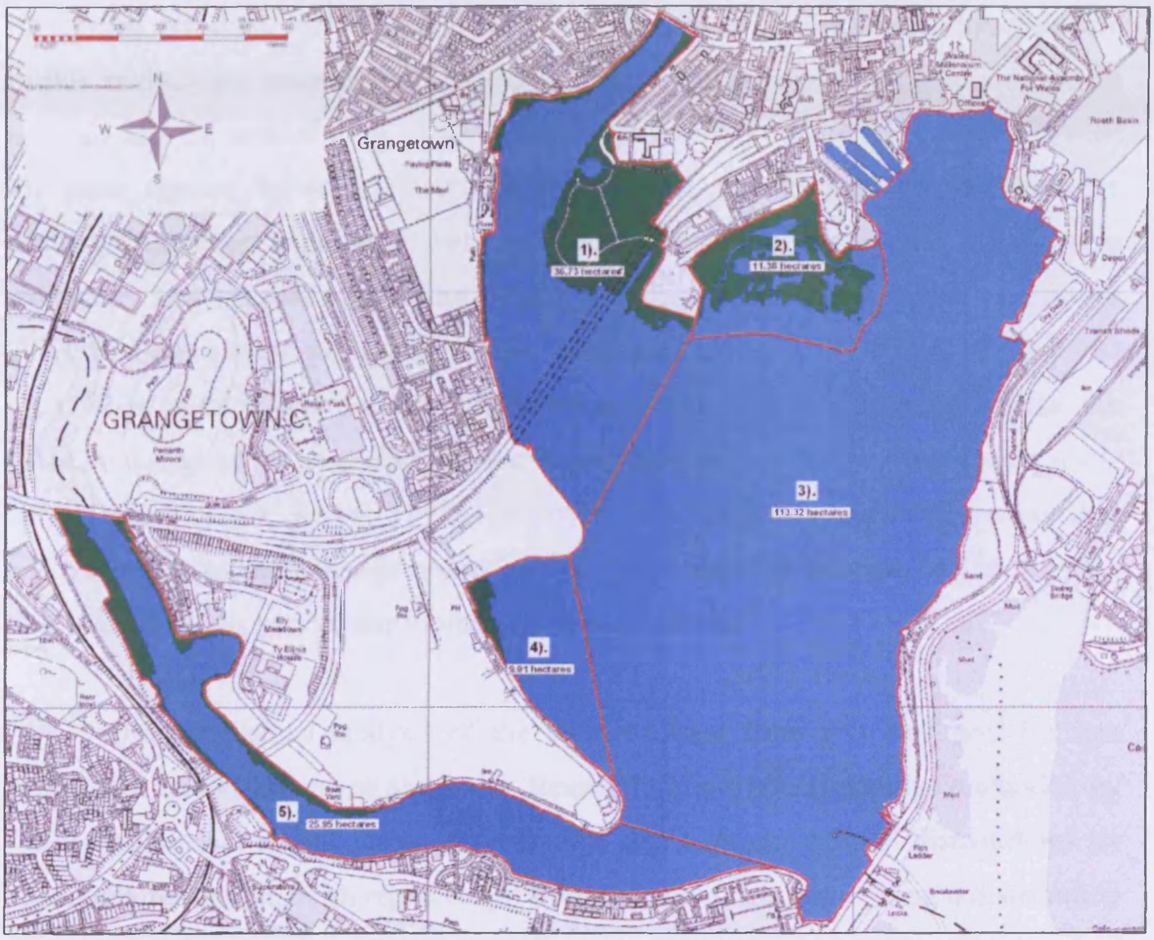
Count Section	Area (Ha)
River Taff	36.73
River Ely	25.95
Wetland Reserve	11.38
Redhouse Marsh	9.01
Open Water/Other	113.32
Total	**196.39**

Figure 6.1: Observation points used for the WeBS counts of Cardiff Bay during the current study. Points were visited in the same order as numbered, starting at point 1.



During the winter period (November to March), the monthly whole bay counts of waterfowl were supplemented by more detailed counts in the Wetland Reserve area via the winter marsh transect surveys described later in this chapter. The inclusion of data from these surveys was necessary to record the large numbers of generally under-recorded species such as Snipe *Gallinago gallinago* and Teal *Anas crecca.* These two species in particular were well hidden in the ditches and other areas of the reserve which could not be accurately surveyed using the point count method described previously.

Figure 6.2: Map showing the extent of the study site as well as the count sections used in the monthly whole bay waterfowl surveys.



Map Legend: *(1) River Taff; (2) Wetland Reserve; (3) Open Bay/Other; (4) Redhouse Marsh; (5) River Ely.*

More regular counts were made of the wetland reserve area alone, using the same observation points for the area as used during the whole bay counts. Although these counts are not covered in the results section of this chapter (because monthly counts were deemed to provide sufficiently detailed data), they can be found in **App. 6.1.**

(ii). *Data Processing*

All raw data, including that collated from counts prior to the commencement of this study, were entered into Minitab and Excel worksheets in order to aid in their analysis and the tabulation of totals. Winter peak counts (the highest counts recorded for each species between November-March) and annual peak counts (between January-December) were calculated, and used to determine 'winter peak count 5 year averages', and 'annual peak count 5 year averages', whereby the peak counts for every five year period were averaged (i.e. for winter counts 91/92-95/96, 92/93-96/97 etc.). This method was utilised simply because five year averages have been the traditional method for assessing 'regular' occurrence of bird species (e.g. Owen *et al.*, 1986; Moser, 1987; Kirby, 1994). However, this method is obviously unsuitable when rapid population change occurs, and so, particularly in the case of Cardiff Bay, it is also necessary to consider monthly, and peak counts.

Initial statistical analysis of the data resulting from pre- and post-Barrage counts was undertaken using statistical 'Resampling' or 'bootstrapping' methodology – a technique that allows the analysis of data sets with non-normal distributions by repeatedly resampling with replacement from the given data, generating a distribution that mimics the sampling distribution (Scheiner & Gurevitch, 2001). This method was used to look at differences in annual peak count 5 year averages obtained from three different five year periods within the developmental history of Cardiff Bay, these being as follows:

- Pre-Barrage Construction (1989/1990-1993/1994), representative of the Bay before construction of the barrage began in May 1994, thus representing a tidal brackish-water habitat under 'normal' conditions.
- During Barrage Construction (1994/1995-1998/1999), the period in which the majority of construction works to the barrage took place, thus representing a largely estuarine yet disturbed habitat.

- Post-Barrage Construction (2001/2002-2005/2006), representing the Bay in the non-tidal freshwater state in which it has been since barrage closure in November 1999 and subsequent freshwater impoundment in spring of 2001.

The software 'Resampling Stats Version 4' was used for analysis of all data tested using this method, with a total of 10,000 resamples being taken from the data sets.

6.2.2. Winter Marsh Transect Surveys

(i). *Data collection*

Belt-transects are a widely recognised, and often utilised method for recording presence of birds and for calculating relative and absolute density estimates (Bibby *et al.*, 2000). One of the main advantages of transects for this study, is that species which are particularly difficult to spot from fixed points, are easily recorded when walking a fixed route – particularly in the case of Snipe *Gallinago gallinago,* which allow close approaches before flushing and are almost impossible to record using any other observation method. Kalejta (1984) undertook a number of surveys of the winter bird population inhabiting the then Taff/Ely saltmarsh (now Cardiff Bay Wetland Reserve) between October and March 1984 (later published as Kalejta-Summers, 1997), using the aforementioned methodology.

Hence, in the current study winter counts of all bird species inhabiting the areas of former salt marsh were made using the belt-transect methodology – firstly, giving a more detailed overview of the winter marsh species present in the post-barrage environment, and secondly, enabling comparison with Kalejta's detailed counts – thus allowing comparisons of the pre- and post-barrage situations.

In order that the counts were made as comparable as possible, the mapped extent of the study area and transect locations used during Kalejta's study were transposed onto digital maps of the Bay area (both from 1984 and in its present state), using the mapping software Map Maker Pro (version 3.5), enabling new transects to be set up as near to the originals as possible (See **Fig. 6.3**). Because of the extent of habitat change which has occurred since 1984, only 4 of the 6 transects undertaken by Kalejta at the Wetland Reserve site were used. Hence, when selecting data for comparison with present day counts, only birds which occurred in the predefined area (to the east of a former tidal ditch/creek) were used (see **Fig. 6.4**).

As can be expected, the precise locations of the belt-transects were slightly altered compared with those originally undertaken by Kalejta – primarily due to the subsequent construction of various open water features. As a result transects were placed to take the largest area of terrestrial marsh area into account (while keeping transect length equal).

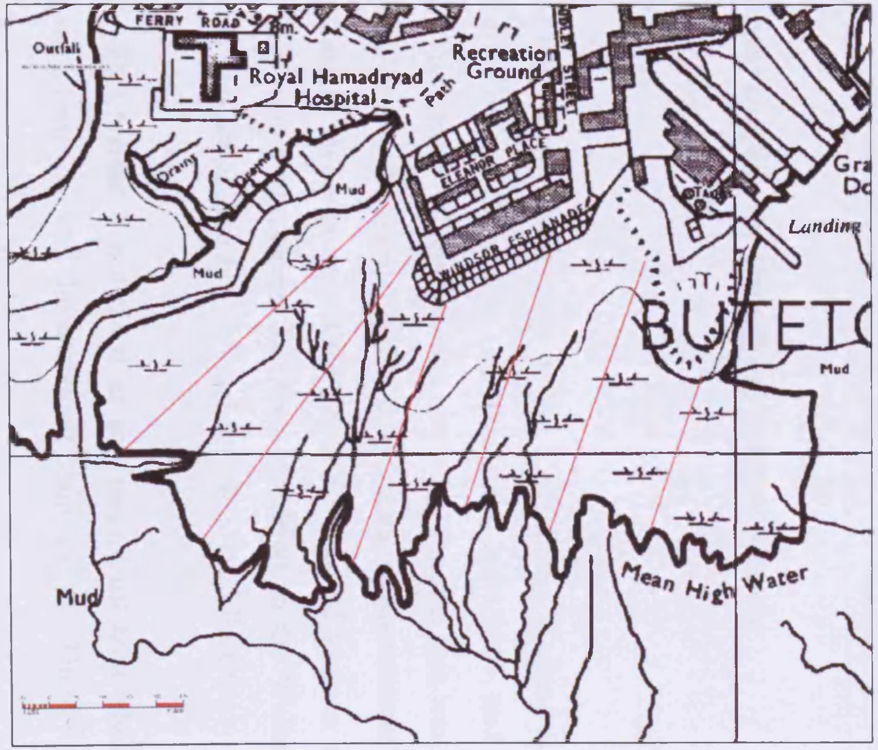
Field observations were undertaken by walking the entire lengths of each of the four transects on a monthly basis between the winter months of November and March on the same day as the priority WeBS counts mentioned previously. All birds seen or heard in the terrestrial habitats of the Wetland Reserve were recorded directly onto a worksheet as birds could be recorded without removing attention from recording, thus avoiding missing individuals. In addition to recording abundance data for each species, all bird records were classified according to a habitat type (as defined in section **6.2.3**), in order to provide an insight into the winter habitat usage of the Wetland Reserve area. This was done simply by appending each species record with the appropriate abbreviation for each habitat (See **App. 6.2**).

(ii). *Data Processing*

Although waders and wildfowl were not analysed in Kalejta's study, all species were recorded, and thus were available for comparison. Data recorded within the specified census area (**Fig. 6.4**) in Kalejta's study were collated from all counts undertaken between 2nd November 1983 and the 11th March 84 (a total of 37 separate counts), leaving out the 4 counts undertaken at the end of October, as October surveys were not undertaken in the current study. Monthly peak counts were calculated for the 1983/1984 counts and these were averaged over the 5 month period to produce a mean winter peak count of all species. This was then compared to the mean winter count for the current data (peaks were not applicable here as only one count per month was undertaken).

Figure 6.3: Location of transects used to record wintering marsh birds during; (A) Kalejta's study in the winter of 1983/1984 (Kalejta, 1984; Kalejta-Summers, 1997); (B) the present study.

A)



B)

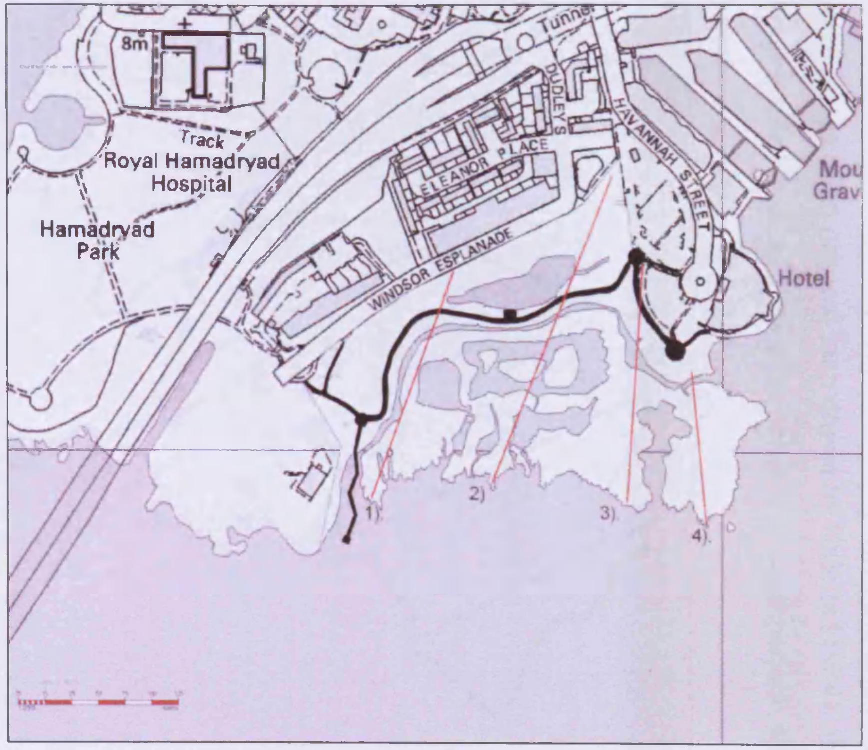
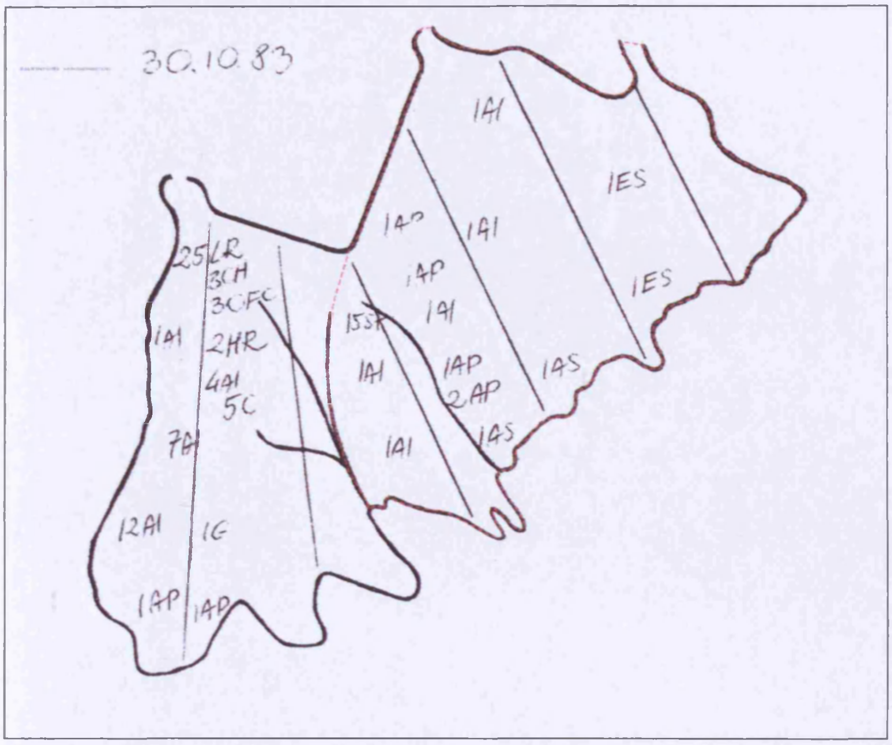


Figure 6.4: Scanned image of an original map drawn by Kalejta (1984), showing the area (dotted red line) inside which all data were collated for comparison with data from the present study.



6.2.3. Winter Habitat Usage in the Cardiff Bay Wetland Reserve

i. *Data Collection*

Assessment of the winter habitat usage in the Cardiff Bay Wetland Reserve was undertaken during the winters (Nov.-Mar.) of 2003/2004, 2004/2005, and 2005/2006. In order to reduce the number of survey visits needed to the site, this was undertaken as a part of the 'monthly WeBS counts' and 'winter marsh transect counts' previously mentioned. This simply involved recording the occurrence of various species and their abundance in a variety of different habitats, identified on the Wetland Reserve during initial visits, as illustrated in **Fig. 6.5** and described as follows:

- **Reed Bed:** – This habitat was defined as any significant area where Common Reed *Phragmites australis* was the dominant plant species. There were areas of this habitat around the margins of the Reservoir, and in smaller areas in other locations at the Wetland Reserve site. The extent of this habitat increased throughout the study period.

- **Reservoir:** – Defined as the feeder reservoir at the highest point of the Wetland Reserve, where water is collected from urban runoff to feed to a number of other lower lying water bodies at the site.
- **Reens & Ditches:** – Consists of the man-made Reen which bisects the reserve into northern and southern parts, and the numerous ditches (formerly tidal) which are predominant throughout the lower lying areas of the Reserve along the southern edge. The majority of these ditches are open to the waters of the Bay, though the Reen is closed to the Bay and receives its water from the Reservoir. Essentially these habitats have an increased marginal vegetation to open water ratio, and thus provide more shelter for both predator and prey.
- **Shallow Scrapes:** – As the name suggests these are man-made habitats aimed at attracting waterfowl to feed by the creation of extensive shallow (<30 cm) water bodies.
- **Raised Areas & Islands:** – These include a series of three small islands within the shallow scrape known as the Wader Scrape, and another raised area on the main body of the reserve. All areas are built up to a level of approximately 6.5 m AOD (2 m above the nominal water level of the Bay) and are aimed at providing protection to nesting birds during periods of high water levels in the Bay.
- **Alder & Willow Carr:** – As the name suggests this habitat is dominated by Alder *Alnus glutinosa* and to a lesser extent Willows *Salix* spp. which vary in form from saplings up to around 3.5 m in height – the latter representing a maximum of 5 years growth. This habitat is associated with the lower lying areas of the reserve, and appear to follow the extent of the ditches mentioned above – a fact that can be attributed to seeds being washed onto the reserve during high water, from the lower (southern) edge.
- **Gravel:** – A small area of barely vegetated habitat with a substrate of small stones exists at the western side of the reserve adjacent to the boardwalk. This is essentially a result of the construction of a track leading to the underwater bund. Though small in area the gravel habitat is unique at the Wetland Reserve, and as such attracts bird species which may not otherwise feed in the other available

habitats – for instance Turnstone *Arenaria interpres* and Ringed Plover *Charadrius hiaticula* have only been recorded in this area of the Reserve (personal observations).

- **Reserve Front (marginal habitat):** – Being the main interface between the open waters of the Bay, and the terrestrial habitats of the Wetland Reserve, this habitat is different to other marginal habitats at the site. The vegetation along the reserve front (within 5 m of the foreshore) is predominantly of Willows *Salix* spp., Alder *Alnus glutinosa*, Great Willowherb *Epilobium hirsutum*, and a variety of sedges *Carex* spp.
- **Open Water/Underwater Bund:** – The open water habitat defined in this survey consists of the area between the reserve front and the litter boom which runs from East to West across the length of the Reserve and lies some 70-80 m away from the reserve front itself. The area on the landward side of the underwater bund is a maximum of around 1 m in depth, on the adjacent side of the boom (Bay side) the depth is a maximum of *c.* 3 m. The bund itself lies only some 20-30 cm below the nominal level of the Bay (4.5 m AOD), and thus is attractive both to bird species which upend, and even to roosting birds when water levels are sufficiently low.
- **Tall-herb Fen & Grassland:** – This habitat covers the majority of the entire area of Cardiff Bay Wetland Reserve, and is made up of two main types of vegetation as the name suggests. The grassland is dominated by Sea Couch *Elytrigia atherica*, whereas the tall-herb fen is far more diverse and consists of a wide variety of predominantly ruderal species.

The vegetation types found within each of these habitats (where relevant) are discussed in more detail in previous chapters – see **'Chapter 4'**. The majority of individuals occurring in the vegetated and terrestrial habitats were recorded during the winter marsh transect surveys, which were undertaken after surveying the open water areas – particularly to the south of the reserve as it was noted during preliminary surveys that many individuals flushed by the transect surveys (particularly Teal *Anas crecca*) would move into this area and thus risked being double counted. Once again gulls were excluded from this survey because of their extremely high abundance.

Figure 6.5: Habitat Types used to identify area preferences of wintering birds at Cardiff Bay Wetland Reserve.

Aerial Photograph © Copyright Cardiff County Council (2005)

6.2.4. Breeding Bird Surveys

(i). *Data Collection*

In order to assess which bird species were breeding/potentially breeding within the post-barrage Cardiff Bay, and which habitats/areas within the Bay were most attractive to breeding birds, monthly breeding bird counts were undertaken between the months of May-August 2003, and March-August 2004 and 2005. Surveys were undertaken by simply mapping the occurrence of all breeding birds seen or heard within the Cardiff Bay Study area as illustrated in **Fig. 6.2**, whilst walking the entire accessible foreshore of the study area. Where significant areas of potential breeding habitat existed, for instance at the Cardiff Bay Wetland Reserve, a number of adequately spaced transects were walked in order to accurately survey as large an area as possible. Only birds which showed some evidence of breeding or of breeding behaviour were recorded, and as such had to fulfill at least one of several criteria. Hence birds were mapped and details recorded for instance if:

- Obviously paired.
- Observed collecting food.
- Showing territorial behaviour (song or display).
- Showing mating/pairing/courtship behaviour (including actual copulation and display e.g. head wagging in Great Crested Grebe *Podiceps cristatus*).
- Displaying nesting behaviour (collecting material and/or building a nest).
- Observed attending a nest (with or without eggs).
- Young were present.

Each occurrence of a breeding pair (or individual) was recorded on a map as a consecutive number, with an additional pre-prepared form being used to record to which species each number referred as well as the numbers of individuals, pairs, nests, eggs and young observed for the species (See **App. 6.3** for example sheet). This is the only survey which provides details of the non-wintering populations of birds other than waterfowl, though these are likely to have been less accurately recorded as records generally relied on locating birds by song – a method with which I was unfamiliar at the beginning of the study, hence accuracy of these (predominantly passerine) records probably improved over time. As with previous surveys a tripod mounted spotting scope (Nikon 33x80 mm) was utilized when required, particularly when access to a site was restricted, in which case observations would be made from the nearest accessible area.

(ii). *Data Processing*

The mapped locations of the birds and the additional data collected during counts were used to complete summary data sheets in Microsoft Excel for each of the count sections identified in **Fig. 6.2** - essentially forming a list of the numbers of nests, eggs, pairs and young of each territory in each section of the Bay. The maps themselves were digitized using Map Maker Pro (Version 3.5), in order to improve and maintain clarity and presentation, and to aid data analysis.

6.2.5. Winter Gull Roost Surveys

(i). *Data Collection*

As mentioned previously, the gull populations of Cardiff Bay were not recorded as part of the monthly counts undertaken for other waterfowl species, because time constraints during these surveys made the inclusion of gulls impractical. This was primarily due to the large populations, and the difficulty in separating species where large flocks were present. Because the gulls are nonetheless an important part of the bird community in Cardiff Bay, separate counts were made in order quantify their population sizes, and in particular, to record the peak winter populations which are achieved as individuals congregate in the open water areas of the Bay used as a nocturnal roost.

These surveys of the winter populations of gulls roosting in the Cardiff Bay area were undertaken six times throughout the winter of 2003/2004 (01st Nov., 14th Dec., 17th and 19th Jan., 21st Feb., and 10th Mar.), twice in the winter of 2004 (25th Nov. and

20th Dec.), and three times in the winter of 2005/2006 (16th Dec., 20th Feb., and 17th Mar.). Due to time constraints and unsuitable weather conditions these surveys were not always possible. Two counts were undertaken in January 2004 as the first yielded unusually low counts, a fact that was later attributed to the prevailing weather conditions. As with the WeBS counts described previously, the "look-see" methodology (Bibby *et al.*, 2000), was utilized to record the birds. Each count was undertaken from the same point within the Bay, namely the end of the boardwalk at Cardiff Bay Wetland Reserve (see **Fig. 6.1** - observation point 4 is in the same location). Previous observations had confirmed this as the place where the majority of birds could be counted without having to travel between several count areas – a method that would have been impractical with the large numbers of gulls present (primarily due to recounting). As might be expected for roost surveys, all counts were undertaken in the evenings – beginning approximately one hour before dusk, and ending when identification of species was no longer possible due to low light levels. Starting at an hour prior to dusk also aided counting, as birds could be identified and counted on the wing as they arrived at the Bay from the surrounding areas, a task which was easier than counting large groups due to the relatively steady flow of birds over time.

Where identification to species was not possible, gulls were classified simply as 'unidentified large gulls'. The two small gull species in Cardiff Bay (Common Gull *Larus canus* and Black-headed Gull *Larus ridibundus*) could always be separately identified. In the case of the large gulls, the generally high abundance of juvenile Lesser-black Backed Gulls *Larus fuscus* and Herring Gulls *Larus argentatus* which were present in the Bay proved difficult to separate under these conditions and thus were grouped together in the former of the categories. In fact, most were probably Herring Gulls since first winter Lesser Black-backed Gulls are relatively uncommon in the Severn Estuary (P.N. Ferns, Personal Communication). Adverse weather conditions, the presence of any likely disturbance, and the state of the tide (outside the Barrage) were all noted additionally.

6.2.6. Compilation of Post-Barrage Species List

(i). *Data Collection*

The post-Barrage species list is a guide to all birds recorded within the Cardiff Bay study area between the closure of the Barrage in November 1999, and the conclusion of my studies in May 2006. This list was compiled from a variety of information sources, and was aimed at providing an overview of all bird species which have utilised the habitats of Cardiff Bay during this period. Although based primarily on my own observations during both casual and standardised surveys mentioned previously, external records were also utilised in order to ensure that the list was as comprehensive as possible. These came from both personal communication with local ornithologists (in particular Vaughan Grantham, County Ecologist, Cardiff County Council and Dave Bull, Cardiff University), as well as from the reports of both local and national bird groups and other organisations. The latter included the website and newsletter of the Glamorgan Bird Club (www.glamorganbirds.org.uk), as well as the solely electronic resources of the Birdguides website (www.birdguides.com).

6.2.7. Bird counts at the Gwent Levels Wetland Reserve

(i). *Data Collection*

All data pertaining to the Gwent Levels Wetland Reserve come from count data kindly provided by Tony Pickup (Countryside Council for Wales (CCW) Senior Reserve Manager at the Gwent Levels Wetlands Reserve). The specific methods used for data collection are as follows (Tony Pickup, Personal Communication):

''All counts come from a combination of methods. Most wintering waterfowl data come from fortnightly "whole reserve counts". These are the normal monthly "WeBS" counts plus a separate high tide count made halfway between each WeBS count. Very occasionally a part count may be undertaken if we think there are an exceptional number of birds on site. In addition to these "standardised" counts we

keep casual records. Counts are made by systematically counting each compartment or field starting one hour before High Tide and finishing one hour after high tide. At least 3 counters are needed to count the whole reserve accurately. Double counting is avoided by noting if a flock moves onto another counter's area and the time of movement noted. Any casual records from non-staff members are vetted for authenticity and no unsubstantiated records are put into our database."

(ii). *Data Processing*

Yearly peak counts were extracted from the raw data files (**App. 6.4**) for the following seasons – winter (November to March), spring passage (April to May), breeding season (June to July) and autumn passage (August to October).

6.2.8. Measurement of Biological Diversity

All measurements of biological diversity featured in this chapter were undertaken according to the methods previously stated in Chapter 5 (5.2.2).

6.3 Results

6.3.1. Post-Barrage Bird Ecology

(i). *General*

Using the results of my own surveys, in collaboration with extensive review of external records, a total of 115 species, within 30 families and 14 orders of birds were recorded within the confines of Cardiff Bay between November 1999 and May 2006 (See **Tab. 6.2**). As can be expected, most species recorded during the period belonged to the Passeriformes (perching birds), with a total of 38 representative species (See **Fig. 6.6**). This fact can be explained by the dominance of the passerines as a whole with c.260 of the 572 British bird species belonging to this order (Dudley *et al.*, 2006). Charadriiformes (waders) and Anseriformes (wildfowl) were the second and third largest orders within Cardiff Bay, as can be expected by the dominant types of habitat present, the former with 36 representative species and the latter with 20 representative species. Of the remaining 11 orders recorded, 6 orders (Podicipediformes (grebes), Ciconiiformes (storks and herons), Gruiformes (rails), Coraciiformes (kingfishers), Gaviiformes (divers), and Pelecaniformes (cormorants)) can also be classified as waterfowl (along with waders and wildfowl), and were represented by a total of 14 species between them. Raptors were represented by three orders Falconiformes (3 species), Accipitriformes (1 species), and Strigiformes (1 species). The final two orders recorded, Apodiformes (swifts) and Columbiformes (pigeons and doves), were represented by just one species each.

It should be noted that, the number of species within the list should be taken as a minimum, as it only contains those species for which records exist – for instance, generally common species which may enter the Bay on rare occasions, will probably not have been recorded by external sources because they are not novel or unusual species. In addition it is important to realise that the list does not classify the species according to abundance, and as such, a large proportion of the species listed will be rare and one-off sightings from within the Bay. It is estimated that only around a half of the species listed are 'common' within Cardiff Bay, and as such are likely to be seen at the relevant time of year. The following sections of this chapter will outline the 'common' species of Cardiff Bay in more detail. A more detailed Table is available in **Appendix 6.5.**

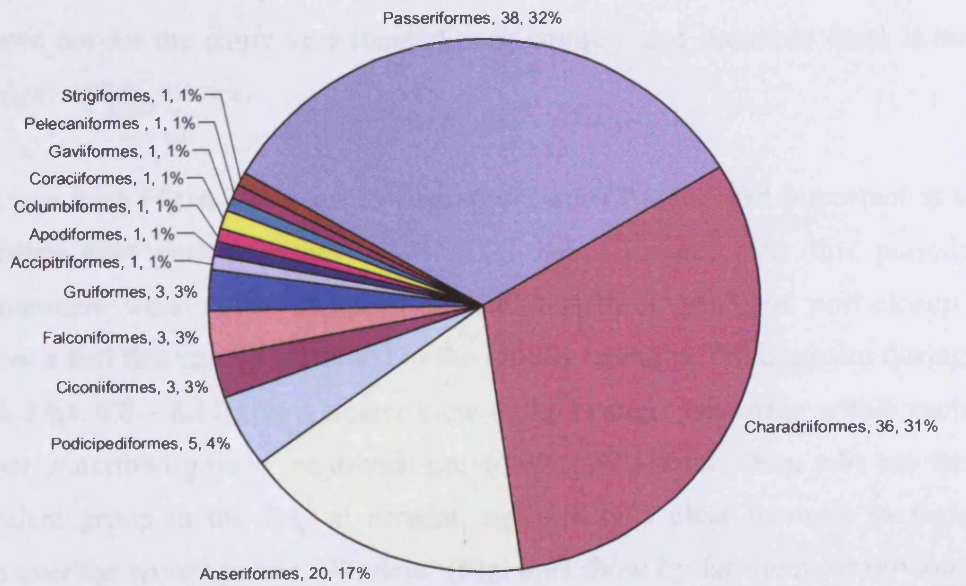
Table 6.2: Species Recorded in Cardiff Bay between November 1999 and May 2006.

Order	Family	Common Name	Scientific Name
Divers, Grebes & Cormorants:			
Gaviiformes	Gaviidae	**Red-throated Diver**	*Gavia stellata*
Pelecaniformes	Phalacrocoracidae	**Cormorant**	*Phalacrocorax carbo*
Podicipediformes	Podicipedidae	**Slavonian Grebe**	*Podiceps auritus*
Podicipediformes	Podicipedidae	**Great Crested Grebe**	*Podiceps cristatus*
Podicipediformes	Podicipedidae	**Red-necked Grebe**	*Podiceps grisegena*
Podicipediformes	Podicipedidae	**Black-necked Grebe**	*Podiceps nigricollis*
Podicipediformes	Podicipedidae	**Little Grebe**	*Tachybaptus ruficollis*
Herons & Storks:			
Ciconiiformes	Ardeidae	**Grey Heron**	*Ardea cinerea*
Ciconiiformes	Ardeidae	**Little Egret**	*Egretta garzetta*
Ciconiiformes	Threskiornithidae	**African Spoonbill**	*Platalea alba*
Perching Birds & Others:			
Passeriformes	Sylviidae	**Sedge Warbler**	*Acrocephalus schoenobaenus*
Passeriformes	Sylviidae	**Reed Warbler**	*Acrocephalus scirpaceus*
Passeriformes	Alaudidae	**Skylark**	*Alauda arvensis*
Coraciiformes	Alcedinidae	**Kingfisher**	*Alcedo atthis*
Passeriformes	Motacillidae	**Rock Pipit**	*Anthus petrosus*
Passeriformes	Motacillidae	**Meadow Pipit**	*Anthus pratensis*
Apodiformes	Apodidae	**Swift**	*Apus apus*
Passeriformes	Fringillidae	**Lesser Redpoll**	*Carduelis cabaret*
Passeriformes	Fringillidae	**Linnet**	*Carduelis cannabina*
Passeriformes	Fringillidae	**Goldfinch**	*Carduelis carduelis*
Passeriformes	Fringillidae	**Greenfinch**	*Carduelis chloris*
Columbiformes	Columbidae	**Rock Dove/Feral Pigeon**	*Columba livia*
Passeriformes	Corvidae	**Raven**	*Corvus corax*
Passeriformes	Corvidae	**Carrion Crow**	*Corvus corone*
Passeriformes	Hirundinidae	**House Martin**	*Delichon urbica*
Passeriformes	Emberizidae	**Reed Bunting**	*Emberiza schoeniclus*
Passeriformes	Turdidae	**Robin**	*Erithacus rubecula*
Passeriformes	Fringillidae	**Chaffinch**	*Fringilla coelebs*
Passeriformes	Fringillidae	**Brambling**	*Fringilla montifringilla*
Passeriformes	Hirundinidae	**Swallow**	*Hirundo rustica*
Passeriformes	Motacillidae	**Pied Wagtail**	*Motacilla alba*
Passeriformes	Motacillidae	**Grey Wagtail**	*Motacilla cinerea*
Passeriformes	Motacillidae	**Yellow Wagtail**	*Motacilla flava*
Passeriformes	Muscicapidae	**Spotted Flycatcher**	*Musciapa striata*
Passeriformes	Turdidae	**Wheatear**	*Oenanthe oenanthe*
Passeriformes	Passeridae	**House Sparrow**	*Passer domesticus*
Passeriformes	Turdidae	**Black Redstart**	*Phoenicurus ochruros*
Passeriformes	Sylviidae	**Chiffchaff**	*Phylloscopus collybita*
Passeriformes	Sylviidae	**Willow Warbler**	*Phylloscopus trochilus*
Passeriformes	Corvidae	**Magpie**	*Pica pica*
Passeriformes	Prunellidae	**Dunnock**	*Prunella modularis*
Passeriformes	Sylviidae	**Goldcrest**	*Regulus regulus*
Passeriformes	Hirundinidae	**Sand Martin**	*Riparia riparia*
Passeriformes	Turdidae	**Stonechat**	*Saxicola torquata*

Order	Family	Common Name	Scientific Name
Passeriformes	Sturnidae	**Starling**	*Sturnus vulgaris*
Passeriformes	Sylviidae	**Blackcap**	*Sylvia atricapilla*
Passeriformes	Sylviidae	**Whitethroat**	*Sylvia communis*
Passeriformes	Sylviidae	**Dartford Warbler**	*Sylvia undata*
Passeriformes	Troglodytidae	**Wren**	*Troglodytes troglodytes*
Passeriformes	Turdidae	**Blackbird**	*Turdus merula*
Passeriformes	Turdidae	**Song Thrush**	*Turdus philomelos*
Rails:			
Gruiformes	Rallidae	**Coot**	*Fulica atra*
Gruiformes	Rallidae	**Moorhen**	*Gallinula chloropus*
Gruiformes	Rallidae	**Water Rail**	*Rallus aquaticus*
Bird of Prey:			
Accipitriformes	Accipitridae	**Sparrowhawk**	*Accipiter nisus*
Strigiformes	Strigidae	**Short-eared Owl**	*Asio flammeus*
Falconiformes	Falconidae	**Merlin**	*Falco columbarius*
Falconiformes	Falconidae	**Peregrine**	*Falco peregrinus*
Falconiformes	Falconidae	**Kestrel**	*Falco tinnunculus*
Waders:			
Charadriiformes	Scolopacidae	**Common Sandpiper**	*Actitis hypoleucos*
Charadriiformes	Scolopacidae	**Turnstone**	*Arenaria interpres*
Charadriiformes	Scolopacidae	**Dunlin**	*Calidris alpina*
Charadriiformes	Charadriidae	**Little Ringed Plover**	*Charadrius dubius*
Charadriiformes	Charadriidae	**Ringed Plover**	*Charadrius hiaticula*
Charadriiformes	Scolopacidae	**Snipe**	*Gallinago gallinago*
Charadriiformes	Haematopodidae	**Oystercatcher**	*Haematopus ostralegus*
Charadriiformes	Scolopacidae	**Black-tailed Godwit**	*Limosa limosa*
Charadriiformes	Scolopacidae	**Jack Snipe**	*Lymnocryptes minimus*
Charadriiformes	Scolopacidae	**Curlew**	*Numenius arquata*
Charadriiformes	Scolopacidae	**Whimbrel**	*Numenius phaeopus*
Charadriiformes	Scolopacidae	**Grey Phalarope**	*Phalaropus fulicarius*
Charadriiformes	Scolopacidae	**Ruff**	*Philomachus pugnax*
Charadriiformes	Scolopacidae	**Spotted Redshank**	*Tringa erythropus*
Charadriiformes	Scolopacidae	**Wood Sandpiper**	*Tringa glareola*
Charadriiformes	Scolopacidae	**Greenshank**	*Tringa nebularia*
Charadriiformes	Scolopacidae	**Green Sandpiper**	*Tringa ochropus*
Charadriiformes	Scolopacidae	**Redshank**	*Tringa totanus*
Charadriiformes	Charadriidae	**Lapwing**	*Vanellus vanellus*
Charadriiformes	Sternidae	**Whiskered Tern**	*Childonias hybridus*
Charadriiformes	Sternidae	**Black Tern**	*Chlidonias niger*
Charadriiformes	Laridae	**Herring Gull**	*Larus argentatus*
Charadriiformes	Laridae	**Yellow-legged Gull**	*Larus cachinnans michahellis*
Charadriiformes	Laridae	**Common Gull**	*Larus canus*
Charadriiformes	Laridae	**Ring-billed Gull**	*Larus delawarensis*
Charadriiformes	Laridae	**Lesser Black-backed Gull**	*Larus fuscus*
Charadriiformes	Laridae	**Iceland Gull**	*Larus glaucoides*
Charadriiformes	Laridae	**Glaucous Gull**	*Larus hyperboreus*
Charadriiformes	Laridae	**Great Black-backed Gull**	*Larus marinus*
Charadriiformes	Laridae	**Mediterranean Gull**	*Larus melanocephalus*
Charadriiformes	Laridae	**Little Gull**	*Larus minutus*
Charadriiformes	Laridae	**Bonaparte's Gull**	*Larus philadelphia*
Charadriiformes	Laridae	**Black-headed Gull**	*Larus ridibundus*
Charadriiformes	Sternidae	**Common Tern**	*Sterna hirundo*
Charadriiformes	Sternidae	**Arctic Tern**	*Sterna paradisaea*
Charadriiformes	Sternidae	**Sandwich Tern**	*Sterna sandvicensis*
Wildfowl:			

Order	Family	Common Name	Scientific Name
Anseriformes	Anatidae	**Pintail**	*Anas acuta*
Anseriformes	Anatidae	**American Wigeon**	*Anas americana*
Anseriformes	Anatidae	**Shoveler**	*Anas clypeata*
Anseriformes	Anatidae	**Teal**	*Anas crecca*
Anseriformes	Anatidae	**Mallard**	*Anas platyrhynchos*
Anseriformes	Anatidae	**Garganey**	*Anas querquedula*
Anseriformes	Anatidae	**Gadwall**	*Anas strepera*
Anseriformes	Anatidae	**Pochard**	*Aythya ferina*
Anseriformes	Anatidae	**Tufted Duck**	*Aythya fuligula*
Anseriformes	Anatidae	**Scaup**	*Aythya marila*
Anseriformes	Anatidae	**Brent Goose**	*Branta bernicla*
Anseriformes	Anatidae	**Canada Goose**	*Branta canadensis*
Anseriformes	Anatidae	**Goldeneye**	*Bucephala clangula*
Anseriformes	Anatidae	**Long-tailed Duck**	*Clangula hyemalis*
Anseriformes	Anatidae	**Mute Swan**	*Cygnus olor*
Anseriformes	Anatidae	**Common Scoter**	*Melanitta nigra*
Anseriformes	Anatidae	**Goosander**	*Mergus merganser*
Anseriformes	Anatidae	**Red-breasted Merganser**	*Mergus serrator*
Anseriformes	Anatidae	**Ruddy Duck**	*Oxyura jamaicensis*
Anseriformes	Anatidae	**Shelduck**	*Tadorna tadorna*
Total Number of Species = 115			

Figure 6.6: Post-Barrage Avian Community Composition. Chart shows the numbers of species within each of the 14 orders of birds recorded in Cardiff Bay since November 1999, and the subsequent percentage contribution of each order to the total.



(ii). *Monthly WeBS Counts*

Monthly standardised counts of the waterfowl of Cardiff Bay undertaken since the closure of the Barrage (**App. 6.6**) reveal the population changes of this group of birds in more detail. Figures **6.7 – 6.12** show the actual monthly changes in the overall total numbers, and the total number of individuals belonging to five major 'groups' of waterfowl recorded in Cardiff Bay between November 1999 and May 2006. For the purpose of simplification, the groups presented are classified largely upon behavioural similarities – and thus grebes, divers, and cormorants are grouped as 'diving birds'. The Grey Heron *Ardea cinerea*, Little Egret *Egretta garzetta* and African Spoonbill *Platalea alba* are grouped as 'herons'. Wildfowl and waders are each grouped separately, with the Kingfisher *Alcedo atthis* being added to the latter group. The final grouping consists of the three species of rails recorded.

Tables **6.3** and **6.4** summarise the changes in all species recorded during the monthly WeBS counts by way of peak counts (i.e. the highest number of individuals recorded during any one count) – the former presenting the winter peak counts of all species recorded between the months of November and March, from the winter of 1999/2000, up to and including the winter of 2005/2006. In the latter table, the peak counts shown are for the entire year (annual peak counts), and therefore there is no bias toward wintering species.

It is obvious from **Fig. 6.7** that the post-barrage Cardiff Bay is most important as a winter habitat, with peak numbers of wildfowl being present over this period; however numbers were rather unstable for the first three years of post-closure colonization, a fact that can be attributed to the rapidly changing environment during this period. **Figs. 6.8 – 6.12** give a clearer view of the changes occurring within each of the major waterfowl groups mentioned previously. 'Wildfowl' (**Fig. 6.8**) are the most prevalent group in the Bay at present, again with a clear increase in their abundance over the winter period. 'Waders' (**Fig. 6.9**) show by far the most obvious winter trend, with only very low numbers present throughout the remainder of the year. This trend is primarily due to the large number of wintering Snipe *Gallinago gallinago* which are attracted to the Wetland Reserve area during the coldest months.

The remaining groups ('Rails' (**Fig. 6.10**); 'Diving Birds' (**Fig. 6.11**) and 'Herons' (**Fig. 6.12**)) appear to boast their peak abundance in late summer/autumn (August – October). In the case of the 'Rails' there is probably a correlation with the large quantities of aquatic vegetation (namely *Elodea* spp.) which occur during this same period. Similarly, the latter two groups, which are both piscivorous to a large degree, are likely to have been attracted by the large shoals of fish which are present during these periods (when surface waters are at their warmest), and which later retreat to deeper water areas of the Bay as the temperature decreases (Pete Clabburn (Environment Agency Wales), Personal Communication).

As can be seen from **Tables 6.3** and **6.4**, there has been a general increase in species diversity (according to both Fisher's alpha and Shannon's Index) over the monitoring period – although there was considerable variation between 1999 and 2002. This variation was probably due to the fact that the habitats and communities had yet to stabilize after barrage closure in 1999 - it is important to remember that 'official' freshwater impoundment did not occur until 2001, although the actual point at which the water became 'fresh', is unclear).

The 'winter peak counts' of individual species outlined in **Tab. 6.3** show clear increases in the abundance of Teal *Anas crecca*, Mallard *Anas platyrhynchos*, Tufted Duck *Aythya fuligula,* Mute Swan *Cygnus olor*, Coot *Fulica atra*, Moorhen *Gallinula chloropus*, Great Crested Grebe *Podiceps cristatus*, and Snipe *Gallinago gallinago.* The latter species, however, should be treated with some caution as it was recorded largely through more detailed surveys (marsh transects) which had not previously been undertaken (prior to May 2003). All other species have either been present at fairly regular levels of abundance (e.g. Shelduck *Tadorna tadorna* and Cormorant *Phalacrocorax carbo*), or have occurred in the Bay on rare occasions (i.e. Dunlin *Calidris alpina* in the winter of 2000/2001 and Pochard *Aythya ferina* in the winter of 2001/2002).

The 'annual peak counts' (**Tab. 6.4**) show similar trends, but include additional species which occurred during periods other than the winter. Further detail on these changes can be found in the following sections.

Figure 6.7: Total Number of Waterfowl (wildfowl, waders, rails, diving birds and herons) recorded during monthly WeBS counts between Nov. 1999 and May 2006.

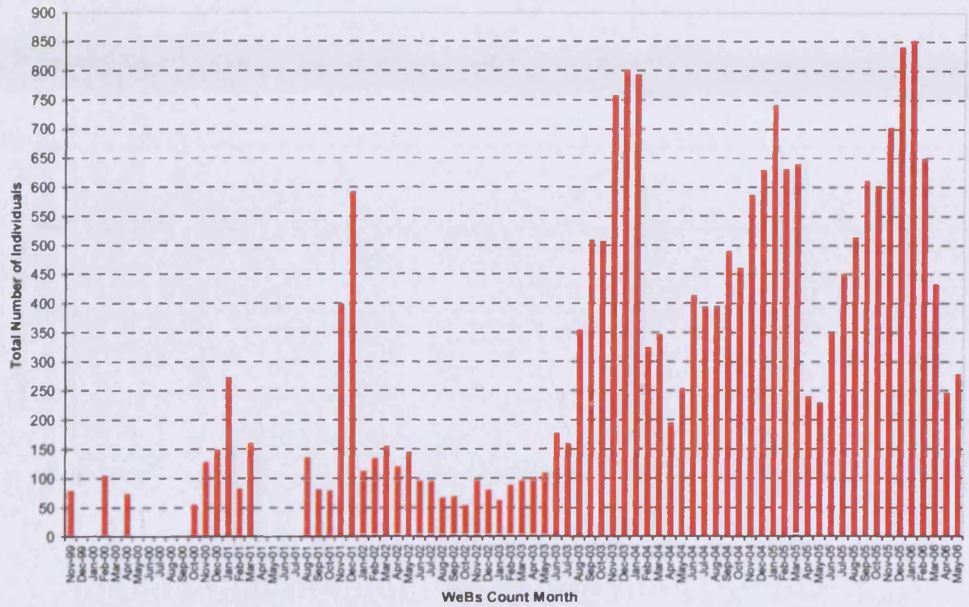


Figure 6.8: Total number of Wildfowl recorded during monthly WeBS counts between Nov. 1999 and May 2006.

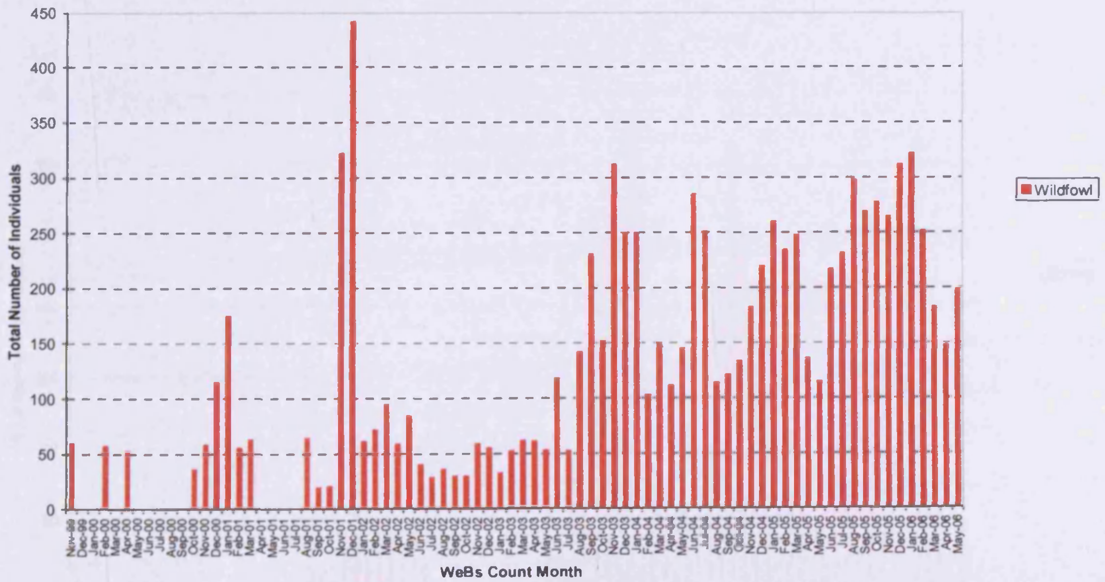


Figure 6.9: Total number of Waders recorded during monthly WeBS counts between Nov. 1999 and May 2006.

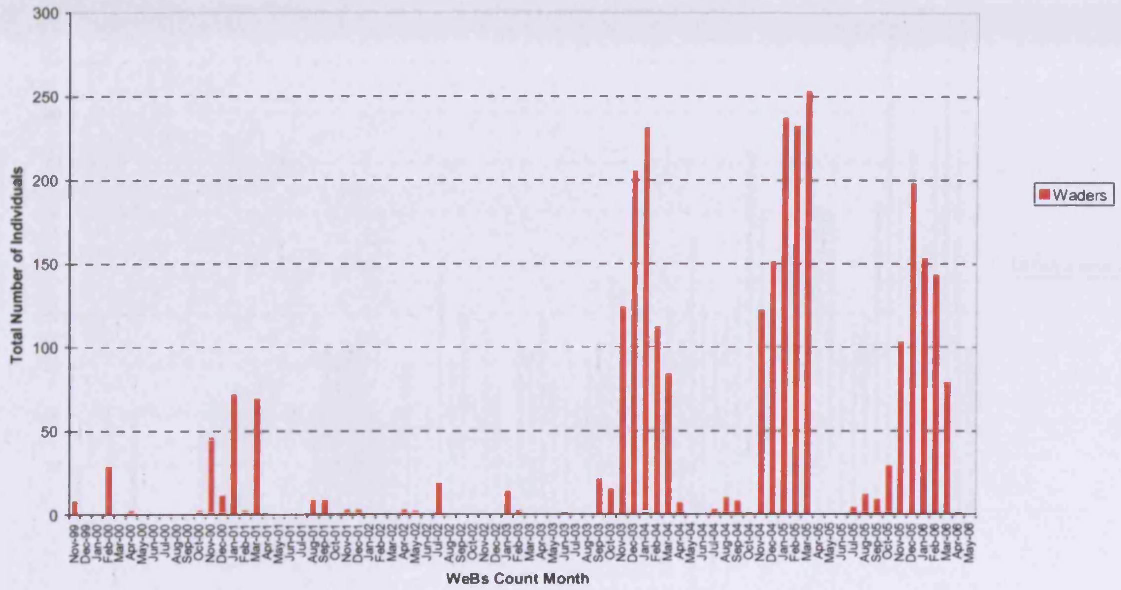


Figure 6.10: Total number of Rails recorded during monthly WeBS counts between Nov. 1999 and May 2006.

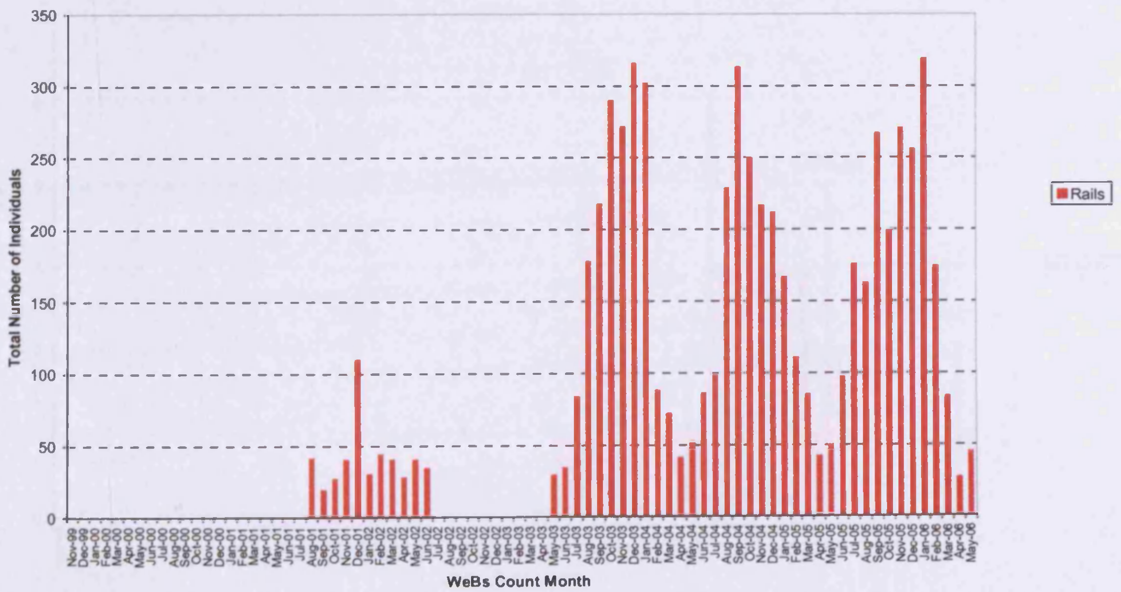


Figure 6.11: Total number of 'Diving Birds' recorded during monthly WeBS counts between Nov. 1999 and May 2006.

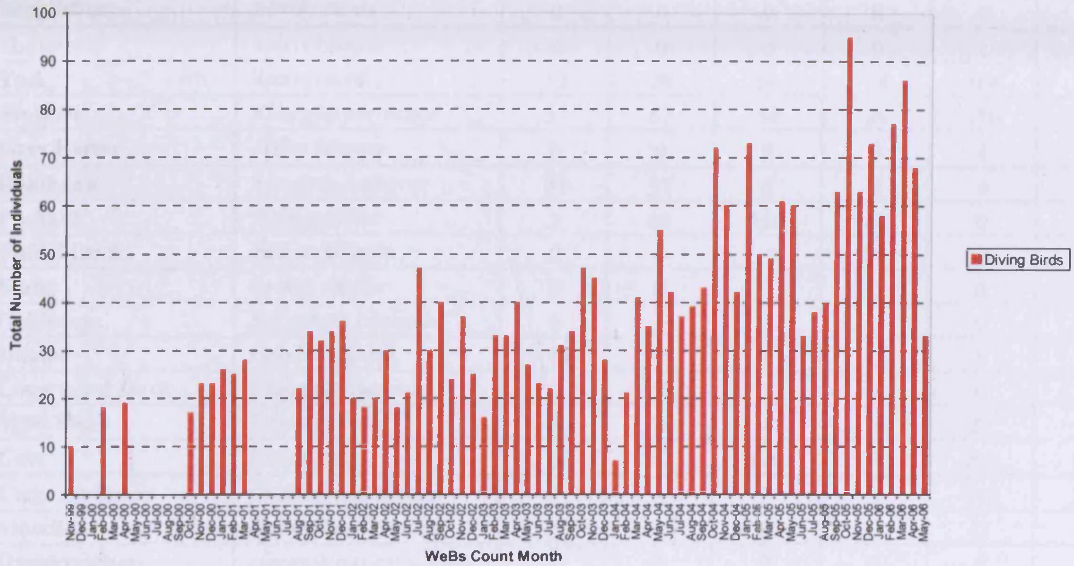


Figure 6.12: Total number of Herons recorded during monthly WeBS counts between Nov. 1999 and May 2006.

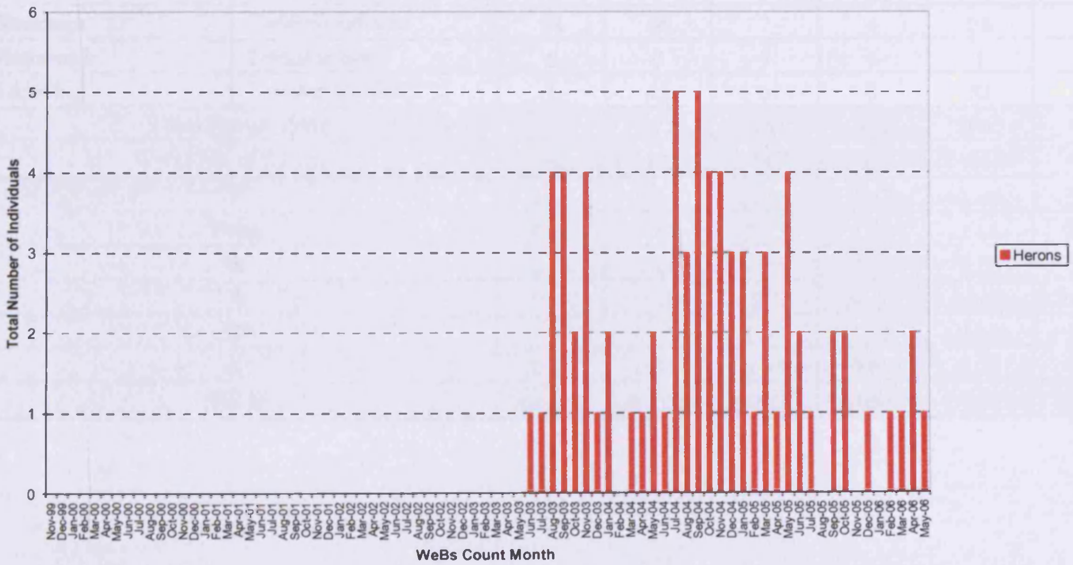


Table 6.3: Winter peak counts (Nov.-Mar.) of all waterfowl recorded 99/00–05/06.

Species		Winter Peak Count (Nov.-Mar.) Year						
		99/00	**00/01**	**01/02**	**02/03**	**03/04**	**04/05**	**05/06**
Common Sandpiper	*Actitis hypoleucos*	0	1	0	0	0	0	0
Kingfisher	*Alcedo atthis*	0	0	0	0	0	4	3
Shoveler	*Anas clypeata*	0	0	0	0	1	0	2
Teal	*Anas crecca*	12	28	50	14	164	107	135
Mallard	*Anas platyrhynchos*	37	67	38	28	150	123	164
Grey Heron	*Ardea cinerea*	0	0	0	0	4	4	1
Redshank	*Arenaria interpres*	21	37	0	0	0	0	3
Pochard	*Aythya ferina*	2	64	350	14	0	1	0
Tufted Duck	*Aythya fuligula*	0	0	18	20	56	61	48
Scaup	*Aythya marila*	0	0	0	0	0	4	0
Goldeneye	*Bucephala clangula*	0	1	0	0	0	4	3
Dunlin	*Calidris alpina*	0	55	1	0	0	0	0
Long-tailed Duck	*Clangula hyemalis*	0	0	1	0	0	0	0
Mute Swan	*Cygnus olor*	0	9	4	13	22	14	30
Coot	*Fulica atra*	0	5	110	185	292	197	305
Common Snipe	*Gallinago gallinago*	0	0	2	0	176	247	158
Moorhen	*Gallinula chloropus*	0	0	0	0	41	20	27
Oystercatcher	*Haematopus ostralegus*	0	2	0	0	0	0	0
Jack Snipe	*Lymnocryptes minimus*	0	0	0	0	0	0	3
Goosander	*Mergus merganser*	5	2	0	0	4	4	5
Curlew	*Numenius arquata*	8	30	0	0	0	0	0
Cormorant	*Phalacrocorax carbo*	17	26	31	23	33	48	38
Slavonian Grebe	*Podiceps auritus*	0	0	1	0	0	0	0
Great Crested Grebe	*Podiceps cristatus*	0	5	9	18	13	22	42
Red-necked Grebe	*Podiceps grisegena*	0	0	0	0	0	0	1
Water Rail	*Rallus aquaticus*	0	0	0	0	0	2	3
Little Grebe	*Tachybaptus ruficollis*	1	1	3	6	10	16	20
Shelduck	*Tadorna tadorna*	14	44	7	4	20	30	16
Redshank	*Tringa totanus*	0	0	3	6	1	6	7
Lapwing	*Vanelus vanellus*	1	45	0	8	53	24	31
Total Peak Count		118	422	628	339	1040	938	1045
Total No. of Species		10	17	15	12	16	20	22
α		2.61	3.56	2.77	2.43	2.69	3.60	3.94
Dmg		9.01	2.65	2.17	1.89	2.16	2.78	3.02
Ds		0.18	0.11	0.35	0.32	0.16	0.15	0.16
d		31.40	15.88	55.73	54.57	28.08	26.33	29.19
H'		1.90	2.35	1.50	1.71	2.09	2.20	2.20
E		0.83	0.83	0.55	0.69	0.75	0.73	0.71
VarH		0.0037	0.0010	0.0024	0.0047	0.0008	0.0011	0.0010

Table 6.4: Annual peak counts (Jan.-Dec.) of all waterfowl recorded 2000–2005. Counts from 1999 are not shown here as barrage closure only occurred in Nov. of this year.

Species		**Annual Peak Count Year**					
		2000	**2001**	**2002**	**2003**	**2004**	**2005**
Common Sandpiper	*Actitis hypoleucos*	1	1	2	3	1	
Kingfisher	*Alcedo atthis*					3	4
Shoveler	*Anas clypeata*					1	2
Teal	*Anas crecca*	24	50	33	136	164	135
Mallard	*Anas platyrhynchos*	42	67	34	150	170	169
Grey Heron	*Ardea cinerea*				4	4	3
Turnstone	*Arenaria interpres*		37		3		
Pochard	*Aythya ferina*	40	350	32			1
Tufted Duck	*Aythya fuligula*		18	12	56	61	44
Scaup	*Aythya marila*					4	
Goldeneye	*Bucephala clangula*		1			1	4
Dunlin	*Calidris alpina*		55		1		
Ringed Plover	*Charadrius hiaticula*				1		
Long-tailed Duck	*Clangula hyemalis*			1			
Mute Swan	*Cygnus olor*	2	12	28	91	112	118
Little Egret	*Egretta garzetta*					3	1
Coot	*Fulica atra*		110	44	289	299	243
Common Snipe	*Gallinago gallinago*		2	1	156	176	247
Moorhen	*Gallinula chloropus*				41	20	28
Oystercatcher	*Haematopus ostralegus*	2	2	3			
Jack Snipe	*Lymnocryptes minimus*						1
Goosander	*Mergus merganser*		2		4	2	5
Curlew	*Numenius arquata*		30	11			
Cormorant	*Phalacrocorax carbo*	23	31	32	33	55	53
African Spoonbill	*Platalea alba*					1	
Slavonian Grebe	*Podiceps auritus*		1	1			
Great Crested Grebe	*Podiceps cristatus*		11	20	19	25	36
Water Rail	*Rallus aquaticus*						3
Little Grebe	*Tachybaptus ruficollis*	1	3	7	12	13	22
Shelduck	*Tadorna tadorna*	7	44	21	21	20	30
Redshank	*Tringa totanus*		3	6	6	5	6
Lapwing	*Vanellus vanellus*	45	6		46	53	31
Total Peak Count		187	836	288	1072	1193	1186
Total No. of Species		10	21	17	19	22	22
α		2.26	3.92	3.96	3.29	3.83	3.84
Dmg		1.72	2.97	2.83	2.58	2.96	2.97
Ds		0.18	0.21	0.10	0.14	0.14	0.13
d		24.06	41.87	15.28	26.96	25.06	20.83
H'		1.81	2.06	2.45	2.22	2.23	2.27
E		0.78	0.68	0.86	0.75	0.72	0.73
VarH		0.0024	0.0017	0.0014	0.0008	0.0007	0.0007

(iii). *Waterfowl Area Preference within Cardiff Bay*

By collecting separate count data from each of the 5 main areas of Cardiff Bay ('River Taff', 'River Ely', 'Wetland Reserve', 'Redhouse Marsh' and 'Open Water/Other') I was able to look at the 'attractiveness' (to waterfowl) of each of these areas in terms of the proportion of the whole Bay's population which they supported throughout the year, from May 2003 until May 2006 (See **App. 6.7**).

An overview of the importance of each area to each of the 32 species recorded during the WeBS counts (over the three year period) is given by **Tab. 6.5.** From this table we can see that there are clear preferences shown by individual species. For example 100% of the 12 records for Goldeneye *Bucephala clangula* came from the Redhouse marsh area. Similarly, all records of Pochard *Aythya ferina* came from the River Ely – an area for which Tufted Duck *Aythya fuligula* also show a clear preference with 45.2% of observations having occurred there. The Great Crested Grebe *Podiceps cristatus*, a species which has been recorded in all areas of the Bay, shows a clear preference for the 'Redhouse Marsh' area. The vast majority of species, however, show a clear preference for the 'Wetland Reserve' area, with 40.1% of all individuals recorded within the area, and with 8 species having been recorded in this area alone.

Figure 6.13 shows more clearly the preference for each of the areas shown by each of the five main groups of waterfowl. Of all the groups, the one with the most marked preference is the waders, with 98.5% of all individuals recorded at the Wetland Reserve site. In fact this site proved to be the most attractive for all groups with the exception of the rails – the most abundant species of which was Coot *Fulica atra.* The rivers Taff and Ely proved most attractive to this latter group – though this figure is largely influenced by the high abundance of Coot which feed upon the easily available aquatic vegetation found in these two rivers. The 'Redhouse Marsh' site, was also important for divers as a whole – though this is largely due to the number of Great Crested Grebe which congregate in the area.

As we would expect, all areas attracted most waterfowl during the winter period, though this pattern is most defined at the Wetland Reserve (see **Figs. 6.14 - 6.18**) – partly due to the large number of wintering Snipe *Gallinago gallinago* and Teal *Anas crecca* which the site attracts.

Table 6.5: Percentage of the total number of individuals (recorded between May 2003 and May 2006) occurring within each of the 5 main areas of Cardiff Bay

Species		**Ely**	**Other**	**Redhouse**	**Taff**	**Wetland Reserve**	**Total No. Individuals Recorded**
Common Sandpiper	*Actitis hypoleucos*				40.0	60.0	5
Kingfisher	*Alcedo atthis*	13.0			13.0	73.9	23
Shoveler	*Anas clypeata*					100.0	6
Teal	*Anas crecca*	2.8	0.1	1.3	6.5	89.4	1418
Mallard	*Anas platyrhynchos*	35.0	10.3	3.5	27.2	24.2	3587
Gadwall	*Anas strepera*					100.0	1
Grey Heron	*Ardea cinerea*	15.6			10.9	73.4	64
Turnstone	*Arenaria interpres*	33.3	33.3			33.3	9
Pochard	*Aythya ferina*	100.0					3
Tufted Duck	*Aythya fuligula*	45.2		24.6	6.4	23.8	755
Scaup	*Aythya marila*				80.0	20.0	5
Canada Goose	*Branta canadensis*					100.0	4
Goldeneye	*Bucephala clangula*			100.0			12
Dunlin	*Caldris alpina*					100.0	1
Ringed Plover	*Charadrius hiaticula*	100.0					1
Mute Swan	*Cygnus olor*	31.1	16.8	4.0	29.8	18.3	1341
Little Egret	*Egretta garzetta*			12.5		87.5	8
Coot	*Fulica atra*	26.6	1.9	1.4	51.2	18.8	5423
Common Snipe	*Gallinago gallinago*					100.0	2153
Moorhen	*Gallinula chloropus*	79.9		0.4	11.3	8.4	477
Oystercatcher	*Haematopus ostralegus*		100.0				1
Jack Snipe	*Lymnocryptes minimus*					100.0	4
Goosander	*Mergus merganser*		23.8	33.3	42.9		21
Cormorant	*Phalacrocorax carbo*	10.6	6.0	0.1	20.5	62.9	957
African Spoonbill	*Platalea alba*					100.0	1
Great Crested Grebe	*Podiceps cristatus*	11.8	0.5	64.2	5.1	18.5	612
Red necked Grebe	*Podiceps grisegena*			100.0			1
Water Rail	*Rallus aquaticus*	44.4			33.3	22.2	9
Little Grebe	*Tachybaptus ruficollis*	34.8		10.4	44.3	10.4	201
Shelduck	*Tadorna tadorna*		9.3	8.8	3.3	78.6	182
Redshank	*Tringa totanus*					100.0	36
Lapwing	*Vanellus vanellus*	6.9				93.1	303
Total %		**23.6**	**4.5**	**5.2**	**26.6**	**40.1**	**17624**
Total No. Species		**16**	**10**	**14**	**16**	**26**	**32**

Figure 6.13: Percentage of total Wildfowl, Waders, Divers, Herons and Rails occurring in each of the 5 main areas of Cardiff Bay. Percentage is based upon the mean count per survey over a period of 37 months (May 2003 - May 2006).

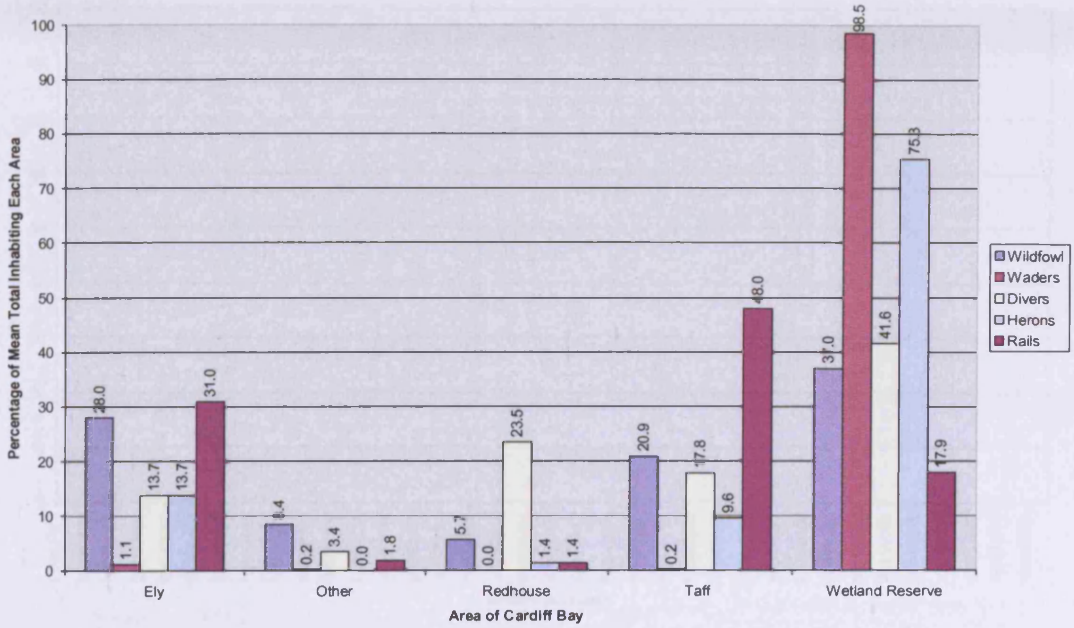


Figure 6.14: Total number of individuals (all wildfowl species) recorded in the River Ely survey area (May 2003 – May 2006).

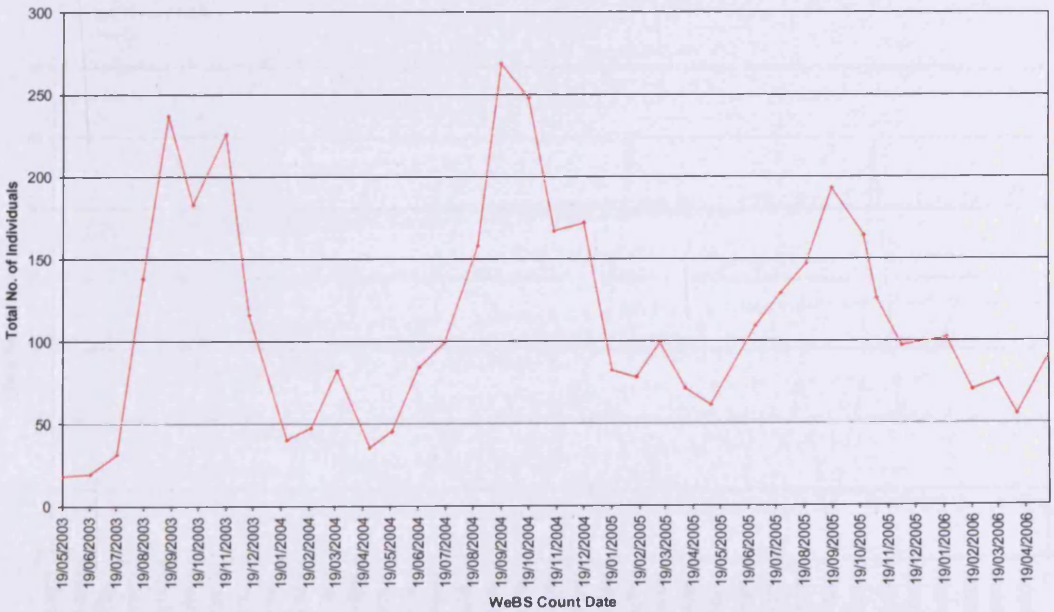


Figure 6.15: Total number of individuals (all wildfowl species) recorded in the 'Open Water/Other' survey areas (May 2003 – May 2006).

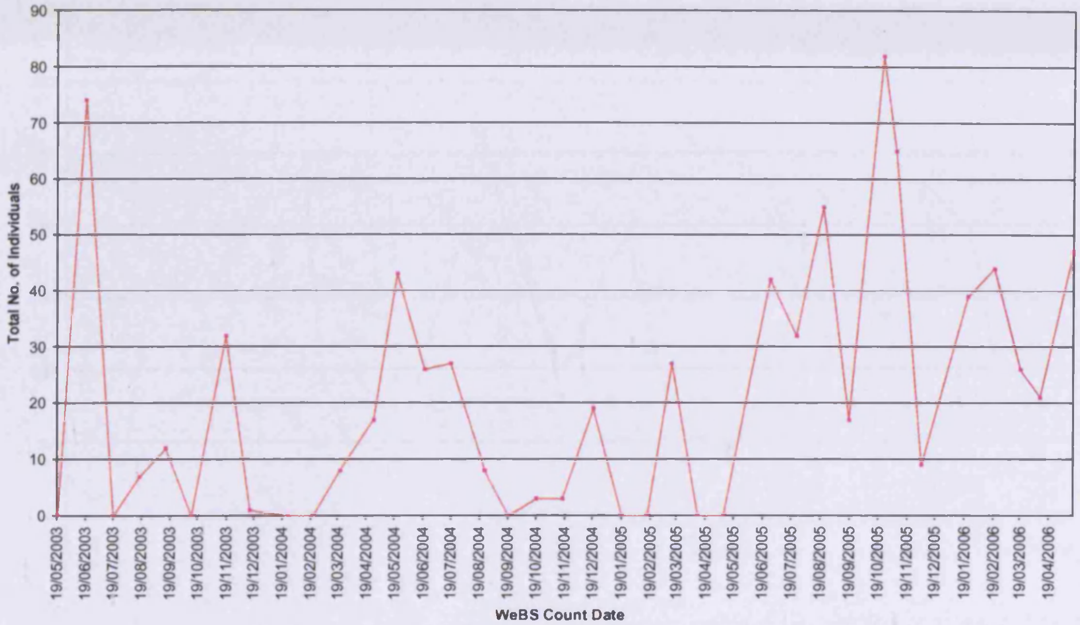


Figure 6.16: Total number of individuals (all wildfowl species) recorded in the 'Redhouse' survey area (May 2003 – May 2006).

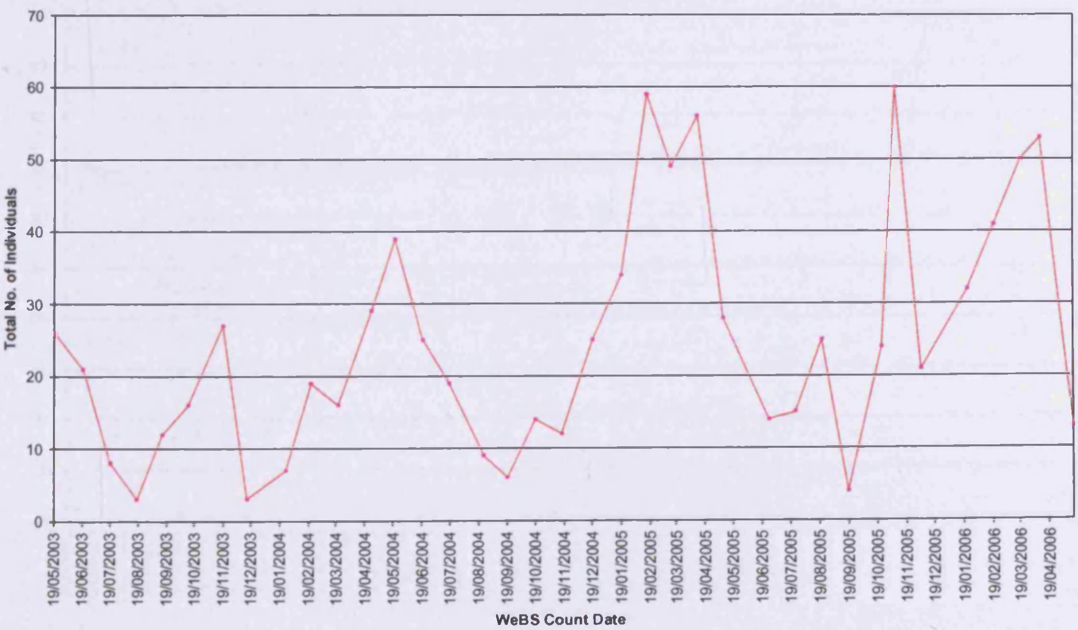


Figure 6.17: Total number of individuals (all wildfowl species) recorded in the 'Taff' survey area (May 2003 – May 2006).

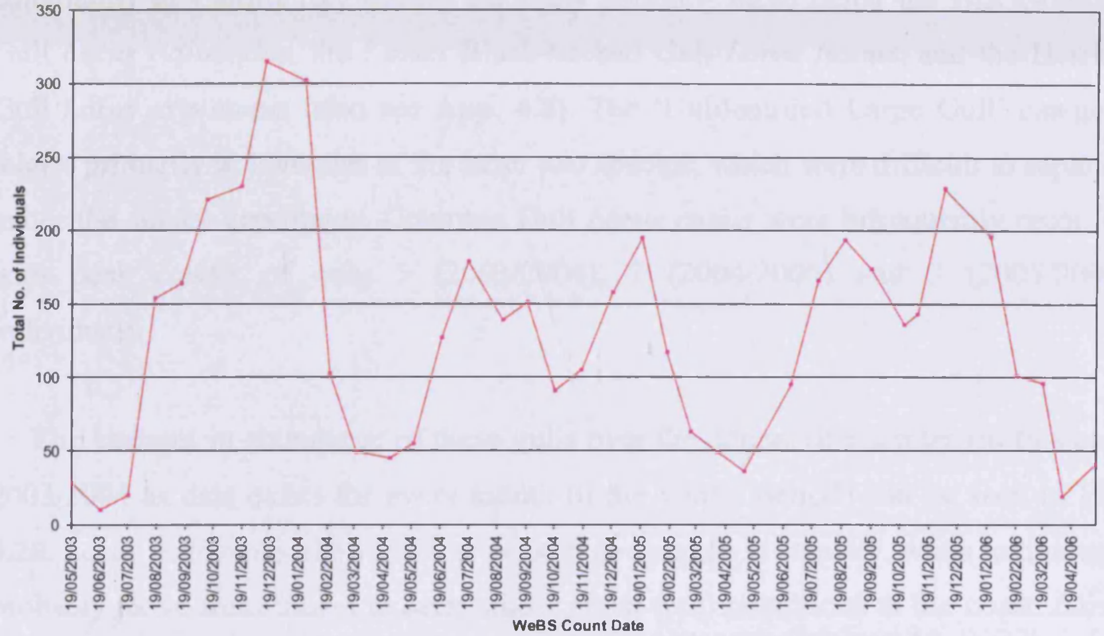
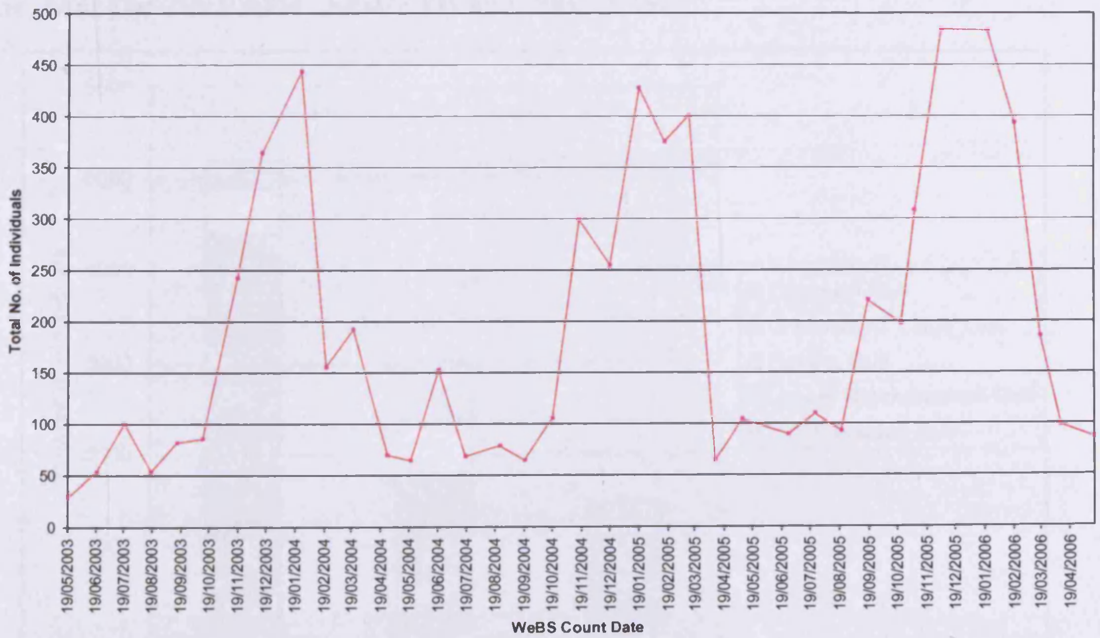


Figure 6.18: Total number of individuals (all wildfowl species) recorded in the 'Wetland Reserve' survey area (May 2003 – May 2006).

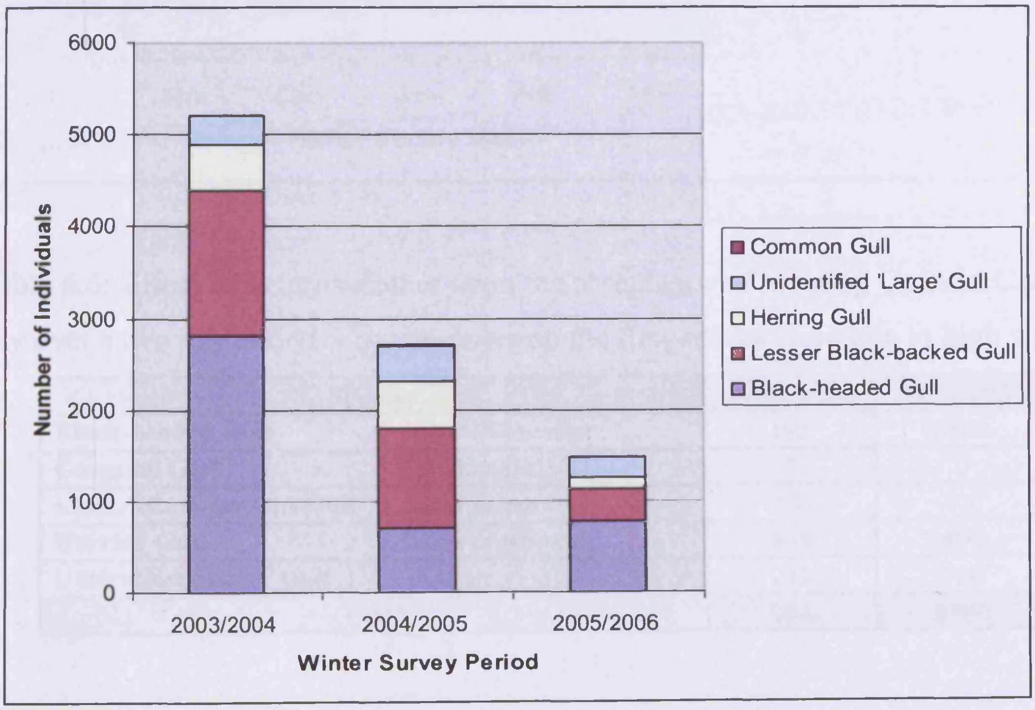


(iv). *Wintering Gull Roost Populations*

As can be seen from **Fig. 6.19,** three species made up the majority of the Gull community in Cardiff Bay during the study period – these being the Black-headed Gull *Larus ridibundus,* the Lesser Black-backed Gull *Larus fuscus*, and the Herring Gull *Larus argentatus* (also see **App. 6.8**). The 'Unidentified Large Gull' category relates primarily to juveniles of the latter two species, which were difficult to separate under the survey conditions. Common Gull *Larus canus* were infrequently recorded with peak counts of only 5 (2003/2004), 7 (2004/2005) and 3 (2005/2006) individuals.

The changes in abundance of these gulls over the course of a winter (in this case 2003/2004 as data exists for every month of the winter period) can be seen in Fig. **6.20.** *Larus ridibundus* shows a clear peak in abundance in January, when individuals probably move from inland to seek milder (frost-free) conditions at the coast. *Larus fuscus* shows a clear decline between November and February, with large numbers of individuals returning by March – simply due to a large proportion of the individuals of this species migrating south to Africa over the winter period.

Figure 6.19: Peak abundance of Gulls recorded in Cardiff Bay during the winters (Nov.-Mar.) of 2003/2004, 2004/2005 and 2005/2006.



It is likely that there is considerable variation in the numbers of all gull species roosting within Cardiff Bay during the winter, with such factors as weather and disturbance playing an important role in the day to day selection of roost sites. This is clearly illustrated in **Tab. 6.6**, which shows that strong winds significantly affect the roost site choice of Gulls in Cardiff Bay, with almost 5 times as many Gulls present under 'normal' conditions – even though there was only a period of two days between counts.

Figure 6.20: Monthly changes in roosting Gull abundance during the winter of 2003/2004.

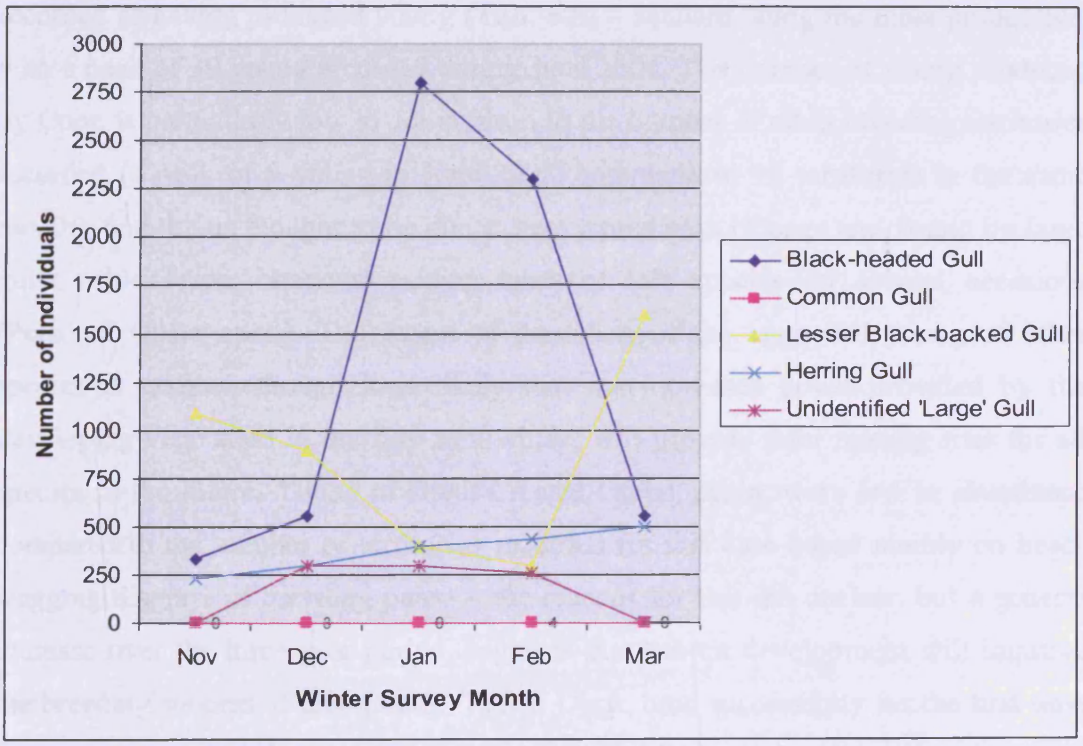


Table 6.6: Effect of severe weather upon the abundance of roosting Gulls in Cardiff Bay over a two day period. Low numbers on the first survey were due to high winds.

Species		17/01/2004	19/01/2004
Black-headed Gull	*Larus ridibundus*	195	2800
Common Gull	*Larus canus*	5	0
Lesser Black-backed Gull	*Larus fuscus*	230	400
Herring Gull	*Larus argentatus*	158	400
Unidentified 'Large' Gull		210	300
Total		**798**	**3900**

(v). *Breeding Waterfowl Populations*

A total of 11 species of waterfowl were recorded as potentially breeding in Cardiff Bay over the current research period (**Tab. 6.7**). These were all species which displayed breeding behaviour, were present in obvious pairs, or had nests, eggs or young. Mallard were by far the most common species showing signs of breeding, though Coot, Mute Swan, Great Crested Grebe and Tufted Duck were also regularly recorded.

Of the 11 species which were recorded as having breeding territories, only 6 were recorded as having produced young (**Tab. 6.8**) – Mallard being the most productive, with a peak of 39 young recorded during June 2004. The number of young produced by Coot, is particularly low in comparison to the number of adult breeding territories recorded (a peak of 5 young in June 2005, compared to 15 territories in the same month), and this is thought to be due to heavy predation of eggs and young by large gulls, which were observed raiding nests of this species on several occasions (Personal Observation). The extent of predation of the eggs and young of other species is unclear, though it is likely that the increased cover provided by the developing vegetation in the Bay as a whole, will provide safer nesting sites for all species in the future. Young of Great Crested Grebe, again, were low in abundance compared to the number of territories recorded (in this case based mainly on head-wagging displays of breeding pairs) – the reasons for this are unclear, but a general increase over the three year period, suggests that habitat development will improve the breeding success of this species. Tufted Duck, bred successfully for the first time in the summer of 2005 (at the Cardiff Bay Wetland Reserve) – again indicating some degree of improvement in breeding habitat.

As can be seen from **Fig. 6.21,** the importance of the 'Wetland Reserve' as an area for breeding waterfowl has increased as it has developed over the last three years. In the first year of the current study (2003), the 'River Ely' was the most important area, with a total of 37 territories recorded there (37.1% more than the 'Wetland Reserve' with 24 territories). However, in 2004 and 2005, the 'Wetland Reserve' became the most important area.

The 'Open Water/Other' area was the least important area for breeding wildfowl in every year – primarily because there are no vegetated marginal habitats within the area, and thus very few suitable nesting sites. The few records which have come from this area, relate to species such as Shelduck *Tadorna tadorna,* and Ringed Plover *Charadrius hiaticula* – neither of which require vegetated habitats for the purpose of breeding (the former nest in holes, the latter on gravel and similar substrates).

The actual locations of the breeding waterfowl territories recorded during the monitoring period are illustrated separately as yearly totals in **Figs. 6.22 - 6.24**, and the separate counts for each month along with individual record ID keys are presented in **App. 6.9**. One of the most obvious findings which these maps present is the importance of the vegetated habitats of Cardiff Bay, in providing suitable breeding and nesting sites, with the vast majority of sightings occurring in the vegetated areas of the 'Wetland Reserve', and the 'Redhouse Marsh'. This is likely to be due to a variety of reasons including shelter from predators, availability of nesting materials, and food resource availability amongst others.

Breeding waterfowl in the River Taff, and River Ely areas were concentrated in the 'inlet' areas (the horseshoe shaped pools) which are present on both rivers, and this is likely to be due to the shelter, and more diverse marginal habitats which they provide.

Table 6.7: Total number of territories of all waterfowl species showing signs of breeding in Cardiff Bay between May-Aug. 2003, and Mar.-Aug. 2004 and 2005.

Species		2003				2004						2005					
		May	Jun.	Jul.	Aug.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Mar.	Apr.	May	Jun.	Jul.	Aug.
Shoveler	*Anas clypeata*						1										
Teal	*Anas crecca*						2						3				
Mallard	*Anas platyrhynchos*	10	13	7	4	7	15	10	6	5	1		25	12	9	1	
Tufted Duck	*Aythya fuligula*					2	6	4	2	1	1	1	2	4	3	1	2
Ringed Plover	*Charadrius hiaticula*	1															
Mute Swan	*Cygnus olor*	3	1	3	2	3	5	5	2	1	2	1	9	5	6	2	3
Coot	*Fulica atra*	6	5	9	3	10	5	5	5	2				6	15	1	2
Moorhen	*Gallinula chloropus*	1	1		3	1				1	2			1	3		3
Great Crested Grebe	*Podiceps cristatus*	5	1	5	3	11	7	12	5	1	3		18	8	6	2	2
Little Grebe	*Tachybaptus ruficollis*										1						1
Shelduck	*Tadorna tadorna*	5				3	7	4	1				1	2			
Total		**31**	**21**	**24**	**15**	**37**	**48**	**40**	**21**	**11**	**10**	**2**	**58**	**38**	**42**	**7**	**13**

Table 6.8: Total number of waterfowl young recorded in Cardiff Bay in 2003 (May-Aug.), 2004 and 2005 (Mar.-Aug.).

Species		2003				2004						2005					
		May	Jun.	Jul.	Aug.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Mar.	Apr.	May	Jun.	Jul.	Aug.
Mallard	*Anas platyrhynchos*	8	13		11	23		11	39	21	4			8	36	6	
Tufted Duck	*Aythya fuligula*															7	7
Mute Swan	*Cygnus olor*	7		10	10	11		6	6	5	12				6	5	6
Coot	*Fulica atra*				3	2			4						5		
Moorhen	*Gallinula chloropus*	2	2		6	1				3	3						5
Great Crested Grebe	*Podiceps cristatus*				3				3	3	4					5	5
Total		**17**	**15**	**10**	**33**	**37**	**0**	**17**	**52**	**32**	**23**	**0**	**0**	**8**	**47**	**23**	**23**

Figure 6.21: Total number of waterfowl territories recorded in each of the five sampling areas in 2003, 2004 and 2005.

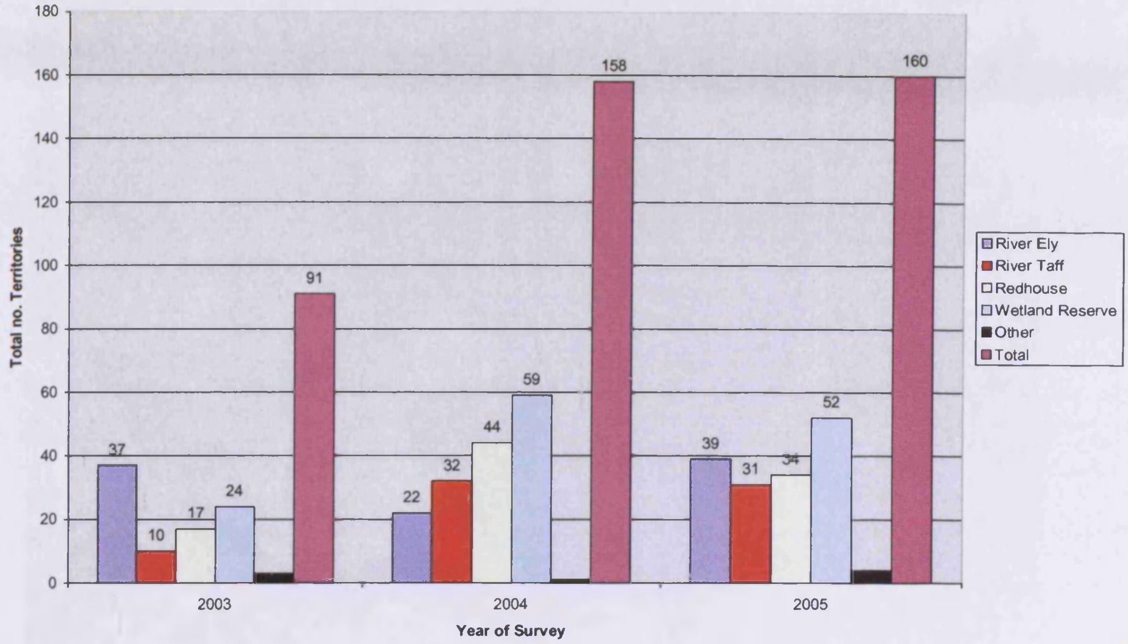


Figure 6.22: The Locations of breeding waterfowl territories 2003 (May-Aug.).

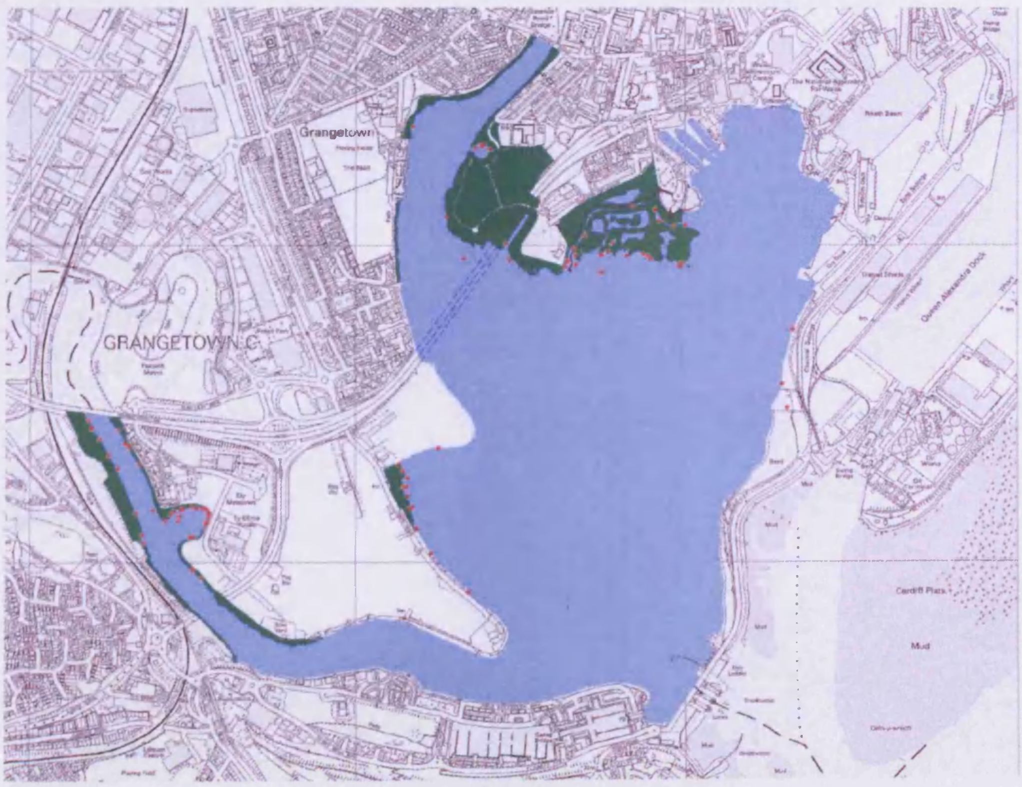


Figure 6.23: The Locations of breeding waterfowl territories 2004 (Mar.-Aug.).

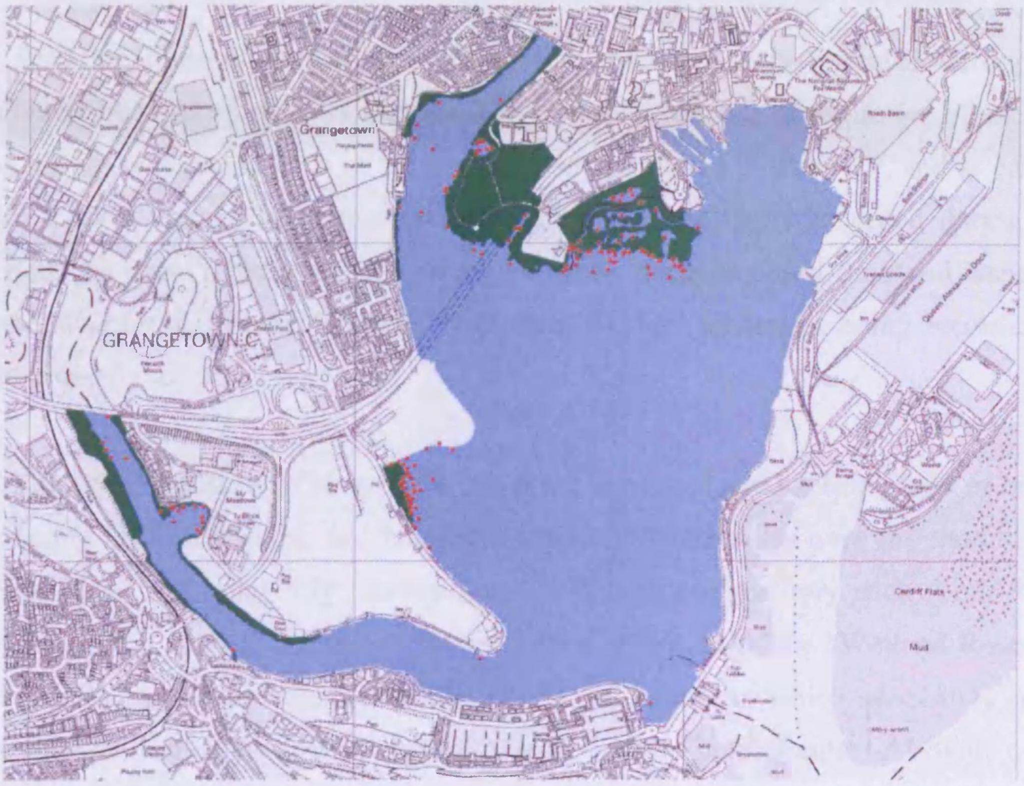
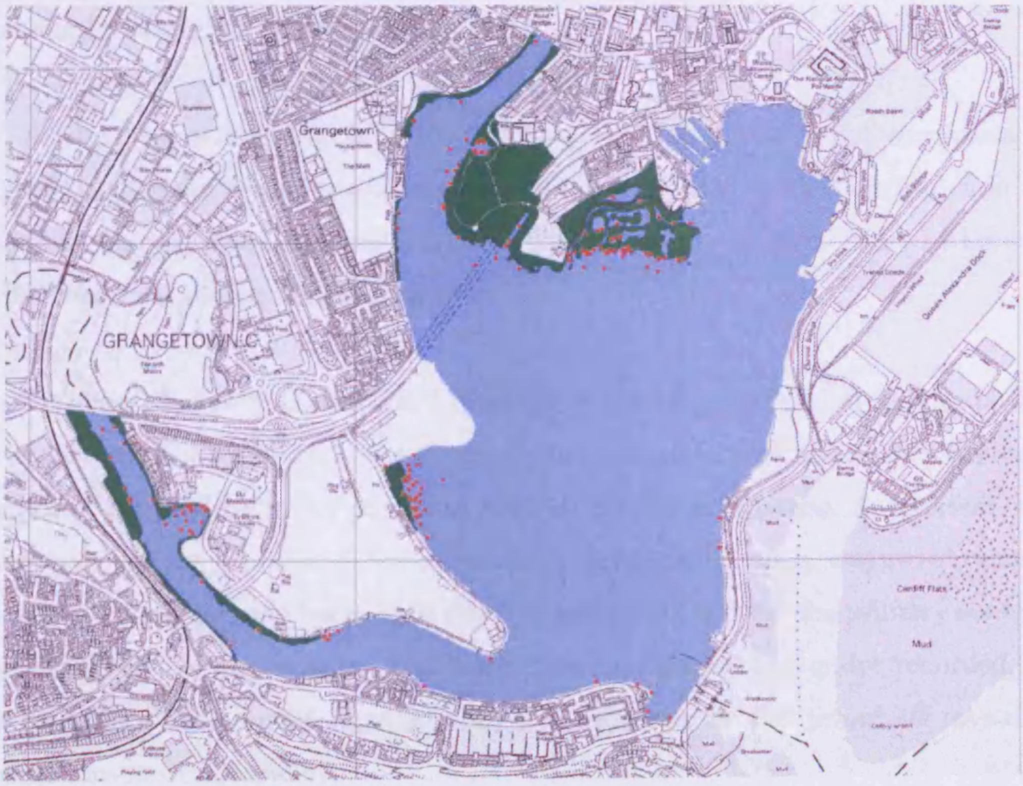


Figure 6.24: The Locations of breeding waterfowl territories 2005 (Mar.-Aug.).



(vi). *Breeding Non-waterfowl Populations*

Breeding birds other than waterfowl were most regularly recorded during the summer (Mar.-Aug.) of 2005 (**App. 6.10**). The total number of territories of each of the species recorded in each of the survey areas are shown in **Tab. 6.9**, and as can be seen, only 4 species of 'non-waterfowl' (all passerines) were recorded during the period. An equal number of territories (six each), were recorded for Reed Bunting, Reed Warbler and Sedge Warbler, with three Skylark territories being recorded in addition.

The 'Wetland Reserve' was by far the most important site for this group of birds, attracting all four species, and holding a total of 19 territories over the monitoring period. The 'Taff' and 'Ely' survey areas held only one territory each (both Reed Warbler). The most likely reason for the added attraction of the 'Wetland Reserve' site is that it provides a sufficient area of suitable habitat in which adequately sized breeding territories can be set up by passerine birds in particular. As with other aspects of the ecology of Cardiff Bay, this area is likely to increase in its overall importance, in the context of Cardiff Bay as a whole, as the habitats and plant communities develop over the coming years.

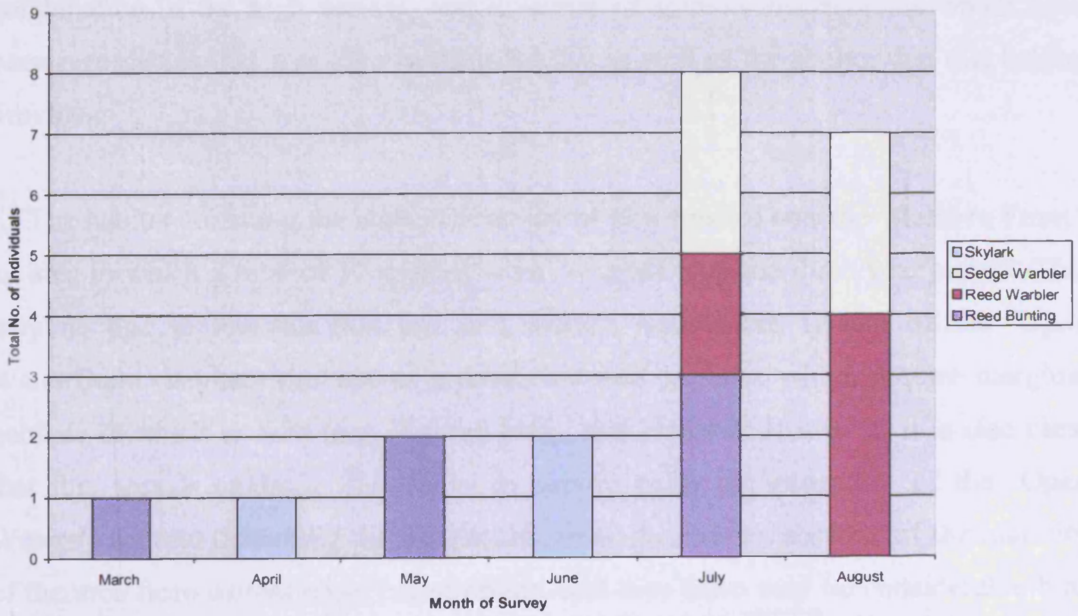
As can be seen from **Fig. 6.25**, the total number of 'non-waterfowl' territories was highest later in the breeding season in the summer of 2005, with 8 territories in July and 7 in August. Reed Bunting were the earliest species to show signs of breeding behaviour, with activity recorded in March.

The generally low abundance and diversity of breeding birds other than waterfowl, is likely to be due to the lack of sufficiently large areas in which the often expansive territories required by many passerine species, can be established. In addition, non-waterfowl species are also a lot more difficult to record than waterfowl, namely because of their size, and because of this, the male song is often the primary source of identification. For this reason, it is likely that this group was under recorded, and would benefit from more detailed 'targeted' surveys in the future to reveal the populations more accurately.

Table 6.9: Total number of territories of breeding non-waterfowl species in Cardiff Bay (Mar.-Aug. 2005).

Species		Taff	Ely	Wetland Reserve	Total
Reed Bunting	*Emberiza schoeniclus*			6	6
Skylark	*Alauda arvensis*			3	3
Reed Warbler	*Acrocephalus scirpaceus*	1	1	4	6
Sedge Warbler	*Acrocephalus schoenobaenus*			6	6
Total		**1**	**1**	**19**	**21**

Figure 6.25: Total number of non-waterfowl territories recorded between March and August 2005.



vii). *Winter Habitat Usage at Cardiff Bay Wetland Reserve*

The results given in **Table 6.10** and **6.11**, together outline the major preferences of all bird species recorded during the winter marsh transects of Cardiff Bay Wetland Reserve – all of which were undertaken over the three year study period. In addition **Figure 6.26** details the total mean habitat usage by all birds species, thus providing an insight into the importance of each of the habitats in attracting birds in general.

It is clear from the latter, that the 'Reens & Ditches' habitat was by far the most productive of the 10 areas sampled, providing habitat for large numbers of Snipe *Gallinago gallinago*, and Teal *Anas crecca* in particular. This is most likely due to a combination of the high density, and diversity of aquatic invertebrates which have been recorded in this area (See **Section 5.3.2**.), as well as the shelter that this habitat provides.

The habitat attracting the highest diversity of bird species was the 'Reserve Front', an area in which a total of 17 species were recorded over the three year period. This may be due to the fact that the area attracts birds more typical of the 'Open Water/Bund' habitats (for use as a roost), as well as those which require marginal habitats in which to feed (e.g. Wading birds, and Herons). However, it is also clear that this area is amongst the easiest to survey (with the exception of the 'Open Waters') without disturbing the inhabitants, with clear views possible of the majority of the area from distant observation points, and thus there may be considerable bias because of this.

The 'Tall-herb Fen' and 'Willow & Alder Carr' habitats attracted the second highest diversity of species (13 each). As one might expect these habitats attracted mostly passerine species – reinforcing the habitat heterogeneity theory mentioned previously. In these more terrestrial areas, the diversity of plant species, and the spatial structure which they provide, serve to attract a very different bird community to the Wetland Reserve, than the marginal wetland habitats do.

The 'Raised Areas' and 'Reservoir' proved the least important habitats to birds, with only 3 species being attracted to each, over the monitoring period. The former attracted significant numbers of Lapwing *Vanellus vanellus* in the winter of 2003/2004 and subsequently failed to attract the species. This is thought to be due to the fact that this habitat was constructed during the Autumn of 2003 and so, at the time of the first survey, provided a raised platform, free from vegetation, which would have provided clear views across the site (of any approaching predators etc) – a feature which appears to be of importance to this species. Ruderal vegetation growth on the raised areas in 2004 meant that this 'safety' feature was short lived. The 'Resevoir', although one of the more mature aquatic habitats at the reserve site, is also the most subject to disturbance, being at the highest point of the reserve and with direct public access, thus this habitat is never likely to attract species which are intolerant of regular disturbance.

The 'Open Water/Bund' habitats attracted predominantly wildfowl, although rails (namely Coot), Grebes, and Cormorant were also common. The latter was commonly observed roosting on the stone bund, litter boom and numerous floating islands that occur within the boundaries of this area.

As mentioned in the methods section, gulls were not included in this survey, primarily because of the additional time it would have taken to record this highly abundant group. However it was noted that Black-headed Gull *Larus ridibundus,* Herring Gull *L. argentatus,* and Lesser Black-backed Gull *L. fuscus* (and to a far lesser extent Common Gull *L. canus* and Great Black-backed Gull *L. marinus*) showed a clear preference for the 'Open Water/Bund' habitat, and were often present in this area in extremely high numbers (except when disturbed). The attraction of the Wetland Reserve to gulls appears to be primarily as a roosting site.

For the sake of interest, the raw data collected during the winter marsh transect surveys are presented in **Appendix 6.11.**

Table 6.10: Mean winter (Nov.-Mar.) abundance of all species recorded within the 'Open Water/Underwater Bund'; 'Gravel'; 'Raised Areas & Islands'; 'Reed Bed'; and 'Reens & Ditches' habitats at Cardiff Bay Wetland Reserve. N.B. No birds were recorded in the 'Reed Bed' habitats in the winter of 2003/2004, or the 'Raised Areas' in the winter of 2004/2005.

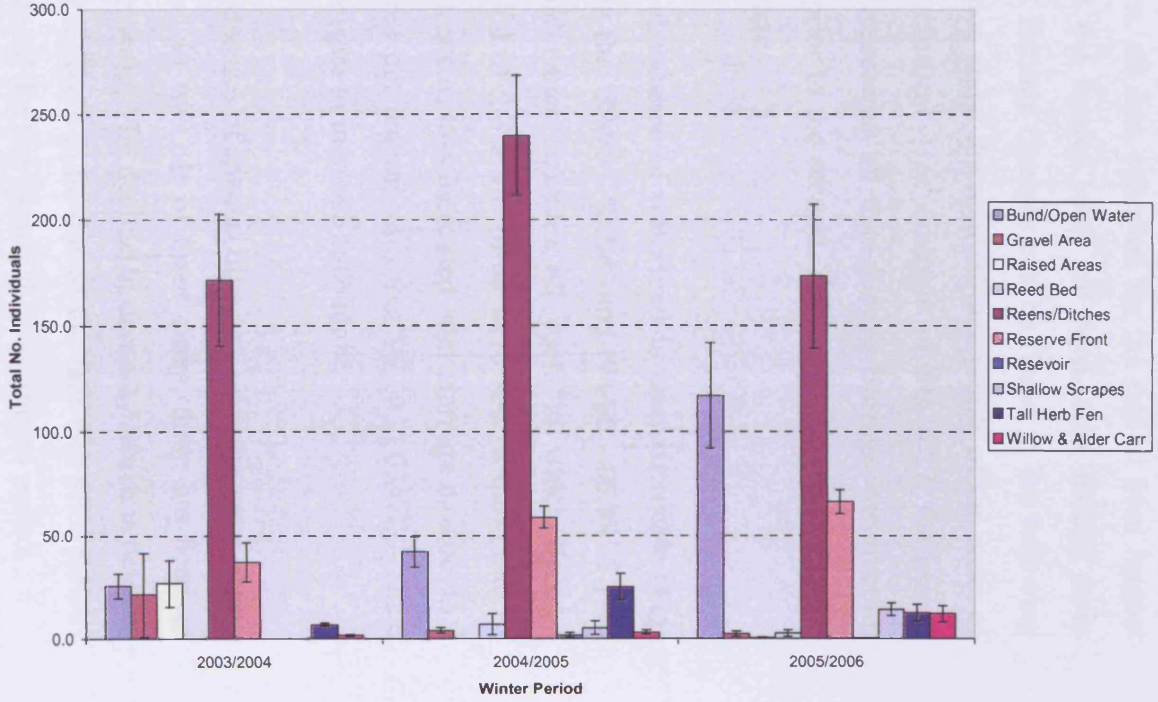
Species		**Open Water/Bund**			**Gravel**			**Raised Areas**		**Reed Bed**		**Reens/Ditches**		
		03/04	04/05	05/06	03/04	04/05	05/06	03/04	05/06	04/05	05/06	03/04	04/05	05/06
Kingfisher	*Alcedo atthis*	-	-	-	-	-	-	-	-	-	-	0.4 ± 0.2	0.8 ± 0.4	0.8 ± 0.4
Shoveler	*Anas clypeata*	-	-	0.2 ± 0.2	-	-	-	-	-	-	-	-	-	0.8 ± 0.5
Teal	*Anas crecca*	-	0.8 ± 0.8	-	-	-	-	-	-	-	-	66.6 ± 24.2	56 ± 12.6	60.6 ± 19.1
Mallard	*Anas platyrhynchos*	2.8 ± 1.7	3 ± 1.8	16.4 ± 6.5	-	-	-	-	-	-	-	0.4 ± 0.4	1.2 ± 0.8	1 ± 1.0
Meadow Pipit	*Anthus pratensis*	-	-	-	-	-	-	-	0.2 ± 0.2	-	-	-	-	-
Grey Heron	*Ardea cinerea*	-	-	-	-	-	-	-	-	-	-	0.4 ± 0.2	1.8 ± 0.5	0.2 ± 0.2
Tufted Duck	*Aythya fuligula*	4.4 ± 1.1	1 ± 0.6	2.6 ± 1.1	-	-	-	-	-	-	-	-	-	-
Goldfinch	*Carduelis carduaelis*	-	-	-	-	-	-	-	-	-	1.2 ± 1.2	-	-	-
Carrion Crow	*Corvus corone*	-	-	-	0.4 ± 0.4	0.4 ± 0.4	0.6 ± 0.4	-	-	-	-	-	-	-
Mute Swan	*Cygnus olor*	0.8 ± 0.5	2.2 ± 0.9	1.4 ± 1.2	-	-	-	-	-	-	-	-	-	3.2 ± 1.5
Reed Bunting	*Emberiza schoeniclus*	-	-	-	-	-	-	-	-	2.4 ± 1.0	0.8 ± 0.4	-	-	-
Coot	*Fulica atra*	3.6 ± 2.4	3 ± 1.9	64 ± 20.7	-	-	-	-	-	-	-	-	-	-
Common Snipe	*Gallinago gallinago*	-	-	-	20.4 ± 20.4	-	-	-	-	4.4 ± 4.4	0 ± 0.0	103.6 ± 20.2	179.2 ± 25.6	105.2 ± 14.2
Moorhen	*Gallinula chloropus*	-	-	0.4 ± 0.4	-	-	-	-	-	-	-	-	0.8 ± 0.5	0.4 ± 0.2
Jack Snipe	*Lymnocryptes minimus*	-	-	-	-	-	-	-	-	-	-	-	-	0.8 ± 0.6
Pied Wagtail	*Motacilla alba*	-	-	-	-	2.2 ± 0.8	1.4 ± 0.7	-	-	-	-	-	-	-
Grey Wagtail	*Motacilla cinerea*		-	-	-	0.8 ± 0.5	0.2 ± 0.2	-	-	-	-	-	-	-
Cormorant	*Phalacrocorax carbo*	11.6 ± 4.4	21.6 ± 6.4	22.8 ± 5.6	-	-	-	-	-	-	-	-	-	-
Magpie	*Pica pica*	-	-	-	-	0.4 ± 0.4	-	-	-	-	-	-	-	-
Great Crested Grebe	*Podiceps cristatus*	1 ± 0.5	-	4.2 ± 2.6	-	-	-	-	-	-	-	-	-	-
Stonechat	*Saxicola torquata*	-	-	-	-	-	-	-	-	-	0.4 ± 0.4	-	-	-
Little Grebe	*Tachybabptus ruficollis*	-	1.8 ± 0.7	0.8 ± 0.8	-	-	-	-	-	-	-	-	-	-
Shelduck	*Tadorna tadorna*	0.8 ± 0.6	8.4 ± 4.5	4.2 ± 3.0	-	-	-	-	-	-	-	-	-	-
Redshank	*Tringa totanus*	-	-	-	-	-	-	-	-	-	-	-	-	0.2 ± 0.2
Blackbird	*Turdus merula*	-	-	-	-	-	-	-	0.2 ± 0.2	-	-	-	-	-
Lapwing	*Vanellus vanellus*	-	-	-	-	-	-	26.2 ± 11.2	-	-	-	-	-	-
Mean total abundance		**25.0 ± 5.9**	**41.8 ± 7.8**	**117.0 ± 24.8**	**20.8 ± 20.3**	**3.8 ± 1.4**	**2.2 ± 1.1**	**26.2 ± 11.2**	**0.4 ± 0.2**	**6.8 ± 4.9**	**2.4 ± 1.5**	**171.4 ± 31.3**	**239.8 ± 28.6**	**173.2 ± 34.2**
No. sp. recorded in habitat		**11**			**5**			**3**		**4**		**10**		

Table 6.11: Mean winter (Nov.-Mar.) abundance of all species recorded within the 'Reserve Front'; 'Reservoir'; 'Shallow Scrapes'; 'Tall Herb Fen & Grassland'; and 'Willow & Alder Carr' habitats at Cardiff Bay Wetland Reserve. N.B. No birds were recorded in the 'Reservoir' or the 'Shallow Scrapes' in the winter of 2003/2004.

Species		Reserve Front			Reservoir		Shallow Scrapes		Tall Herb Fen			Willow/Alder Carr		
		03/04	04/05	05/06	04/05	05/06	04/05	05/06	03/04	04/05	05/06	03/04	04/05	05/06
Sparrowhawk	*Accipiter nisus*													0.2 ± 0.2
Kingfisher	*Alcedo atthis*	0.4 ± 0.2	0.8 ± 0.4				0.2 ± 0.2	0.6 ± 0.2						
Shoveler	*Anas clypeata*	0.2 ± 0.2												
Teal	*Anas crecca*	10.6 ± 7.3	16.6 ± 2.7	18.6 ± 3.2			2.6 ± 2.6	5.4 ± 2.6						
Mallard	*Anas platyrhynchos*	9.4 ± 1.9	14.2 ± 1.6	10.2 ± 3.2	0.8 ± 0.5		1.4 ± 1.4	1.8 ± 1.8						
Meadow Pipit	*Anthus pratensis*								0.4 ± 0.4	10.8 ± 2.4	2 ± 1.2			
Grey Heron	*Ardea cinerea*	1 ± 0.3	0.4 ± 0.2	0.2 ± 0.2			0.2 ± 0.2			0.2 ± 0.2				
Tufted Duck	*Aythya fuligula*	4.4 ± 4.4	0.4 ± 0.4											
Lesser Redpoll	*Carduelis cabaret*													4.4 ± 4.4
Goldfinch	*Carduelis carduaelis*										1.2 ± 0.7			
Carrion Crow	*Corvus corone*									1.2 ± 0.5	2.4 ± 0.8			
Mute Swan	*Cygnus olor*	0.4 ± 0.4	0.4 ± 0.4	1 ± 0.8	0.8 ± 0.8			0.6 ± 0.6	0.4 ± 0.4					
Little Egret	*Egretta garzetta*			0.2 ± 0.2										
Reed Bunting	*Emberiza schoeniclus*									0.4 ± 0.4	0.2 ± 0.2	0.4 ± 0.4	0.4 ± 0.4	0.8 ± 0.4
Robin	*Erithacus rubecula*										0.2 ± 0.2			
Kestrel	*Falco tinninculus*										0.2 ± 0.2		0.6 ± 0.2	0.4 ± 0.2
Chaffinch	*Fringilla coelebs*											0.2 ± 0.2		1.4 ± 0.5
Coot	*Fulica atra*	4.8 ± 1.9	7.8 ± 3.3	10.4 ± 1.3				0.4 ± 0.4						
Common Snipe	*Gallinago gallinago*		3.4 ± 1.7	3.8 ± 2.5				4.4 ± 2.2						
Moorhen	*Gallinula chloropus*	0.8 ± 0.4	2.6 ± 0.7	1.2 ± 0.5		0.2 ± 0.2								
Pied Wagtail	*Motacilla alba*								2.2 ± 0.7					
Grey Wagtail	*Motacilla cinerea*								0.8 ± 0.4					
Great Tit	*Parus major*													0.4 ± 0.2
Magpie	*Pica pica*													1.8 ± 0.2
Great Crested Grebe	*Podiceps cristatus*			0.4 ± 0.4										
Dunnock	*Prunella modularis*													0.4 ± 0.2
Water Rail	*Rallus aquaticus*			0.4 ± 0.4										
Stonechat	*Saxicola torquata*								1 ± 0.4	2.8 ± 1.0	1.6 ± 1.0	0.4 ± 0.4	0.4 ± 0.4	
Starling	*Sturnus vulgaris*									4.8 ± 3.1			1.4 ± 1.4	
Little Grebe	*Tachybabptus ruficollis*		0.8 ± 0.5	0.4 ± 0.4										

Species		Reserve Front			Reservoir		Shallow Scrapes		Tall Herb Fen			Willow/Alder Carr		
		03/04	04/05	05/06	04/05	05/06	04/05	05/06	03/04	04/05	05/06	03/04	04/05	05/06
Shelduck	*Tadorna tadorna*	4 ± 4.0	2 ± 1.3	2.6 ± 2.1										
Redshank	*Tringa totanus*	0.2 ± 0.2	2.4 ± 0.8	3 ± 1.3			0.6 ± 0.6	0.6 ± 0.6						
Wren	*Troglodytes troglodytes*								1.8 ± 0.2	4.2 ± 1.3	4.4 ± 1.2	0.4 ± 0.2		0.6 ± 0.4
Blackbird	*Turdus merula*													1.2 ± 0.5
Song Thrush	*Turdus philomelos*													0.2 ± 0.2
Lapwing	*Vanellus vanellus*	0.4 ± 0.4	7.2 ± 4.8	14.2 ± 4.9										
Mean total abundance		**36.6 ± 9.84**	**59 ± 5.36**	**66.6 ± 5.75**	**1.6 ± 1.2**	**0.2 ± 0.2**	**5 ± 3.3**	**14 ± 3**	**6.6 ± 0.8**	**24.4 ± 6.49**	**12 ± 4.1**	**1.4 ± 0.4**	**2.8 ± 1.1**	**12 ± 4**
No. sp. recorded in habitat		**17**			**3**		**8**		**13**			**13**		

Figure 6.26: Mean (± SE) total habitat usage by all birds recorded in the winters of 2003/2004, 2004/2004 and 2005/2006.



6.3.2. Historical Comparisons

(i). *Historical Waterfowl Population Change*

This section aims to highlight the major changes in waterfowl populations which occurred prior to the construction and subsequent closure of Cardiff Bay Barrage in 1999. For the sake of added interest, all data collected for the period from August 1969 until May 2006 is shown in the figures (also see **App. 6.6**), though more detailed analysis of the Pre to Post Barrage changes can be found in the following section. All figures within this section show the approximate points of the onset of Barrage construction, and Barrage closure – for example in **Fig 6.27**, the period before the first red line (dashed) represents all data before Barrage construction began, likewise, all data occurring prior to the second red line (solid) relates to the period before the closure of the Barrage.

The drastic decline in the total abundance of waterfowl is unquestionable **(Fig. 6.27)** – in the 5 year period between the '89/90 - 93/94' and '94/95 - 98/99' 5 year mean peak count periods (a period which includes all years in which Barrage construction took place), a mean total of 2.3×10^3 birds were lost (a mean rate of approximately 500 per annum). This rate of loss increased after Barrage closure, to a mean rate of approximately 800 birds per annum until the '99/00 – 03/04' – since when the total mean abundance has begun to increase once more.

However, when we look at the measures of species diversity over the same period **(Figs. 6.28 - 6.30)**, we can see that, in two out of three cases, there has been an increase in diversity since Barrage closure. The decline in diversity which is obvious for the final '01/02 – 05/06' period is likely to be due to the fact that prior periods would have included birds which entered the Bay during the transitional period.

Particularly harsh winters are known to have occurred in 1979, 1982 and 1986. Ferns (1994) noted the effects of these winters on a number of wading bird species in the Severn Estuary as a whole. Generally, during abnormally cold periods, U.K populations are supplemented by those from colder areas of mainland Europe (the

Zuider sea for example), causing a significant increase in overall U.K numbers. This same pattern is also obvious in the trends presented for many of the species in Cardiff Bay, with obvious peaks in abundance occurring at around this time. Though the effect is obvious for the majority of species (and is obvious from the total abundance illustrated in **Fig. 6.27**), the most significantly affected were Dunlin, Knot, Redshank, and Shelduck (**Fig. 6.31**); Mallard (**Fig. 6.32**); Turnstone and Pochard (**Fig. 6.33**); Greylag Goose and Grey Plover (**Fig. 6.34**); Tufted Duck, Ruddy Duck and Pintail (**Fig. 6.35**); and finally, Wigeon (**Fig. 6.36**). Thus when considering the pre- and post-Barrage importance of Cardiff Bay with regards to the abundance and diversity of waterfowl, it is important to realize that the two periods are not necessarily comparable as no harsh winters have occurred post-barrage to draw parallels with. On the other hand, it is important to remember that the use of the Bay as a hard winter refuge was extremely important to those species, and their very survival would have depended on a suitable feeding ground during the period.

Species abundance trends caused by the Barrage construction and subsequent closure are clear in **Figs. 6.31 – 6.36**, and require no detailed discussion here as they are covered in the following section. Worth a mention however, are the unusual trends displayed for Knot (**Fig. 6.31 B)**) and Oystercatcher (**Fig. 6.33 D).** The former shows huge variation in abundance that can partly be attributed to the effect of the harsh winters mentioned previously, however the species disappears from the Bay prior to the onset of construction in the Bay, for no obvious reason. The UK population has been shown to be closely affiliated with the Dutch population of this species e.g. declines in the UK often result in increases in Dutch numbers, and vice-versa (Banks *et al.,* 2006), thus it is likely that there was simply an interchange of populations. The latter species shows an increase in abundance over the period of Barrage construction, but the population immediately declines after Barrage closure. This is likely to be due to either reduced habitat quality outside of the Bay due to construction work, or improved habitat quality inside of the Bay for the same reason. One possible explanation is that there was an extension to the period of time in which the preferred feeding sites within the Bay were exposed by the tide, because of the gradual closure of the Barrage wall (and hence obstruction to inward and outward flow).

Figure 6.27: 'Five year mean winter peak' total abundance of waterfowl individuals (all species) recorded between 1969 and 2006.

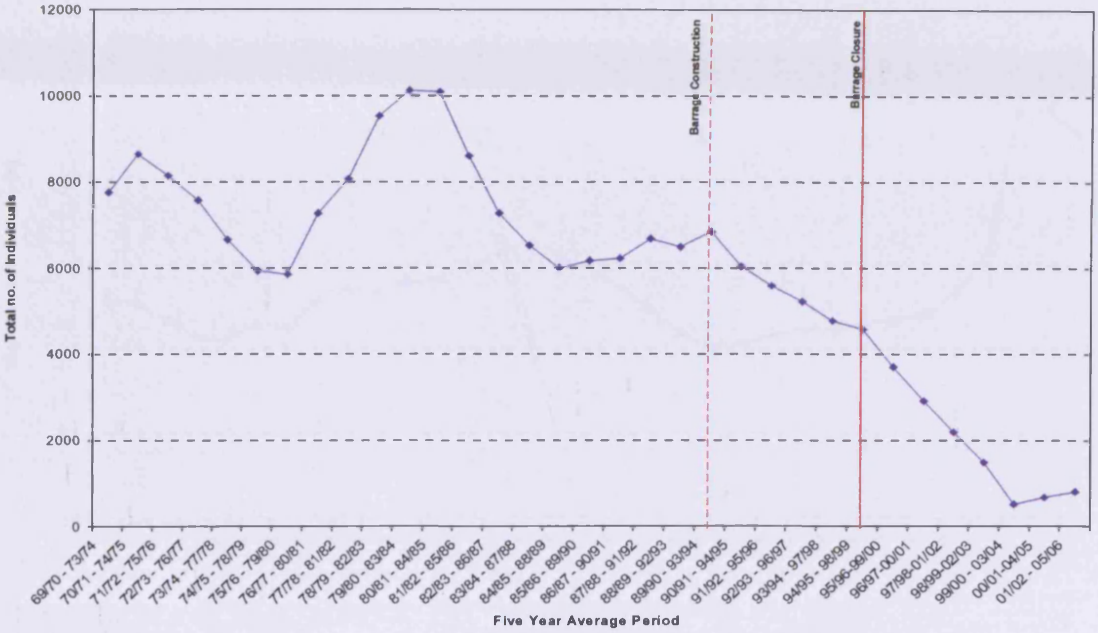


Figure 6.28: Total number of waterfowl species (all species) recorded in each of the winter peak 5 year periods between 1969 and 2006.

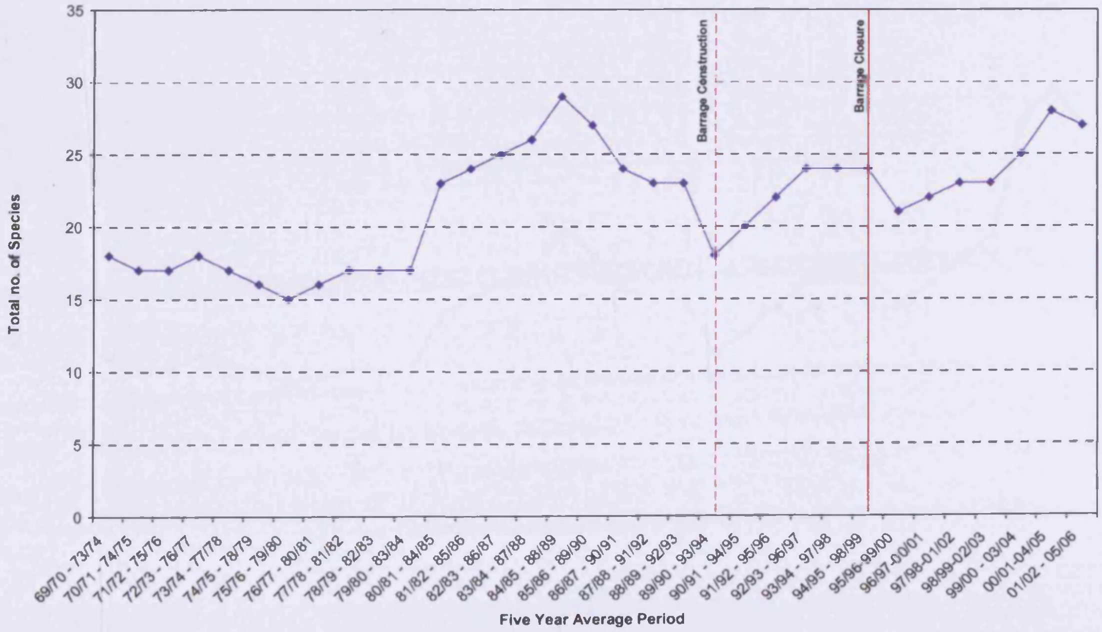


Figure 6.29: Shannon's Diversity Index based upon the 'five year mean winter peak' total number of waterfowl species (all species) recorded between 1969 and 2006.

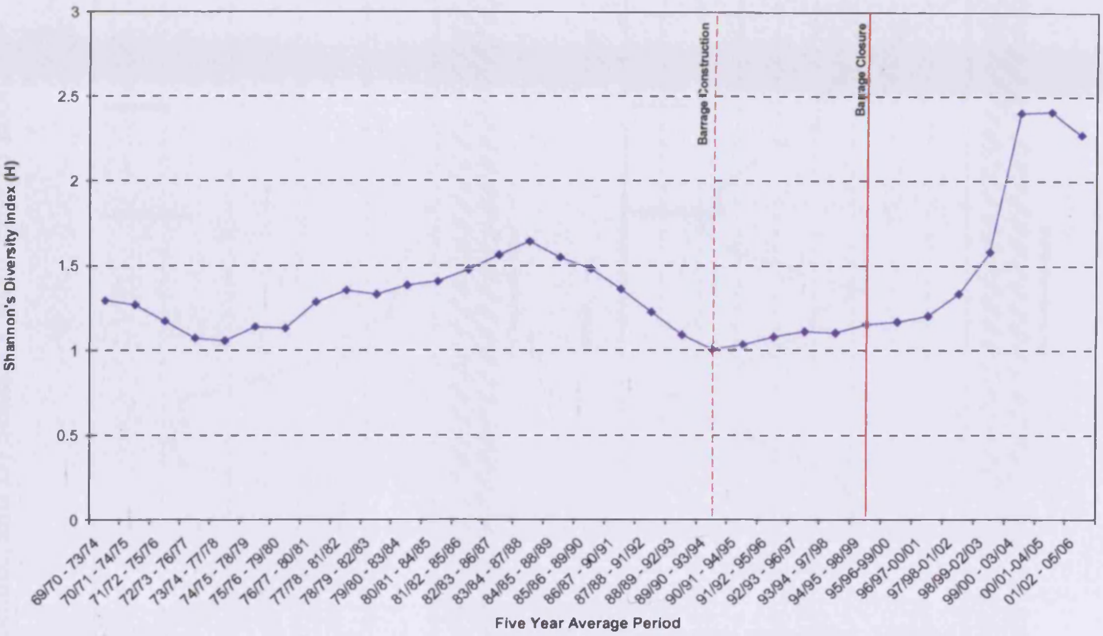


Figure 6.30: Alpha Diversity Index based upon the 'five year mean winter peak' total number of waterfowl species (all species) recorded between 1969 and 2006.

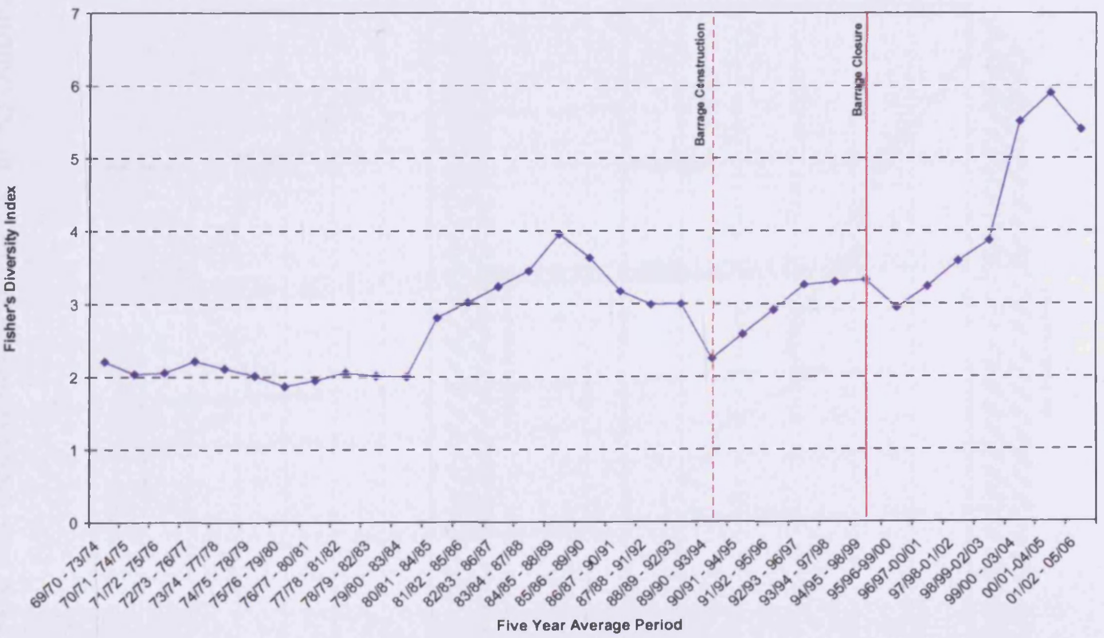


Figure 6.31: 'Five year mean winter peak counts' of A) Dunlin; B) Knot; C) Redshank; and D) Shelduck from 1969 to 2006.

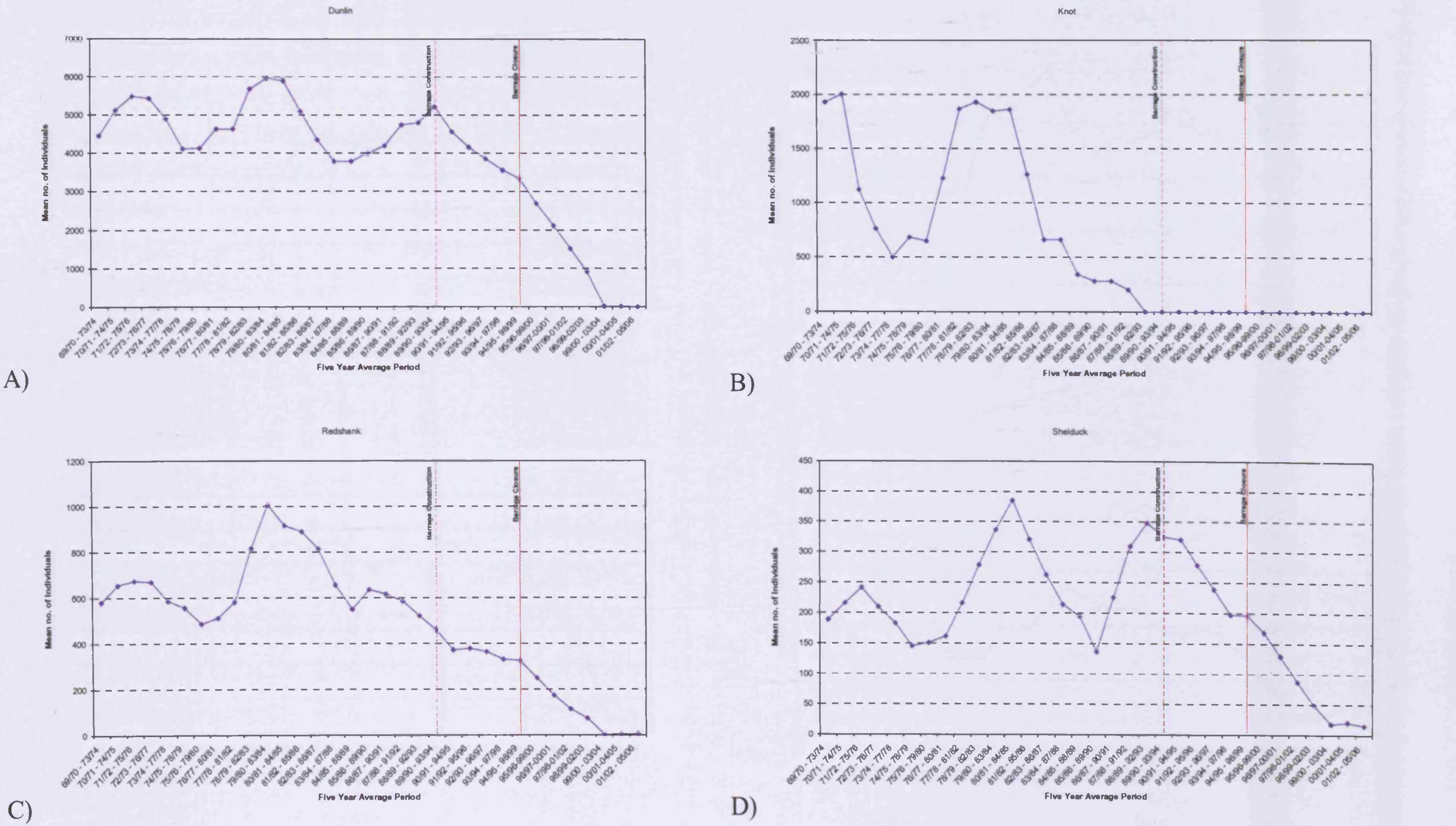
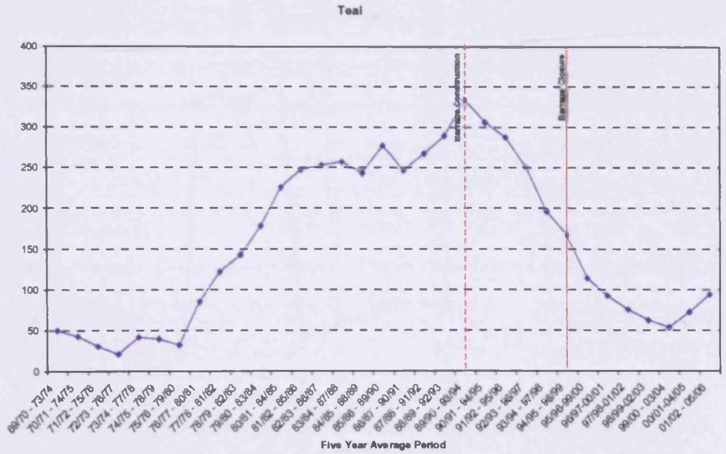
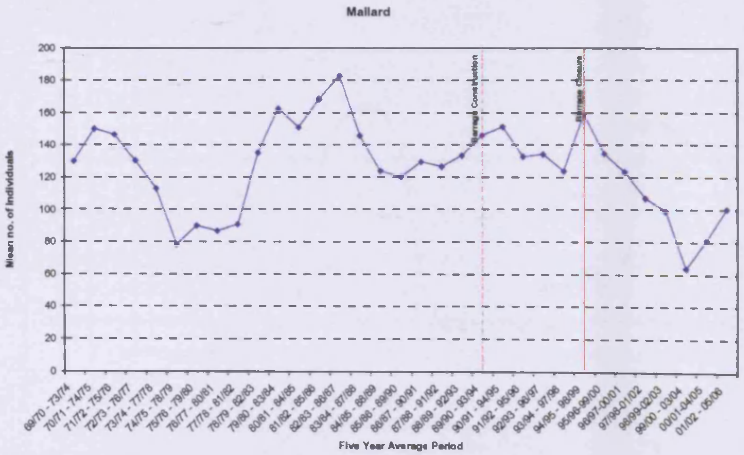


Figure 6.32: 'Five year mean winter peak counts' of A) Teal; B) Mallard; C) Curlew; and D) Lapwing from 1969 to 2006.



A)



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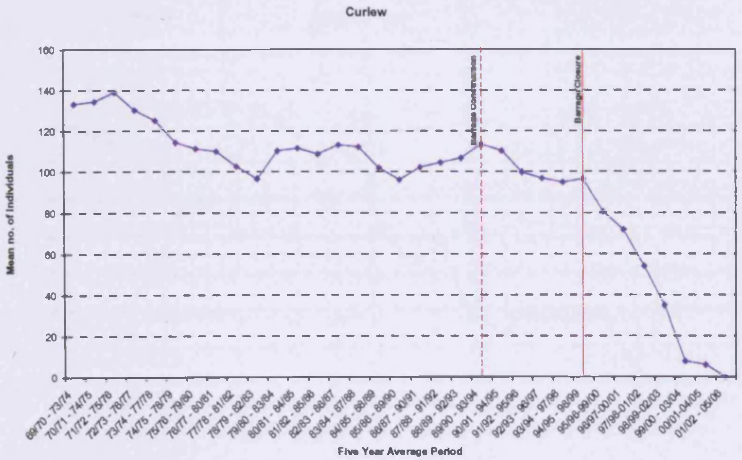
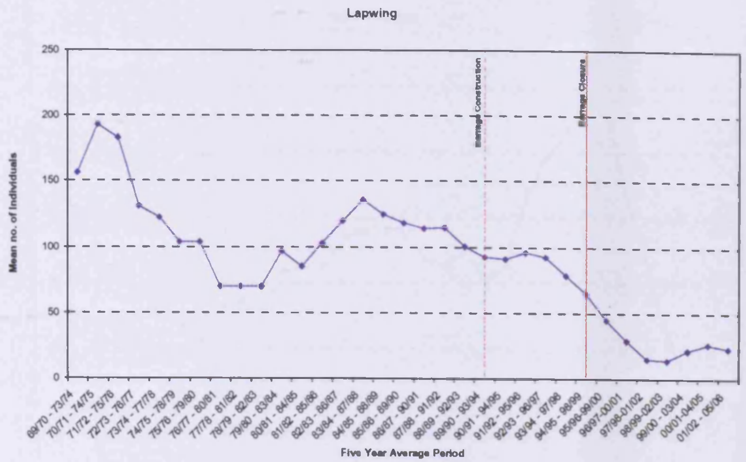


C)



D)

Figure 6.33: 'Five year mean winter peak counts' of A) Turnstone; B) Pochard; C) Ringed Plover; and D) Oystercatcher from 1969 to 2006.

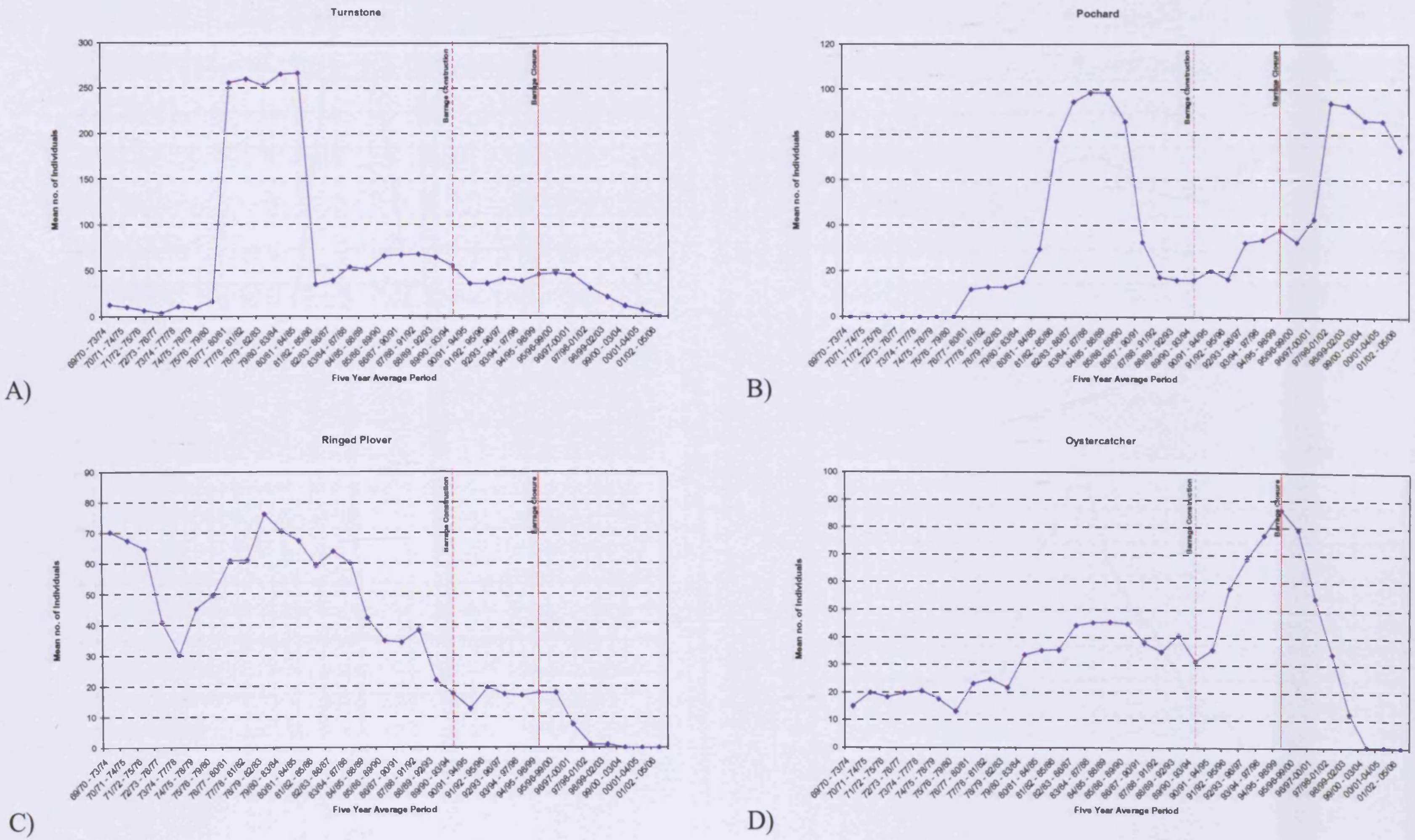


Figure 6.34: 'Five year mean winter peak counts' of A) Greylag Goose; B) Cormorant; C) Coot; and D) Grey Plover from 1969 to 2006.

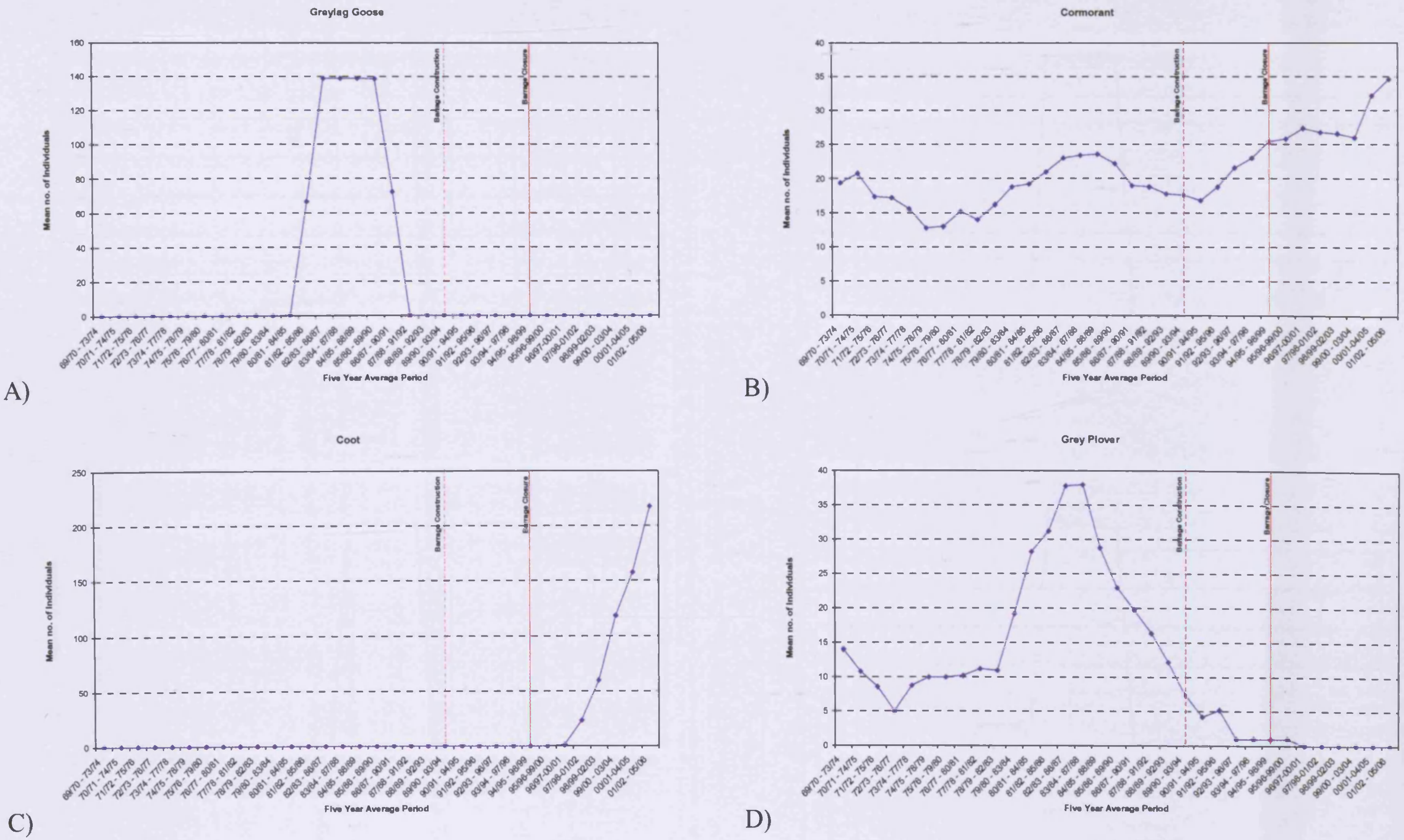
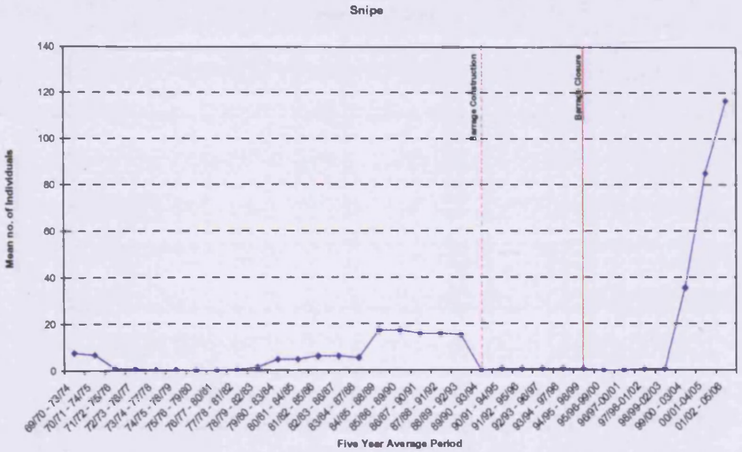
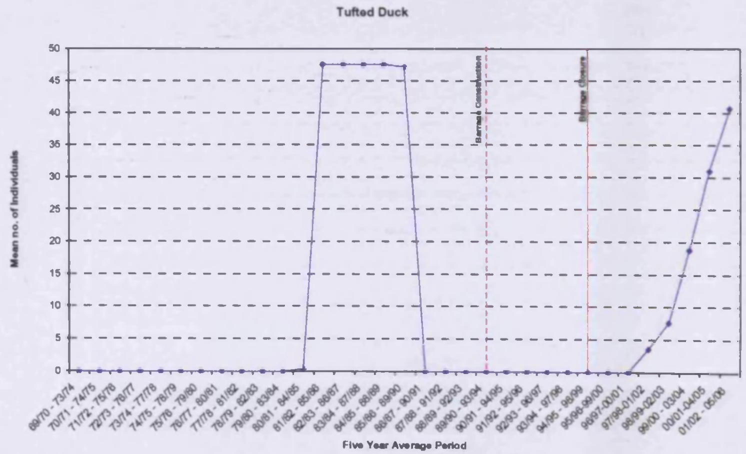


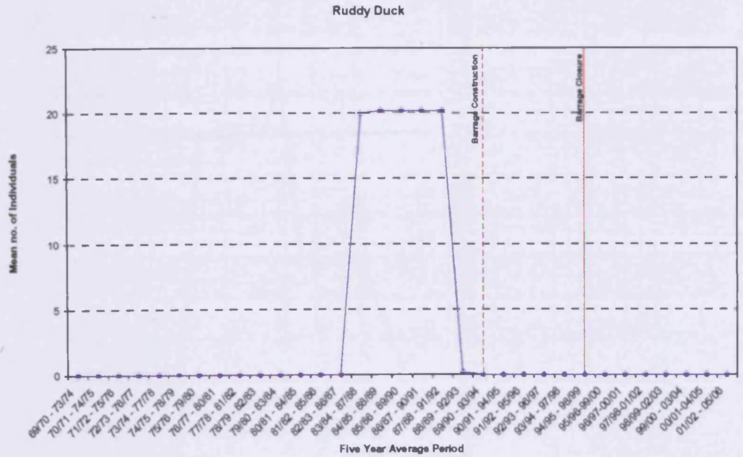
Figure 6.35: 'Five year mean winter peak counts' of A) Snipe; B) Tufted Duck; C) Ruddy Duck; and D) Pintail from 1969 to 2006.



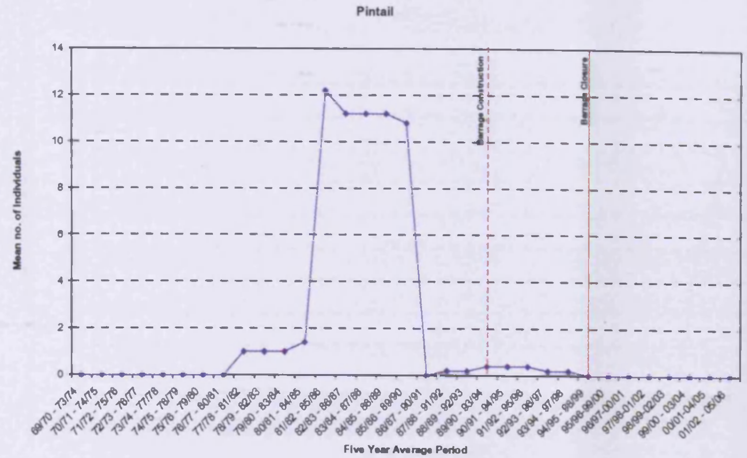
A)



B)



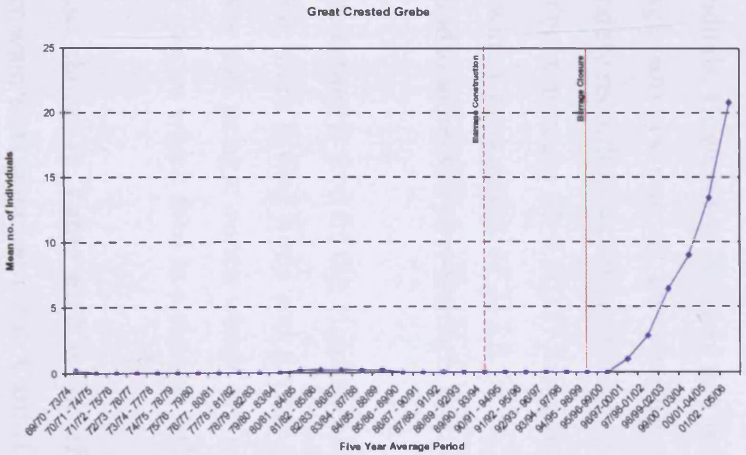
C)



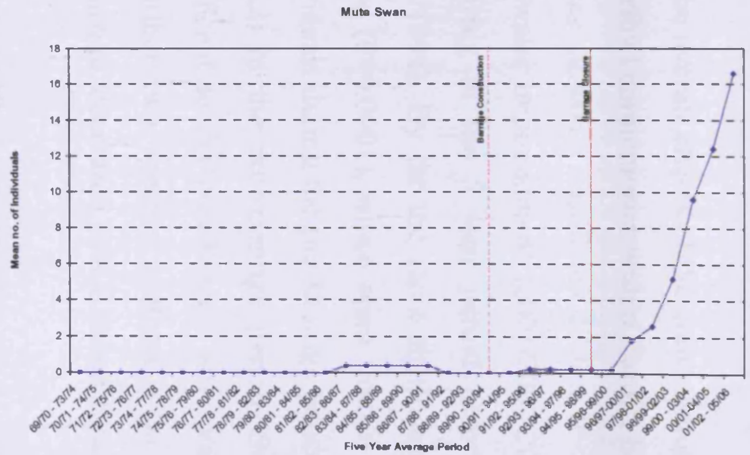
D)

Figure 6.36: 'Five year mean winter peak counts' of A) Great Crested Grebe; B) Mute Swan; C) Wigeon; and D) Moorhen from 1969 to

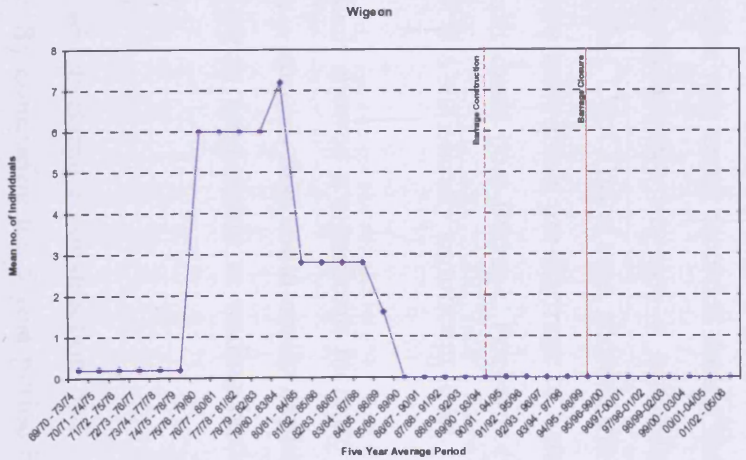
2006.


Great Crested Grebe
Mean no. of Individuals
Five Year Average Period
Barrage Construction
Barrage Closure

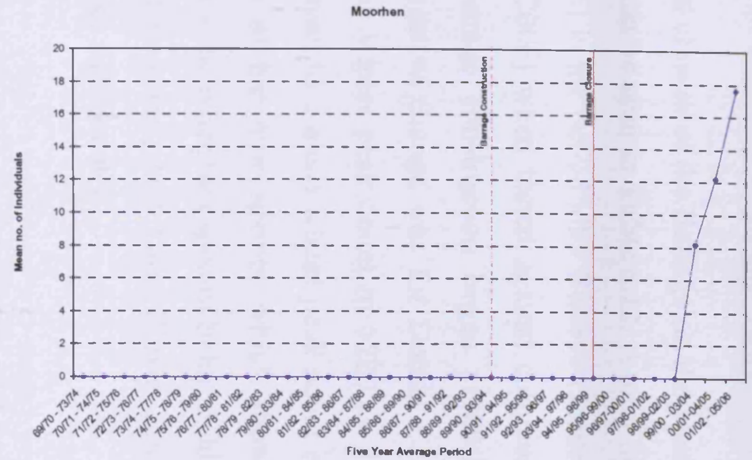
A)


Mute Swan
Mean no. of Individuals
Five Year Average Period
Barrage Construction
Barrage Closure

B)


Wigeon
Mean no. of Individuals
Five Year Average Period
Barrage Construction
Barrage Closure

C)


Moorhen
Mean no. of Individuals
Five Year Average Period
Barrage Construction
Barrage Closure

D)

(ii). *Pre- to Post-Barrage Waterfowl Population Change*

The overall effects of the construction and closure of the Barrage on the wintering waterfowl communities within Cardiff Bay can be seen in **Table 6.12**. A total of nine species showed a significant decline ($P<0.05$) in the period after Barrage closure and freshwater impoundment (2001/2002-2005/2006) when tested against communities occurring in the 5 year period before barrage construction began (1989/1990-1993/1994). By far the most significant negative change was for Dunlin *Calidris alpina* ($P=0.0001$), which went from a mean winter peak count of 5220 (± 378.7) individuals during the pre-Barrage period, down to a mean winter peak count of 0.2 (± 0.2) in the post-Barrage period. Seven of the nine species which showed a significant decline post-barrage were waders – the other two species being wildfowl. A further two species, Mallard *Anas platyrhynchos*, and Grey Plover *Pluvialis squatarola*, decreased post-Barrage, though not significantly.

Conversely, 8 species showed a significant increase in abundance post-barrage, including one species of wading bird, Snipe *Gallinago gallinago*, which increased from zero individuals pre-Barrage, to a winter peak 5 year average of 116.6 (± 49.5) individuals. However, it is likely that this species was under recorded during the pre-Barrage surveys due to the absence of marsh-transect surveys, a necessity for accurately recording secretive species such as this. Coot *Fulica atra*, showed the most significant increase ($P=0.0015$) rising from zero individuals pre-Barrrage to a mean 5 year winter peak count of 217.8 (± 36.2) individuals post-Barrage. Pochard *Aythya ferina* also increased post-Barrage, though not at a statistically significant level.

Interestingly, five of the eight species which showed a significant increase post-barrage, were diving birds and diving ducks – species that could easily exploit the benthos and pelagic zones which are now largely unavailable to wading birds and those species which feed in a similar fashion.

Also shown in **Table 6.12** is the effect which Barrage construction had on the winter waterfowl populations in Cardiff Bay. By comparing the 5 year period before barrage construction began (1989/1990-1993/1994) with the 5 year period in which

Barrage construction took place (1994/1995-1998/1999) we can see that Dunlin *Calidris alpina*, Teal *Anas crecca*, and Shelduck *Tadorna tadorna* all decreased significantly as a result of the construction work, whereas Oystercatcher *Haematopus ostralegus* increased significantly during the same period. A further nine species decreased, and seven species increased (at non-significant levels) during this period.

Table 6.12: '5 Year Mean' Winter Peak Counts (Nov.-Mar.) of 20 most abundant waterfowl species in Cardiff Bay over the three periods (before, during and after, Barrage construction), along with the results of a resampling test (10,000 resamples) showing the significance of, and direction of community change.

Species		**5 Year Mean Peak Count (± SE)**			**Result of 10,000 resamplings**					
		Pre	**During**	**Post**	**Pre vs. Post con.**			**Pre vs. During con.**		
		(89/90-93/94)	**(94/95-98/99)**	**(01/02-05/06)**	**P-Value**	**(+/-)***	**Sig.**	**P-Value**	**(+/-)***	**Sig.**
Dunlin	*Calidris alpina*	5220.0 ± 378.7	3340.0 ± 292.6	0.2 ± 0.2	0.0001	-	y	0.0053	-	y
Redshank	*Tringa totanus*	460.0 ± 92.1	326.4 ± 32.5	4.6 ± 1.1	0.0038	-	y	0.0784	-	n
Teal	*Anas crecca*	334.8 ± 31.3	167.2 ± 34.0	94.0 ± 27.5	0.0017	-	y	0.0062	-	y
Shelduck	*Tadorna tadorna*	325.6 ± 59.5	196.2 ± 14.8	15.4 ± 4.7	0.002	-	y	0.0305	-	y
Mallard	*Anas platyrhynchos*	146.0 ± 18.3	159.0 ± 44.2	100.6 ± 28.4	0.0847	-	n	0.3797	+	n
Coot	*Fulica atra*	0.0 ± 0.0	0.0 ± 0.0	217.8 ± 36.2	0.0015	+	y		-	n
Curlew	*Numenius arquata*	113.4 ± 5.6	96.6 ± 10.8	0.0 ± 0.0	0.0005	-	y	0.0884	-	n
Lapwing	*Vanellus vanellus*	92.6 ± 5.1	65.0 ± 22.3	23.2 ± 9.3	0.0015	-	y	0.1075	-	n
Pochard	*Aythya ferina*	16.2 ± 4.1	38.2 ± 14.6	73.0 ± 69.3	0.2606	+	n	0.0661	+	n
Oystercatcher	*Haematopus ostralegus*	31.4 ± 10.4	86.4 ± 16.7	0.0 ± 0.0	0.0131	-	y	0.014	+	y
Common	*Gallinago gallinago*	0.0 ± 0.0	0.6 ± 0.6	116.6 ± 49.5	0.0205	+	y	0.2801	+	n
Turnstone	*Arenaria interpres*	54.8 ± 16.1	45.8 ± 8.9	0.6 ± 0.6	0.0076	-	y	0.2964	-	n
Cormorant	*Phalacrocorax carbo*	17.6 ± 2.7	25.4 ± 4.2	34.6 ± 4.1	0.0068	+	y	0.0648	+	n
Tufted Duck	*Aythya fuligula*	0.0 ± 0.0	0.0 ± 0.0	40.6 ± 9.1	0.0032	+	y		-	n
Ringed	*Charadrius hiaticula*	17.6 ± 8.1	18.0 ± 10.5	0.0 ± 0.0	0.0277	-	y	0.4901	+	n
Great	*Podiceps cristatus*	0.0 ± 0.0	0.0 ± 0.0	20.8 ± 5.7	0.0069	+	y		-	n
Moorhen	*Gallinula chloropus*	0.0 ± 0.0	0.0 ± 0.0	17.6 ± 7.9	0.027	+	y		-	n
Mute Swan	*Cygnus olor*	0.0 ± 0.0	0.2 ± 0.2	16.6 ± 4.4	0.0056	+	y	0.2608	+	n
Little Grebe	*Tachybaptus ruficollis*	0.0 ± 0.0	0.2 ± 0.2	11.0 ± 3.1	0.0066	+	y	0.277	+	n
Grey Plover	*Pluvialis squatarola*	7.4 ± 4.6	1.0 ± 1.0	0.0 ± 0.0	0.0687	-	n	0.1006	-	n

* Indicates whether numbers increased (+) or decreased (-), irrelevant of the significance of the resampling tests.

(iii). *Changes in Wintering Marsh-Inhabiting Bird Species at Cardiff Bay Wetland Reserve*

As we have seen in Chapters 3 and 4, the marsh areas of Cardiff Bay have changed from being highly productive saltmarsh habitats with abundant invertebrate food resources, and relatively few plant species (along with low habitat heterogeneity as a result), to highly diverse, but less productive, freshwater marsh habitats. As a result, one might expect a decrease in the number of individuals (or density) of the bird species supported, but an increase in the number of species as more habitats and types of plants have become available.

The results shown in **Table 6.13** show the differences between the wintering bird communities (expressed as a whole winter (Nov.-Mar. average) recorded in 1983/1984 (data from Kalejta, 1984 (**App. 6.12**); 2003/2004; 2004/2005 and 2005/2006 (**App. 6.13**). All counts were recorded in exactly the same area (the site now known as Cardiff Bay Wetland Reserve), using the same methodology.

As can be seen from **Tab. 6.13**, the diversity of bird species using the Wetland Reserve's marsh habitats decreased significantly immediately following Barrage closure in comparison to those counts undertaken by Kalejta in 1984. However, over the three year period of monitoring undertaken for the current study, the species diversity has shown a gradual increase, and by the winter of 2005/2006, was approaching the levels of diversity recorded 21 years previously – in fact 32% more species were present than in 1984, although diversity indices varied because of the increased dominance of Teal *Anas crecca* and Snipe *Gallinago gallinago* in the post-Barrage surveys. The abundance of Snipe in particular is interesting and highly relevant to the current study, as one of the predictions made by the Cardiff Bay Environmental Statement (EAU, 1991) was that:

"It is expected that the wintering and breeding populations of Snipe will be lost in the short-term, and probably permanently"

Though this may be true of the breeding population, it is clear that the wintering populations have actually benefited from the closure of the Barrage, and are present at far higher abundances than recorded previously.

The fact that the species diversity was at its lowest earlier on in the current study (2003/2004), is not surprising, and can be attributed to the fact that the comparisons are being made between a mature saltmarsh and an immature freshwater marsh. As the freshwater habitats have undergone succession and seed producing plants have become established, the habitats have attracted more passerine species in particular. As we have seen from earlier sections, year-by-year fluctuations in bird numbers mean that comparisons of data in relatively brief windows of time within the pre- and post-Barrage periods need to be treated with caution, but represent the only basis upon which we can make comparisons at this early stage in the development of Cardiff Bay's wetlands.

Table 6.13: Comparison of mean winter counts of all species during 'winter marsh transect surveys' of the Cardiff Bay Wetland Reserve in the winters (Nov.-Mar.) of 1983/1984* (37 counts), 2003/2004, 2004/2005 and 2005/2006 (5 counts each).

Species		1983/1984*		2003/2004		2004/2005		2005/2006	
		Mean ± SE	**Max.**	**Mean ± SE**	**Max.**	**Mean ± SE**	**Max.**	**Mean ± SE**	**Max.**
Sparrowhawk	*Accipiter nisus*							0.2 ± 0.2	1
Skylark	*Alauda arvensis*	16.0 ± 2.6	61						
Kingfisher	*Alcedo atthis*			0.4 ± 0.2	1	1.6 ± 0.5	3	1.0 ± 0.4	2
Shoveler	*Anas clypeata*							0.4 ± 0.4	2
Teal	*Anas crecca*	0.3 ± 0.3	10	66.6 ± 24.2	136	58.2 ± 11.2	87	65.4 ± 17.9	107
Mallard	*Anas platyrhynchos*	0.5 ± 0.3	12					1.0 ± 1.0	5
Meadow Pipit	*Anthus pratensis*	14.0 ± 1.0	29	0.2 ± 0.2	1	10.8 ± 2.4	19	2.2 ± 1.4	6
Water Pipit	*Anthus spinoletta*	1.9 ± 0.2	6						
Grey Heron	*Ardea cinerea*			0.2 ± 0.2	1	2.2 ± 0.4	3		
Lesser Redpoll	*Carduelis cabaret*							4.4 ± 4.4	22
Linnet	*Carduelis cannabina*	1.4 ± 1.1	40						
Goldfinch	*Carduelis carduelis*	0.8 ± 0.5	10					2.4 ± 1.7	9
Greenfinch	*Carduelis chloris*	0.2 ± 0.1	3						
Carrion Crow	*Corvus corone*	<0.1	1	0.4 ± 0.4	2	1.6 ± 0.4	2	3.0 ± 0.6	5
Mute Swan	*Cygnus olor*							1.0 ± 0.6	3
Reed Bunting	*Emberiza schoeniclus*	7.9 ± 1.0	30	0.4 ± 0.4	2	3.2 ± 1.0	5	1.8 ± 0.6	4
Robin	*Erithacus rubecula*	<0.1	1					0.2 ± 0.2	1
Kestrel	*Falco tinnunculus*					0.4 ± 0.2	1	0.6 ± 0.2	1
Chaffinch	*Fringilla coelebs*	16.9 ± 4.8	110	0.2 ± 0.2	1			1.4 ± 0.5	3
Brambling	*Fringilla montifringilla*	0.7 ± 0.3	7						
Common Snipe	*Gallinago gallinago*	4.4 ± 0.7	17	124.0 ± 18.4	176	184.0 ± 28.0	247	112.0 ± 14.3	158
Moorhen	*Gallinula chloropus*					0.8 ± 0.5	2	0.2 ± 0.2	1
Jack Snipe	*Lymnocryptes minimus*							0.8 ± 0.6	3
Pied Wagtail	*Motacilla alba*			2.2 ± 0.7	4	2.2 ± 0.8	5	1.4 ± 0.7	4
Grey Wagtail	*Motacilla cinerea*			0.8 ± 0.4	2	0.8 ± 0.5	2	0.2 ± 0.2	1
Blue Tit	*Parus caeruleus*								
Great Tit	*Parus major*							0.4 ± 0.2	1
House Sparrow	*Passer domesticus*	0.3 ± 0.3	10						
Black Redstart	*Phoenicurus ochruros*	<0.1	1						
Magpie	*Pica pica*					0.4 ± 0.4	2	1.8 ± 0.2	2
Snow Bunting	*Plectrophenax nivalis*	<0.1	1						
Dunnock	*Prunella modularis*							0.4 ± 0.2	1
Stonechat	*Saxicola torquata*			1.4 ± 0.6	3	3.2 ± 1.2	6	2.0 ± 0.9	4
Starling	*Sturnus vulgaris*					6.2 ± 2.9	15		
Shelduck	*Tadorna tadorna*	0.6 ± 0.5	20						
Redshank	*Tringa totanus*	<0.1	1			0.4 ± 0.4	2	0.8 ± 0.6	3
Wren	*Troglodytes troglodytes*			2.2 ± 0.4	3	4.2 ± 1.3	8	5.0 ± 1.5	10
Blackbird	*Turdus merula*							1.4 ± 0.4	2
Song Thrush	*Turdus philomelos*							0.6 ± 0.4	2
Lapwing	*Vanellus vanellus*			0.4 ± 0.4	2			3.4 ± 2.4	12
Total		**65.9 ± 8.0**	**370**	**194.8 ± 38.9**	**334**	**280.2 ± 34.9**	**409**	**215.8 ± 37.5**	**375**
Number of Species		**19**		**13**		**16**		**28**	
α		**8.95**		**3.14**		**3.69**		**8.58**	
Dmg		**4.30**		**2.27**		**2.66**		**5.03**	
Ds		**0.177**		**0.496**		**0.475**		**0.362**	
d		**25.6**		**62.2**		**65.7**		**52.0**	
H'		**1.90**		**0.89**		**1.17**		**1.52**	
E		**0.65**		**0.35**		**0.42**		**0.46**	
Var H'		**0.0123**		**0.0047**		**0.0062**		**0.0103**	

* From counts undertaken by Kalejta (1984)

6.3.3. Avian Ecology at the Gwent Levels Wetland Reserve

As can be seen from the maximum annual and seasonal counts in **Tab. 6.14**, the wide range of different habitats provided by the Gwent Levels Wetland Reserve (notably reed beds, wet meadows and freshwater pools), rapidly began to support a rich and diverse array of wetland birds, including wildfowl, wading birds and passerines.

Although they have not yet been fully censused, and thus their numbers are not fairly reflected in **Tab. 6.14,** there are substantial breeding populations of Reed Warbler, Sedge Warbler and Reed Bunting in the reed beds (a habitat worthy of high conservation priority in Wales). The wet meadows and freshwater pools support small, but regionally significant breeding populations of Avocet, Oystercatcher, Lapwing, Ringed Plover, Little Ringed Plover, Redshank and Snipe.

Only one species has been present in Nationally Important numbers when averaged over a five year period (Shoveler in winter 2000/01- 2004/05), but Nationally Important numbers of Pintails were present in the winters of 2000/01 and 2001/02, and of Black-tailed Godwits in the winters of 2003/04 and 2004/05. In fact, Black-tailed Godwit numbers reached International Importance in the winter of 2004/05. Although 5-year periods are normally used when comparing sites, such a period is not specified in the objectives of the Gwent Levels Wetland Reserve, which only refers to the fact that levels of importance should be sustained. It would therefore be churlish to deny that the objective of supporting two species in Nationally Important numbers has been met. There are fewer well-established criteria for assessing the relative importance of breeding populations, but the fact that the site supports Wales' only breeding Avocets, clearly makes the site of great importance in that context.

Table 6.14: 'Winter' (Nov.-Mar.), 'Spring Passage' (Apr.-May), 'Breeding' (Jun.-Jul.) and 'Autumn Passage' (Aug.-Oct.) peak counts of all bird species recorded at the Gwent Levels Wetland Reserve between Jan. 2000 and Aug. 2005 (raw data provided by Tony Pickup, CCW). Highlighted figures indicate a nationally (Red) and internationally (blue) important level for that species.

Species		Winter (Nov.-Mar.)						Spring Passage (Apr.-May)						Breeding (Jun.-Jul.)						Autumn Passage (Aug.-Oct.)					
		99/00*	00/01	01/02	02/03	03/04	04/05	00	01	02	03	04	05	00	01	02	03	04	05	00	01	02	03	04	05**
Sparrowhawk	*Accipiter nisus*		1	2	1	1	1					1		1				1	1	3	2	2	1	1	
Aquatic Warbler	*Acrocephalus paludicola*																				1				
Sedge Warbler	*Acrocephalus schoenbaenus*							p			1			p						2	1				
Reed Warbler	*Acrocephalus scirpaceus*							p						p						1					
Common Sandpiper	*Actitis hypoleucos*							1	1		1	1	1	7	1	1	7	6		9	4	1	4	4	
Long-tailed Tit	*Aegithalos caudatus*	p	p		5			p					2	p						40		10		9	
Skylark	*Alauda arvensis*	10	p					p						p						p		25	3		
Kingfisher	*Alcedo atthis*		2	1	1	1	1							1				1	1	1	2	3	2	1	2
Red-legged Partridge	*Alectoris rufa*										1														
Egyptian Goose	*Alopochen aegyptiacus*																	1							
Pintail	*Anas acuta*	149	380	309	271	184	163	5		12	10	1	10							79	47	15	5	41	
Shoveler	*Anas clypeata*	70	163	215	150	122	184	8	4	16	6	3	58	13	7	4	1	8		23	49	15	16	83	
Teal	*Anas crecca*	593	1066	1034	618	820	516	32	2	147	100	18	78	9	30	5	9	6	1	908	459	475	286	270	
Wigeon	*Anas Penelope*	308	580	1097	1178	1684	2032	8		13	18	3	38	1	1			1		413	473	523	141	928	
Mallard	*Anas platyrhynchos*	178	668	565	607	351	302	82		185	100	122	75	201	288	158	306	293	199	679	765	851	358	509	
Garganey	*Anas querquedula*				1			2	2	5		2	1	2	1	3				6	2		1		
Chiloe Wigeon	*Anas sibilatrix*				2																	2			
Gadwall	*Anas strepera*	9	62	61	45	65	81	10	12	15	20	21	13	20	22	15	11	7		25	21	14	14	27	
Greylag Goose	*Anser anser*		1		5	7		3		2	5	2	3	2			2					1	1		
Bar-headed Goose	*Anser indicus*																							2	
Rock Pipit	*Anthus petrosus*	4	6	2	5																1				
Meadow Pipit	*Anthus pratensis*	p	p					p						p						250	157	8			
Water Pipit	*Anthus spinoletta*		1																						
Tree Pipit	*Anthus trivialis*							1												20	3				
Common Swift	*Apus apus*							200	1	3	110	150		120			100			1		3	6	1	
Grey Heron	*Ardea cinerea*	2	9	17	12	8	11	9		9	8	14	4	11	20	13	12	8	1	8	33	21	6	7	
Turnstone	*Arenaria interpres*	27	4		1		40	11			12	2		1	3	2	2	1		11	1	5	1	2	
Short-eared Owl	*Asio flammeus*		2	3	4	1	4			2	1	1												1	

Species		Winter (Nov.-Mar.)						Spring Passage (Apr.-May)						Breeding (Jun.-Jul.)						Autumn Passage (Aug.-Oct.)					
		99/00*	00/01	01/02	02/03	03/04	04/05	00	01	02	03	04	05	00	01	02	03	04	05	00	01	02	03	04	05**
Little Owl	*Athene noctua*			1		1		1	1		1	1		2	1		1			1	1			1	
Ring-necked Duck	*Aythya collaris*		1	1		1			1	1		1									1		1		
Pochard	*Aythya ferina*		44	59	26	31	15		3	5	1	1	1	1	3	5		3		5	7		1	3	
Pochard	*Aythya ferina x ferina x*			1							2														
Pochard	*Aythya ferina x fuligula*			4		1																			
Tufted Duck	*Aythya fuligula*		84	102	88	78	51	4	60	46	69	61	16	14	30	15	33	23	37	33	24	13	41	30	
Tufted Duck	*Aythya fuligula x ferina*			1						4															
Scaup	*Aythya marila*			8																					
Great Bittern	*Botaurus stellaris*			1	2	1	1																		
Dark-bellied Brent	*Branta bernicula bernicula*		1																	2					
Light-bellied Brent	*Branta bernicula hrota*		1		5																1				
Canada Goose	*Branta canadiensis*	1	6	77	189	252	124	17		19	24	16	18		2	9	16	8	9		145	123	75	137	
Barnacle Goose	*Branta leucopsis*			1	4						5	2													
Goldeneye	*Bucephala clangula*	1	2	4	7	8	10														2				
Common Buzzard	*Buteo buteo*	3	2	3	1	1	1	5		1				5			1	1		3	1	1	3	2	
Lapland Bunting	*Calcarius lapponicus*		1			45																			
Sanderling	*Calidris alba*							5			1	9								2	1			2	
Dunlin	*Calidris alpina*	350	4500	2100	2300	3000	1500	1247	125	35	625	262	109	160	81	30	194	400		640	1200	600	200	350	
Baird's Sandpiper	*Calidris bairdii*																			1					
Knot	*Calidris canutus*		2	11	14	24	800	36	2		7	14		4	9	4				305	95	220	210	400	
Curlew Sandpiper	*Calidris ferruginea*							2				1			1		1			19	28	4	2	12	
White-rumped	*Calidris fuscicollis*																1								
Purple Sandpiper	*Calidris maritima*		1																						
Pectoral Sandpiper	*Calidris melanotos*													1						1		1		1	
Little Stint	*Calidris minuta*					1		1							1					6	26	1	1	3	
Temminck's Stint	*Calidris temminckii*											1													
Lesser Redpoll	*Carduelis cabaret*																					10			
Linnet	*Carduelis cannabina*			20		15		p		12	4		6	p			10			100	160	60	6	50	
Goldfinch	*Carduelis carduelis*	p	p	25		22		p						42			1			170	80	25	20	50	
Greenfinch	*Carduelis chloris*	p					22	p						p							150				
Redpoll	*Carduelis flammea*		2			1														1					
Siskin	*Carduelis spinus*																			6		4			
Common Treecreeper	*Certhia familiaris*																			1					
Cetti's Warbler	*Cettia cetti*		4	6		1		2				1		p	1			3		3	2				

Species		Winter (Nov.-Mar.)						Spring Passage (Apr.-May)						Breeding (Jun.-Jul.)						Autumn Passage (Aug.-Oct.)					
		99/00*	00/01	01/02	02/03	03/04	04/05	00	01	02	03	04	05	00	01	02	03	04	05	00	01	02	03	04	05**
Kentish Plover	*Charadrius alexandrinus*							1																	
Little Ringed Plover	*Charadrius dubius*				4		2	5	7	11	8	5		24	11	9	9	4	5	10	1	3	5		
Ringed Plover	*Charadrius hiaticula*		22	31	10	13	11	151	33	21	60	51	2	70	20	1	18	18		157	107	46	50	83	
Black Tern	*Chlidonias niger*							11												1	4		1		
Marsh Harrier	*Circus aeruginosus*									2			2								1		1		
Hen Harrier	*Circus cyaneus*			1	1	1	1	1														1		1	
Long-tailed Duck	*Clangula hyemalis*	1						1																	
Stock Dove	*Columba oenas*			6		2								p	7			2			2				
Woodpigeon	*Columba palumbus*	p	900					p						p						p					
Raven	*Corvus corax*		4	4	2	4	4	3									5			3		5	9	2	
Carrion Crow	*Corvus corone*	p	p		9	7		p						p						p	33	12		35	
Common Cuckoo	*Cuculus canorus*							p		3	4	2	2	p		1	1	1						1	1
Bewick's Swan	*Cygnus columbianus*			15																					
Whooper Swan	*Cygnus cygnus*			1	1				1	1	1				1	1	1				1	1	1		
Mute Swan	*Cygnus olor*	30	96	76	56	39	48	51		45	31	19	17	79	60	41	34	16	5	76	86	55	25	60	
House Martin	*Delichon urbica*							210			300	150		60		30				300			30	30	
Great Spotted	*Dendrocopus major*		1	4	2	2	1						1	1						1	2	1	2		
Little Egret	*Egretta garzetta*		3	26	19	30	31	1	4	19	16	20	18	11	10	12	15	22	4	30	27	34	22	26	22
Yellowhammer	*Emberiza citrinella*									1						1								1	
Reed Bunting	*Emberiza schoeniclus*	15	p			60	71							p		1				p		4			
Robin	*Erithacus rubecula*	p	p					p						p						p					
Merlin	*Falco columbarius*		1	2	1	1	1				1									1		1		1	
Peregrine	*Falco peregrinus*	1	2	1	1	1	1	1						1		3				2	2	1		1	
Hobby	*Falco subbuteo*							1	1			1				1		1	4	2	1	2			
Kestrel	*Falco tinnunculus*	p	p	1	2	1	2	1						p		1				p	2	4	1	1	
Pied Flycatcher	*Ficedula hypoleuca*																			2					
Chaffinch	*Fringilla coelebs*	p	p				10	p						p						p					
Brambling	*Fringilla montifringilla*																			2					
Coot	*Fulica atra*	32	144	149	90	153	237	39		120	50	73	49	89	151	57	49	127	19	246	304	60	81	153	
Common Snipe	*Gallinago gallinago*		79	42	50	16	42			6	8			4		36	2			18	16	12	10	1	1
Moorhen	*Gallinula chloropus*	5	3	7	6	37	23	1		4	13	6	6	p	6	8	10	55	2	4	9	28	25	50	67
Jay	*Garrulus glandarius*					1																	2		
Oystercatcher	*Haematopus ostraegus*	12	11	47	36	18	46	14	4	8	9	47	43	5	5	18	38	23		10	8	38	56	75	
Swallow	*Hirundo rustica*		1			1		100	30		50	200		p				100		2500		25	50	50	

Species		Winter (Nov.-Mar.)						Spring Passage (Apr.-May)						Breeding (Jun.-Jul.)						Autumn Passage (Aug.-Oct.)					
		99/00*	00/01	01/02	02/03	03/04	04/05	00	01	02	03	04	05	00	01	02	03	04	05	00	01	02	03	04	05**
Herring Gull	*Larus argentatus*	35	p			1	4	50	1					64		3	3		2	80		40	15		
Common Gull	*Larus canus*	24	150	17	20			1			1			3	1	1				p					
Lesser Black-backed	*Larus fuscus*	47	p		3			100						147		3			1	p		10			
Iceland Gull	*Larus glaucoides*							1																	
Great Black-backed Gull	*Larus marinus*	4	4	3		1		2							1						2	1			
Mediterranean Gull	*Larus melanocephalus*	1	1					1	1					1						1		1			
Little Gull	*Larus minutus*		1						1								1			1					
Black-headed Gull	*Larus ridibundus*	704	p	175	310	30	400	428			1			809	95	350	189	150	361	p		450	260	200	
Long-billed Dowitcher	*Limnodromus scolopaceus*						1																		
Bar-tailed Godwit	*Limosa lapponica*		2		5		6	85	5		23	21	5	2		13		3		6	14	2		6	
Black-tailed Godwit	*Limosa limosa*		14	22	8	281	385	10	18	14	32	80		4	21	10	42	13		47	110	146	261	197	
Grasshopper Warbler	*Locustella naevia*											1						1							
Jack Snipe	*Lymnocryptes minimus*					1	2															1			
Common Scoter	*Melanitta nigra*																			1					
Goosander	*Mergus merganser*		4			1																			
Red-breasted Merganser	*Mergus serrator*																				1				
Pied Wagtail	*Montacilla alba*	p	p		3	20		p						p						5					
Grey Wagtail	*Montacilla cinerea*		1			1								1	1					3	1			1	
Yellow Wagtail	*Motacilla flava*							9	4	1				2						93	15	6	9	16	
White Wagtail	*Motacilla alba*	1					4		30			2								1	4				
Spotted Flycatcher	*Muscicapa striata*							1												1		1			
Red-crested Pochard	*Netta rufina*																			2	1				
Curlew	*Numenius arquata*	308	234	308	265	278	436	6		5	51	4	94	315	95	100	114	81	45	300	355	304	300	493	
Whimbrel	*Numenius phaeopus*							102	46	60	43	76	6	20	4	1	6	1		33	10	1	1		
Wheatear	*Oenanthe oenanthe*			3		2		3	1		1						1			5	2	3	3	3	
Ruddy Duck	*Oxyura jamaicensis*		1			2	4		2		2	5	4		1	1	8	14	1		2	2	3	4	
Osprey	*Pandion haliaetus*												1												
Coal Tit	*Parus ater*																				2				
Blue Tit	*Parus caeruleus*		p					p						p						p					
Great Tit	*Parus major*	p	p					p						p						p					
Willow Tit	*Parus montanus*																								
House Sparrow	*Passer domesticus*	p	p					p						p						p					
Tree Sparrow	*Passer montanus*														1					2					
Grey Partidge	*Perdix perdix*									1															

Species		Winter (Nov.-Mar.)						Spring Passage (Apr.-May)						Breeding (Jun.-Jul.)						Autumn Passage (Aug.-Oct.)					
		99/00*	00/01	01/02	02/03	03/04	04/05	00	01	02	03	04	05	00	01	02	03	04	05	00	01	02	03	04	05**
Honey Buzzard	*Pernis apivorus*																			1					
Cormorant	*Phalacrocorax carbo*	2	12	3	30	6	2	5		9	9	4	2	35	44	7	3	9	3	32	38	5		1	
Grey Phalarope	*Phalaropus fulicarius*			1																					
Red-necked Phalarope	*Phalaropus lobatus*																					1			
Pheasant	*Phasianus colchicus*		p			8		p						p						p			3		
Ruff	*Philomachus pugnax*			4	4	3	2	1			1	1		2	1					7	8	1	4	2	
Black Redstart	*Phoenicurus ochruros*		2																						
Redstart	*Phoenicurus phoenicurus*													1		1				4			1		
Chiffchaff	*Phylloscopus collybita*							p						p						16		5			
Wood Warbler	*Phylloscopus sibilatrix*																			1					
Willow Warbler	*Phylloscopus trochilus*				2	1		p						p						p					
Magpie	*Pica pica*	p	p	48		20		p						p						p	8	1			
Green Woodpecker	*Picus viridis*					1	2											1		1			1		1
Common Spoonbill	*Platalea leucorodia*							1				2		2			3	1	2						
Golden Plover	*Pluvialis apricaria*		7	31	4	1		2		2				1						1	1	2	3		
Grey Plover	*Pluvialis squatarola*	1	64	70	144	48	71	17		2		2			1			1		22	47	35		54	
Slavonian Grebe	*Podiceps auritus*																			1					
Great Crested Grebe	*Podiceps cristatus*			1	1	2	5		3	2	2	5	6	1	2	1	2	6	4	1	3		5	1	
Black-necked Grebe	*Podiceps nigricolis*		1												1					1	1				
Dunnock	*Prunella modularis*	p	p					p						p						p					
Bullfinch	*Pyrrhula pyrrhula*			1	2	1		p												2					
Water Rail	*Rallus aquaticus*		1	10	7	4	8		1		1	1									2	2	1		
Avocet	*Recurvirostra avosetta*			1	3	2		1			4	5	5				6	5					5		
Firecrest	*Regulus ignicapillus*		1																						
Goldcrest	*Regulus regulus*	p	4		3			p						p						10	2				
Sand Martin	*Riparia riparia*				2			5	90	40	6	200		500		300		200		1		90	400	4	
Kittiwake	*Rissa tridactyla*			1																					
Whinchat	*Saxicola rubetra*								1											13				2	
Stonechat	*Saxicola torquata*	1	5	12	2	2	3										1			7		2	3	1	
Woodcock	*Scolopax rusticola*		1			1																			
Common Tern	*Sterna hirundo*								1					1											
Arctic Tern	*Sterna paradisaea*							p																	
Sandwich Tern	*Sterna sandvicensis*															2									
Unidentified Tern	*Sterna* spp.										1						1								

Species		Winter (Nov.-Mar.)						Spring Passage (Apr.-May)						Breeding (Jun.-Jul.)						Autumn Passage (Aug.-Oct.)					
		99/00*	00/01	01/02	02/03	03/04	04/05	00	01	02	03	04	05	00	01	02	03	04	05	00	01	02	03	04	05**
Collared Dove	*Streptopelia decaocto*							p						p						p					
Turtle Dove	*Streptopelia turtur*						3																		
Starling	*Sturnus vulgaris*	p	2500	11000	8000	14000		p					200	p		100	1000			p	3500		200		
Blackcap	*Sylvia atricapilla*				1			p						p						p					
Garden Warbler	*Sylvia borin*																			1					
Whitethroat	*Sylvia communis*							p	1		1			p						p					
Lesser Whitethroat	*Sylvia curruca*							p			1			p						p					
Dartford Warbler	*Sylvia undata*					1																			
Little Grebe	*Tachybaptus ruficollis*	2	5	10	15	22	13	2	2	4	15	17	15	8	17	6	9	32	10	12	24	42	34	29	
Ruddy Shelduck	*Tadorna ferruginea*																	1							
Shelduck	*Tadorna tadorna*	485	482	450	324	437	540	200		100	142	155	89	156	45	90	109	91	35	22	87	43	22	59	
Spotted Redshank	*Tringa erythropus*		1						2			1				2				3	5	1	2		
Wood Sandpiper	*Tringa glareola*										1			1			1			1	3	1			
Greenshank	*Tringa nebularia*				1			15	3	1		4		6	4		1	2		11	5	3	13	13	
Green Sandpiper	*Tringa ochropus*					1					1			5	2	2	1	3		9	2	4	6	2	
Redshank	*Tringa totanus*	53	58	66	40	49	77	19	8	23	28	28	50	7	28	29	45	68		60	26	24	31	7	
Wren	*Troglodytes troglodytes*	p	P					p						p						p					
Buff-breasted Sandpiper	*Tryngites subruficollis*																			1					
Redwing	*Turdus iliacus*		60	6		40	200													1		1			
Blackbird	*Turdus merula*	p	P					p						p						p					
Song Thrush	*Turdus philomelos*	p	P					p						p						p					
Fieldfare	*Turdus pilaris*		1000	340	100	400	260																		
Mistle Thrush	*Turdus viscivorus*	p					1	p				1													
Barn Owl	*Tyto alba*					1					1												1		
Lapwing	*Vanellus vanellus*		374	1020	466	324	1630	20	20	33	54	92	64	98	67	49	70	55	2	35	77	100	12	2	
Total No. of Species		55	91	70	69	81	60	100	40	46	61	59	38	93	47	50	51	49	24	123	82	81	70	66	6

** Jan.-Mar. 2000 only*

*** Aug. 2005 only*

6.4 Conclusions

As with the other aspects of Cardiff Bay's ecology which have been discussed in previous chapters (habitats, invertebrates and macrophytes), one of the most notable findings with regards to birds, is that despite the losses of some groups of species, notably wading birds, there has been an overall increase in bird species diversity as a result of the creation of the freshwater lake that is Cardiff Bay.

It is also clear from the results presented here, that appropriate management aimed at improving habitat quality and increasing invertebrate food resources will not only help to maintain the current diversity of birds, but will also help to improve it. One aspect in particular, which could possibly be addressed in the future, regards the distribution and extent of 'emergent wetland' (or 'palustrine') habitats (see **Chapter 3.3.2.**). These habitats, as we have seen from this chapter, provide the most important focus habitats for birds in general, and the construction of even small areas of marginal emergent wetland, in areas otherwise devoid of vegetation, can only serve to improve the abundance and diversity of species – particularly in the case of breeding species as the Bay's potential for this aspect of avian ecology has clearly not been fulfilled, as is evidenced by the low proportion of breeding birds which have successfully reared young over the research period.

The Gwent Levels Wetland Reserve has also proved to be highly successful in attracting a broad diversity of avian species. Although the birds present at the reserve do not directly replace those lost within Cardiff Bay, it is clear that the area goes some way toward providing an important habitat for wetland birds in particular, a habitat which, in the future (with correct management), may provide adequate direct 'compensation' towards Cardiff Bay's losses.

7. Conclusions

7.1. General

The results presented in this thesis provide an interesting insight into the changes which have occurred in four major aspects of the ecology of Cardiff Bay following closure of the Barrage in 1999. Firstly, the brackish waters of the Severn Estuary have been replaced by fresh water discharged from the rivers Taff and Ely. Secondly, the tidal regime has been replaced by a permanent lake. Thirdly, numerous habitat changes have occurred as a consequence of this replacement of a brackish, tidal regime by a permanent body of standing fresh water with a well-defined transition between water and land. Lastly, many plant and animal community changes have been associated with the loss of the old habitats and the development of new ones.

Because salinity is such an important environmental variable, and is a major limiting factor for a wide variety of organisms, changes in salinity alone would be expected to significantly affect the plant and animal communities present. In its post-Barrage state Cardiff Bay lacks any substantial tidal cycle and therefore has lost the temporary availability of the mudflats which gave the area (because of their importance to foraging shorebirds) its main conservation status prior to Barrage construction. This loss was viewed by many as an environmentally negative consequence, and the biodiversity of the area was expected to suffer adversely as a result. However, it is important to remember that, because estuaries are continuously changing, they are in many respects harsh environments, with the organisms which live in them having a wide range of physiological adaptations to enable them to cope with the fluctuating and often difficult conditions.

It is clear that the overall abundance and density of birds and macroinvertebrates has declined as a consequence of the construction of the Barrage. However, this has been balanced to some extent by an increase in overall diversity. This increase in diversity is primarily a result of the increased habitat heterogeneity of the Bay in its post-Barrage state, and the fact that it now represents a less harsh environment, that can support a range of species that lack the evolutionary adaptations needed to inhabit an estuarine environment.

Before these issues are examined in more detail, it is worth examining the specific environmental objectives that emerged during the development of the ideas behind the Barrage, and the specific conservation commitments that were entered into when approval for the project was sought.

7.2. Attainment of Specific Objectives

7.2.1. Overall aims of the study

The general aim of the Cardiff Bay Barrage and the regeneration program for Cardiff Docks was "to put Cardiff on the international map as a superlative maritime city which will stand comparison with any such city in the world, thereby enhancing the image and economic well-being of Cardiff and Wales as a whole". Five specific aims and objectives were identified within this general framework (see Chapter 2). These will not be repeated here, nor is it proposed to attempt to judge whether or not they have been successfully met, since these are political and economic issues beyond the scope of this thesis which is solely concerned with the plant and animal community changes.

The specific objectives of the study described in this thesis were to provide answers to the following two ecological research questions:

1. How have the communities of aquatic macro-invertebrates, macrophytes, and birds within Cardiff Bay (and at the Gwent Levels Wetland Reserve in the case of birds) developed since the closure of the barrage in November 1999, and more specifically within the three year research period?
2. What are the primary differences between the habitats, aquatic macro-invertebrates, macrophytes, and birds of the post-Barrage Cardiff Bay in comparison to the pre-Barrage situation?

The answers to these two questions have been set out in detail in Chapters 3-6, but can be summarised as follows. The estuarine ecosystem that was present before construction of the barrage was based on a variety of energy sources, notably organic materials washed down the Rivers Taff and Ely, and brought in by the tide from the Severn Estuary in suspension (allochthonous sources), and in situ primary production from the saltmarshes and the algal biofilm on the exposed mudflat surface (autochthonous sources). These supplied energy to a dense, but limited range of mud-dwelling macroinvertebrates, dominated by *Hydrobia ulvae*, *Hediste diversicolor* and *Macoma balthica*, which in turn were fed upon by a community of shorebirds. The latter included plovers (Ringed Plover and Grey Plover), sandpipers (Dunlin, Knot, Redshank and Curlew), wildfowl (Shelduck) and gulls. In addition, some shorebirds were associated with the saltmarshes (Mallard, Teal, Snipe), open waters (Cormorant) and rocky shores (Turnstone).

Since Barrage construction, the community is based upon allochthonous organic materials washed down the Rivers Taff and Ely, together with autochthonous materials from surrounding vegetated areas and from aquatic macrophytes and phytoplankton. This provides food for a diverse array of different communities of aquatic macroinvertebrates in the different habitats that are present, especially the differently vegetated fringes and smaller water bodies present in the Cardiff Bay Wetland Reserve and elsewhere. The community of the more exposed soft bottoms is dominated by chironomids. These invertebrates provide a rich food source for a range of fish and bird species. The birds of the open mudflats have been replaced by those characteristic of permanent standing waters, namely aquatic macrophyte feeders (Mute Swan, Coot, Moorhen), chironomid feeders (Mallard, Teal, Tufted Duck) and fish feeders (Great Crested Grebe, Little Grebe, Cormorant). The Cardiff Bay Wetland Reserve continues to support significant numbers of wintering Snipe, and is also now occupied by a substantial population of Field Voles *Microtus agrestis*, as identified in a separate study by McIntosh & Ferns (Unpublished) during the winter of 2005/2006 (see **Appendix 7.1**).

In addition, the quantitative invertebrate surveys which took place as part of the study had the following specific aims.

1. To gain an insight into the colonisation of the formerly aquatic habitats by freshwater macro-invertebrate species.
2. To determine any variation in macro-invertebrate diversity and density between the various water bodies studied, and to attempt to explain these differences.
3. To provide, based upon the findings, recommendations on the future management of the aquatic habitats in order to increase macro-invertebrate diversity and abundance.

The colonisation of the Cardiff Bay Wetland Reserve by freshwater invertebrates was rapid in those parts closest to Cardiff Bay itself, and a little slower in those parts further inland. The area now supports a large and diverse community. All of the smaller water bodies are now more diverse than the waters of Cardiff Bay itself, no doubt because of the greater shelter afforded by its densely vegetated edges.

The Wetland Reserve will require regular management if it is to be prevented from undergoing a natural process of ecological succession from mixed grassland and scrub to carr woodland, dominated at first, by Alder. For this reason a regular program of coppicing is already underway, as well as measures to control invasive species such as Himalayan Balsam *Impatiens glandulifera*, and Japanese Knotweed *Fallopia japonica*. In order to maintain diversity between the different pools in the Reserve, they need to retain their different character i.e. the wader scrape needs to be kept free of emerging and fringing vegetation. This will also favour its use by waders. While one of the pools could be allowed to become completely occupied by reeds, others need to retain some open water along at least one side. Subterranean nesting sites for Shelduck *Tadorna tadorna* could be provided on the wader roosting island, and artificial sandbanks or similar could help to attract breeding Kingfisher *Alcedo atthis* and Sand Martin *Riparia riparia*.

As is clear from this thesis, increasing the habitat diversity of the Wetland Reserve (and of all habitats in general) is the key to attracting the maximum diversity of all species which rely on it, and all preceding suggestions aim to fulfil this. One further option, which would aid the process of habitat enrichment, would be to remove all vegetation from certain areas on a rotation basis, allowing pioneer communities to take hold, thus providing directly not only additional plant species, but also indirectly providing additional food plants, habitats, and microhabitats to a variety of organisms. Likewise certain areas should be left to attain full maturity, for the same reasons.

7.2.2. Gwent Levels Wetlands Reserve

The Gwent Levels Wetlands Reserve in Newport was the primary component of a compensation package agreed between the U.K government and the E.C for the loss of the inter-tidal habitats within the Taff/Ely Estuary, as mentioned previously. Its specific objectives were as follows.

1. Sustain Nationally Important numbers of at least two species of waterfowl.
2. Be eligible for designation as a Special Protection Area (SPA) alongside the Severn Estuary SPA within five years.
3. In the long term, attract internationally important numbers of certain bird species.

The Gwent Levels Wetlands Reserve has achieved the first of these objectives by now regularly supporting 'Nationally Important' (i.e. over 1% of the estimated British population) numbers of Black-tailed Godwit *Limosa limosa*, Pintail *Anas acuta,* and Shoveler *Anas clypeata* (See **Tab. 7.1**)*,* though the first two species were only present at abundances over the national threshold on two of the six winters analysed, and the latter species on four of the six winters. Whether these species will continue to be present at such levels depends on correct habitat management at the reserve to specifically target these species. Several other species are likely to be attracted at national levels in the near future if the reserve continues to develop, and is managed in the correct manner, including Shelduck *Tadorna tadorna*, Dunlin *Calidris alpine,* Teal *Anas crecca* and Gadwall *Anas strepera.*

Table 7.1: Species which have attained 'Nationally' (red) and 'Internationally' important populations (blue) at the Gwent Levels Wetland Reserve.

Species		**Importance Threshold***		**Winter Peak Count**					
		National	**International**	**99/00**	**00/01**	**01/02**	**02/03**	**03/04**	**04/05**
Shoveler	*Anas clypeata*	148	400	70	163	215	150	122	184
Pintail	*Anas acuta*	279	600	149	380	309	271	184	163
Black-tailed Godwit	*Limosa limosa*	150	350	-	14	22	8	281	385

* National threshold is 1% of the estimated British population. International threshold is 1% of entire population of a species, or over 20,000 individuals (Banks *et al.*, 2006)

The site is certainly worthy of SPA designation in the context of its use by Severn Estuary waders and wildfowl as a roosting site and supplementary feeding area. Its breeding populations of Lapwing *Vanellus vanellus*, Redshank *Tringa totanus*, Little Ringed Plover *Charadrius dubius* and Avocet *Recurvirostra avosetta* are an added bonus.

The third objective has been only partly attained, because although internationally important numbers of *Limosa limosa* have been present on one occasion (November 2004) the site must regularly hold over the threshold to qualify for this status. In any case, fulfilment of this objective is a long term aspiration, and continued species targeted improvements will no doubt allow this in the foreseeable future.

7.2.3. Cardiff Bay Wetland Reserve

Within Cardiff Bay itself, a small area of former salt marsh was developed as a non-compensatory freshwater wetland reserve. This was never intended to provide compensation or mitigation, but instead formed part of the Cardiff Bay Regeneration Strategy's aim to bring back conservation interest to the bay itself. This is because of specific commitments that included the following.

"The creation of new freshwater and other natural or semi-natural habitats must be an integral part of the strategy"

There was, in addition, a similar requirement set out in the Cardiff Bay Barrage Bill.

"When operating the barrage ...the Development Corporation shall have regard to the desirability of developing and conserving flora and fauna in the inland bay".

These objectives have clearly been fulfilled. The site is a major focus for the birdlife of the Cardiff Bay area, supporting a highly significant proportion of its current total population. It also supports interesting breeding and wintering passerine bird populations. It has been visited by a number of rare species (see **Table 7.2 & Appendix 6**) and because of this it is popular with both bird watchers and members of the general public.

Table 7.2: 'Rare' bird species recorded in Cardiff Bay.

Species	
African Spoonbill	*Platalea alba*
American Wigeon	*Anas Americana*
Black-necked Grebe	*Podiceps nigricollis*
Bonaparte's Gull	*Larus philadelphia*
Dartford Warbler	*Sylvia undata*
Glaucous Gull	*Larus glaucoides*
Iceland Gull	*Larus hyperboreus*
Red-necked Grebe	*Podiceps grisegena*
Ring-billed Gull	*Larus delawarensis*
Ruddy Duck	*Oxyura jamaicensis*
Slavonian Grebe	*Podiceps auritus*
Whiskered Tern	*Childonias hybridus*

Although it lacks a substantial tidal cycle, there is still a tendency under certain tidal conditions for the waters of the post-Barrage lake to rise at high tide. This occurs only on spring tides when there is also substantial river flows. For a short period during such conditions, the barrage is closed to exclude the tide and thus levels in the lake rise in response to river discharge. The amount of the rise is usually just a few centimetres, but it can be greater. The time budgets of Shelducks feeding in Cardiff Bay continue to display a distinct tidal influence, with birds tending to sleep around the time that the tide is high outside the barrage (Ferns & Reed, unpublished manuscript).

The most likely explanation for this phenomenon is that they avoid feeding at high tide because of the tendency for water levels to be slightly higher at this time. Most of their feeding is by upending to reach the lake bed and this obviously becomes more difficult when the water depth is greater, though it is not a significant constraint upon foraging because the birds can feed for far longer than they could in a normal tidal environment. Although there are far fewer of them than prior to Barrage construction, they are in better body condition (Ferns & Reed, unpublished manuscript).

7.3. Overall Conclusions

I would argue that the 'value' of Cardiff Bay as a habitat for plant and animal communities has increased in terms of the diversity of species which it supports. However, diversity is only one aspect of 'value'. The 'value' of a habitat should also reflect the rarity of that habitat in the context of its geographic location – be it on a local, national, international or even global scale. In a review of European wetlands (Nivet & Frazier, 2004), estimates of the major types of wetland habitats found in the UK were compiled by using various sources. The values relevant to the pre- and post-Barrage Cardiff Bay are given in **Tab. 7.3**, and as can be seen, there is very little difference between the total values of the broad habitat types, with the freshwater wetland habitats (typical of the post barrage situation) only being 11.8% larger in total extent in the UK than the total estuarine habitats, hence the differences in value according to rarity are negligible.

It is important to realise that not all of the habitat extent outlined in **Tab.7.3** is 'ecologically valuable' for a variety of reasons (e.g. pollution may reduce the value of some sites). However, the information necessary to refine estimates to this level of detail are simply not available.

Another aspect that must be considered with respect to value inferred by habitat rarity, is the current rate of loss of each of the broad habitat types, as well as the future potential for habitat loss. Although there is currently very little difference in extent between the two major habitat types relevant to this study, this may (and most likely will) change in the future, and thus it is imperative that an assessment of the stability of a habitat is made when considering a development that will result in the loss of that habitat.

Table 7.3: The total UK extent (best estimates), of wetland habitats typical of the pre- and post-Barrage Cardiff Bay. All data is from Nivet & Frazier (2004).

Habitats typical of pre-Barrage Bay		**Habitats typical of post-Barrage Bay**	
Habitat	***Extent (ha)***	***Habitat***	***Extent (ha)***
Estuarine water	265,844	**Inland water courses**	80,000
Intertidal flats	279,321	**Inland water bodies**	210,000
Saltmarsh	45,000	**Freshwater marsh**	370,000
Total	**590,165**		**660,000**

Studies of the past losses of wetland extent on a national scale are rather patchy in their coverage, but several studies give a broad idea of the scale of the threats faced by freshwater and estuarine wetlands. Once again, these losses were summarised by Nivet & Frazier (2004), and provide a general overview of the need for conservation in each case.

In the future, it is to be hoped that the rate of loss of both freshwater and estuarine habitats will be reduced as a consequence of improving site designation and habitat protection legislation. However, recent developments suggest that this is not yet happening. The Welsh Assembly Government together with several Severn Estuary English local authorities are currently backing a proposal for a Severn tidal power barrage that will result in substantial estuarine habitat loss. The provisions of the European Habitats and Birds Directives (collectively known as Natura 2000) make it difficult to imagine how such a development could take place without the creation of substantial new habitat for displaced species, notably shorebirds.

Furthermore, most intertidal wetlands face another new threat in the form of sea level rise associated with climate change. For this reason, and bearing in mind the ecological services that such habitats provide, the conservation of intertidal wetland habitats deserves a high priority.

The final aspect of this study which needs to be addressed is whether the bird species and communities present in the pre- and post-Barrage environments are of comparable value. Perhaps the simplest way to put a value on the species present in each of the two situations, is to look at the wider picture, and assess them in relation to their present and past (at the time that the compensation decisions were made) conservation status at national and international levels.

Two species were present in Nationally Important numbers in the years prior to Barrage closure, namely Redshank and Dunlin. It is for this reason that compensatory measures designed to cater for these two mudflat foraging wading bird species were initially planned. A recent assessment of these initial measures, put the cost of compensation, for Redshank at least, at about £8,500 per bird accommodated. The area would have reduced the post-Barrage Redshank mortality at the Rumney Estuary (where many of the Cardiff Bay Redshank moved to), from about 7% per annum, back to the 3% per annum it was before Barrage construction (Goss-Custard *et al.*, 2006).

These initial compensatory measures were rejected because they were too expensive and their efficacy too uncertain. Instead, the scheme for the Gwent Levels with its objective of supporting any two species of wildfowl in Nationally Important numbers was chosen. With its much more flexible objectives, this scheme has generally been a great success.

The very flexibility of the objectives of the Gwent Levels scheme, raises the question as to whether the mitigation provided for the loss of the intertidal wetlands in Cardiff Bay has been adequate, or would like-for-like compensation have been more appropriate? For this to be the case, an additional category of environmental amelioration ought to be added to the four defined in **Section 1.6**. This category might be termed **restitution** i.e. the replacement of a lost or developed habitat with one capable of supplying *all* the lost requirements of the species or community affected.

In my view, the closure of Cardiff Bay Barrage in November 1999, simply signified the start of a new era of habitat development in the Bay, and with it, bought the opportunity to study what is an unusual and interesting suite of ecological changes. Hopefully, my findings will provide some insights into what the future may hold for similar wetland development and reclamation in years to come.

7.4 The Future Ecology of Cardiff Bay

It is clear that the future of the ecology of Cardiff Bay is very much dependant upon the extent and type of management applied to the habitats of the area. There are however, several broad predictions that can be made, based upon the continuation of the current management regime.

Starting with the macrophytes, we can expect a gradual reduction in the dominance of Sea Couch *Elytrigia atherica* and a replacement by a more diverse community of grasses, and other species more typical of freshwater grassland areas. Alder *Alnus glutinosa,* and other invasive species such as Japanese Knotweed *Fallopia japonica*, will continue to colonise the lower lying areas - the extent of colonisation depending upon the severity of flooding of the wetland habitats. The overall diversity of all macrophytes is likely to increase over time, though it is clear that the rate of colonisation will be very much dependent upon the degree of disturbance which the terrestrial and aquatic areas receive. It is likely that some species (*Elytrigia atherica* in particular) will persist for many years into the future – 30 years or more if comparisons with the Zuider Sea are to be made.

The increase in diversity of plant species will invariably lead to a greater diversity of invertebrates and birds, and the highly abundant populations of certain species (such as chironomids) seen over the study period are likely to decrease to 'normal' levels. This will probably lead to an overall decrease in the abundance of birds utilising the bay – though the diversity is likely to continue to rise for a number of years.

The diversity and number of species of all kinds of organisms is always likely to be limited by the size of the available habitats in Cardiff Bay – with relatively little of the available marginal area being utilised to attract wildlife. The creation of new targeted habitats in the Bay – particularly in the mouths of the Rivers Taff and Ely would undoubtedly lead to a higher holding capacity, and the creation of new habitat types would lead to an overall increase in diversity.

7.5 Further Research

Because of the huge scope of the current study, it is clear that a number of valuable research opportunities have been missed, primarily due to time constraints. One area in particular which could have received further study, is the use of in-situ habitat manipulation experiments to investigate the effect of varying substrate types on the rates of macrophyte and invertebrate colonisation. Similarly, controlled experiments into the effects of disturbance on the vegetated communities may have revealed interesting ecological interactions. For instance, treating adjacent experimental plots to differing degrees of disturbance would have revealed the extent to which this factor influences ecological succession in newly created habitats, such as at the Cardiff Bay Wetland Reserve.

A more in depth predator exclusion experiment, would be beneficial in order to separate out the effects of different groups of predators (e.g. birds and fish), and controls could have revealed the effects of the experimental cages themselves (e.g. due to shelter and shading).

One other particularly interesting aspect of the type of ecological change encountered in Cardiff Bay, is the effect upon the behavioural ecology of certain groups (especially birds), for instance it is clear that the feeding ecology of Shelduck *Tadorna tadorna* has been significantly changed as a result of Barrage closure (Ferns & Reed, unpublished manuscript), and it is likely that other species which have remained in the Bay have also adapted their behaviour accordingly.

Because Cardiff Bay is only separated from the Severn Estuary by the Barrage itself, it is likely that the tidal cycle still has a significant effect upon the Bays' ecology, a hypothesis which appears to be supported by initial personal observations, and further research may reveal interesting patterns related to the abundance and behaviour of a number of species.

Above all, it is clear that any similar future Barrage schemes would benefit from long-term monitoring over a suggested minimum period of 10 years either side of construction (though this would depend upon the length of the construction period), with detailed separate studies of as many aspects of the areas' ecology as possible. As the bare minimum, a representative group from each trophic level should be studied in detail, which would subsequently allow further research, aimed at identifying interactions between trophic groups, to be undertaken at a later stage.

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Appendices

(Additional appendices are included on the enclosed Cd-Rom)

Appendix 2.1

Taff/Ely SSSI Designation

SOUTH GLAMORGAN

TAFF/ELY ESTUARY SSSI

City of Cardiff
Vale of Glamorgan
Borough

Local Planning Authorities:	City of Cardiff
	Vale of Glamorgan
Date of Notification:	1980
National Grid Reference:	ST 185735
O.S. 1:50,000 Sheet No.:	171
1:25,000 Sheet No.:	ST 17

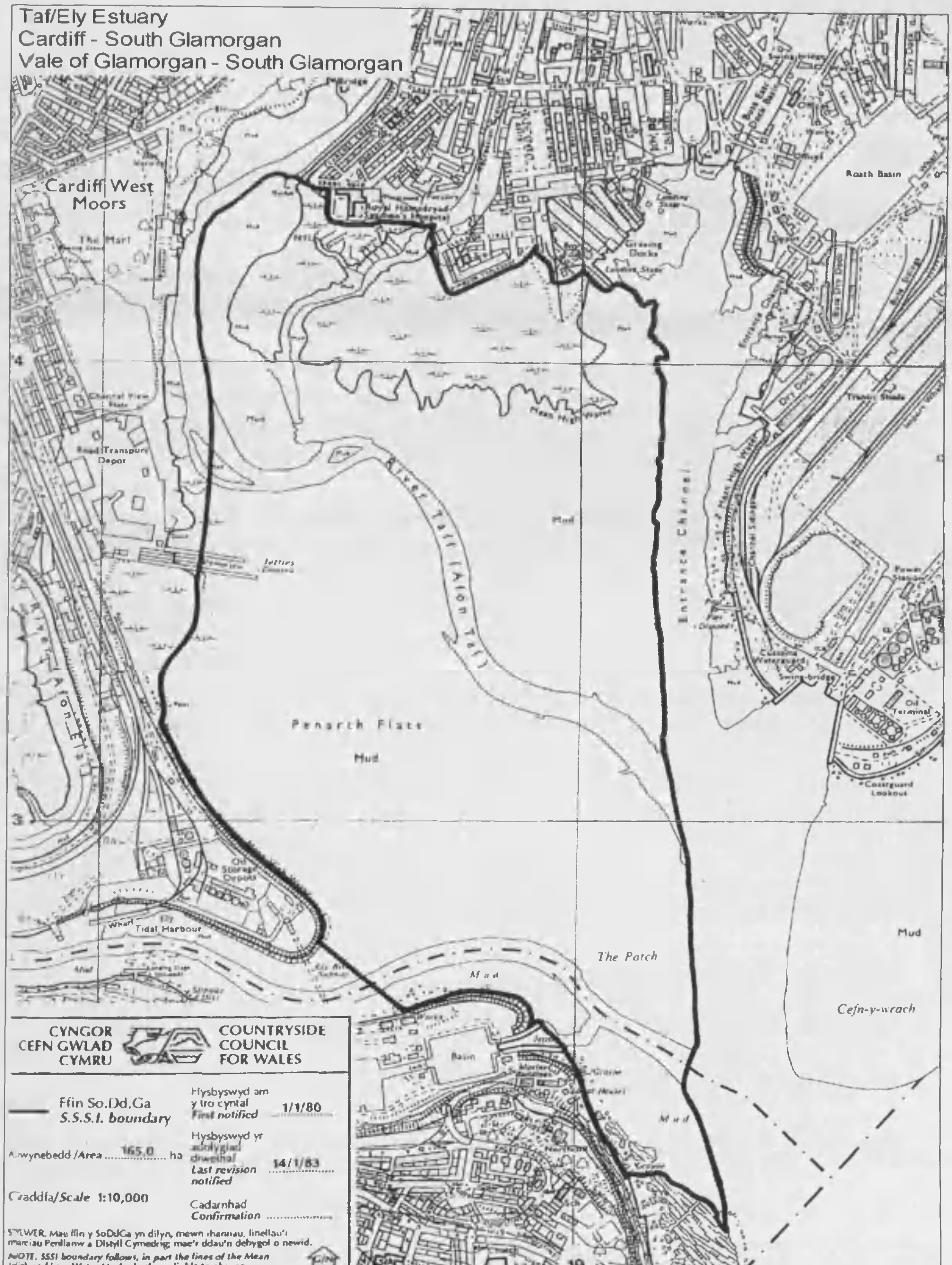
Site Area: 165 hectares (407.7 acres)

Description:

The Taff/Ely Estuary provides feeding grounds for around 8000 birds during the winter months and has the highest density of waders for any site of its size in the Severn Estuary complex. Dunlin, redshank, and curlew are the principal species along with smaller numbers of knot, grey plover, ringed plover, shelduck, mallard, and widgeon.

Remarks:

New Site.


Taf/Ely Estuary
Cardiff - South Glamorgan
Vale of Glamorgan - South Glamorgan
Cardiff West Moors
Roath Basin
Entrance Channel
River Taff (Afon Taf)
Penarth Flats
Mud
Jetties
Road Transport Depot
Oil Storage Depots
Tidal Harbour
The Patch
Cefn-y-wrach
Power Station
Oil Terminal
Coastguard Lookout
Basin
Penarth Head
CYNGOR CEFN GWLAD CYMRU
COUNTRYSIDE COUNCIL FOR WALES
Ffin So.Dd.Ga
S.S.S.I. boundary
Hysbyswyd am y tro cyntaf
First notified 1/1/80
Arwynebedd /Area 165.0 ha
Hysbyswyd yr adolygiad diweddaf
Last revision notified 14/1/83
Graddfa/Scale 1:10,000
Cadarnhad
Confirmation
NOTE. SSSI boundary follows, in part the lines of the Mean High and Low Water Marks; both are liable to change.
Crown copyright reserved.

Appendix 2.2

Severn Estuary Designations

NOTIFIED TO THE SECRETARY OF STATE ON 2 FEBRUARY 1989

COUNTRIES: ENGLAND/WALES SITE NAME: SEVERN ESTUARY

COUNTIES: England: Somerset/Avon/Gloucestershire
Wales: Gwent/South Glamorgan

DISTRICTS: Somerset: Sedgemoor Avon: Woodspring/Bristol/Northavon
Gloucestershire: Stroud/Forest of Dean
Gwent: Monmouthshire/Newport
South Glamorgan: Cardiff/Vale of Glamorgan

Status: Site of Special Scientific Interest (SSSI) notified under Section 28 of the Wildlife and Countryside Act, 1981, (as amended).

Local Planning Authorities:

England: Somerset County Council/Avon County Council/Gloucestershire County Council, Sedgemoor District Council/Woodspring District Council, Bristol City Council/Northavon District Council/Stroud District Council, Forest of Dean District Council
Wales: Gwent County Council/South Glamorgan County Council, Monmouth District Council/Newport Borough Council, Cardiff City Council/Vale of Glamorgan Borough Council

National Grid Reference: ST 480830 Approx Area: 15950 (ha.) 39410 (ac.)

Ordnance Survey Sheets 1:50,000: 162/171/172/182
1:25,000: ST 25-35/ST 26-36/ST 47-57/ST 48-58/ST 49/59/
ST 69-79/ST 28-38/ST 17-27/ST 06-16/SO 60

Date Notified (Under 1949 Act): 1976 Severn Estuary, 1952 Brean Down and Uphill Cliff

Date Notified (Under 1981 Act): 1989 Date of Last Revision: –
Date of Last Revision: –

Other Information:

This site overlaps with the following SSSIs:
(Avon): Spring Cove Cliffs/Middle Hope/Portishead Pier to Black Nore/Aust Cliff
(Glos): Purton Passage
(S. Glam): Penarth Coast

This site includes two areas previously notified as SSSI under the National Parks and Access to the Countryside Act 1949:
1. Severn Estuary (1976)
2. Part of Brean Down and Uphill Cliff (1952)

The Severn Estuary SSSI forms part of a larger area which includes the Upper Severn Estuary SSSI, the Taf/Ely Estuary SSSI and Bridgwater Bay National Nature Reserve and proposed SSSI. This larger area of the Severn Estuary is proposed as a Special Protection Area under the terms of the European Community Directive 79/409/EEC on the Conservation of Wild Birds and for inclusion on the list of Wetlands of International Importance under the Ramsar Convention ('Ramsar' site). The Upper Severn Estuary SSSI and Bridgwater Bay NNR parts of this proposed Ramsar site are already included on the list. The site is listed in 'A Nature Conservation Review' (1977 ed D A Ratcliffe, CUP).

Description and Reasons for Notification:

The Severn Estuary lies on the south west coast of Britain at the mouth of four major rivers (the Severn, Wye, Usk and Avon) and many lesser rivers. The immense tidal range (the second highest in the world) and classic funnel shape make the Severn Estuary unique in Britain and very rare worldwide. The intertidal zone of mudflats, sand banks, rocky platforms and saltmarsh is one of the largest and most important in Britain. The estuarine fauna includes: internationally important populations of waterfowl; invertebrate populations of considerable interest; and large populations of migratory fish, including the nationally rare and endangered Allis Shad *Alosa alosa*. The SSSI forms the major part of a larger area of estuarine habitat, which includes the Upper Severn Estuary, the Taf/Ely Estuary and Bridgwater Bay.

The estuary has a diverse geological setting and a wide range of geomorphological features, especially sediment deposits. It is important for the interpretation of coastline dynamics and land-forms, and also past changes, in sea level, sediment supply, climate and river flow. The estuary's overall interest depends on its large size, and on the processes and interrelationships between the intertidal and marine habitats and its fauna.

Beds of eel-grass *Zostera* spp. occur on the more sheltered mud and sand banks. The estuary fringes have large areas of saltmarsh. These are generally grazed by sheep and/or cattle, a significant factor determining the plant communities. A range of saltmarsh types is present, with both gradual and stepped transitions between bare mudflat and upper marsh. Glassworts *Salicornia* spp. and Annual Sea-blite *Suaeda maritima* colonise bare mud on the lower saltmarshes, and disturbed areas at higher levels. Common Cord-grass *Spartina anglica* is abundant on the seaward fringes of marshes, where it occurs as dense monocultures, or with other species, such as Sea Aster *Aster tripolium*, Greater Seaspurrey *Spergularia media* and Common Saltmarsh-grass *Puccinellia maritima*. The middle marsh is mainly dominated by Common Saltmarsh-grass, and frequent associates include Sea-milkwort *Glaux maritima*, English Scurvygrass *Cochlearia anglica* and Sea Arrowgrass *Triglochin maritima*, together with two nationally scarce plants Bulbous Foxtail *Alopecurus bulbosus* and Slender Hare's-ear *Bupleurum tenuissimum*. There are a few localities for an uncommon middle marsh community, which is characterised by Sealavender *Limonium vulgare* and Thrift *Armeria maritima*. Prominent species on the upper marsh are Red Fescue *Festuca* *rubra* and Saltmarsh Rush *Juncus gerardi*. Nationally scarce species occurring on the upper marshes include Sea Clover *Trifolium squamosum* and Sea Barley *Hordeum marinum*. Highly saline drying pans on the upper marsh support a community with abundant Reflexed Saltmarsh-grass *Puccinellia distans* and Lesser Seaspurrey *Spergularia marina*. The highest saltmarsh around the driftline is usually dominated by Sea Couch *Elymus pycnanthus*, with Spear-leaved Orache *Atriplex prostrata*. Some brackish pools and depressions on the upper marshes have small stands of Common Reed *Phragmites australis* or Sea Club-rush *Scirpus maritimus*. Corn Parsley *Petroselinum segetum*, a European rarity, occurs within the site.

The fluctuating salinity and highly mobile sediments with consequent high turbity limits the benthic invertebrates to relatively few species. Those which are tolerant of such conditions occur in very high densities on the more stable mudflats. The most prominent species are ragworm *Nereis* spp., Lugworm *Arenicola marina*, Baltic Tellin *Macoma balthica* and the spire shell *Hydrobia ulvae*. A greater variety of invertebrates tend to occur on the intertidal rock platforms, a more stable habitat with rock pools and a relatively high cover of seaweeds.

Seven species of migratory fish move through the Estuary between the sea and rivers. There are particularly large numbers of Atlantic Salmon *Salmo salar* and Common Eel *Anguilla anguilla*. The other species are Allis Shad, the nationally rare Twaite Shad *Alosa fallax*, the Sea Trout *Salmo trutta*, Sea Lamprey *Petromyzon marinus* and the Lampern or River Lamprey *Lampetra fluviatilis*.

The SSSI is of international importance for wintering and passage wading birds, with total winter populations averaging about 44,000 birds. Numbers can be considerably higher during severe winters when, owing to its mild climate, the Severn supports wader populations that move in from the colder coasts of Britain. The SSSI holds most of the estuary's internationally important Curlew *Numenius arquata* and Redshank *Tringa totanus* populations, and most of its nationally important Ringed Plover *Charadrius hiaticula* and Grey Plover *Pluvialis squatarola* populations. Other waders which occur in significant numbers within the SSSI are Common Snipe *Gallinago gallinago*, Knot *Calidris canutus*, Whimbrel *Numenius phaeopus* and Turnstone *Arenaria interpres*.

The SSSI is internationally important for Dunlin *Calidris alpina* and supports about 7.5% of the British wintering population of this species. The estuary as a whole supports about 10.5% of the British wintering population and is the single most important wintering ground of Dunlin in Britain.

In late winter and early spring the SSSI supports nationally important numbers of Shelduck *Tadorna tadorna*, following the partial dispersal from their moulting grounds in Bridgwater Bay. There are also significant numbers of Wigeon *Anas penelope*.

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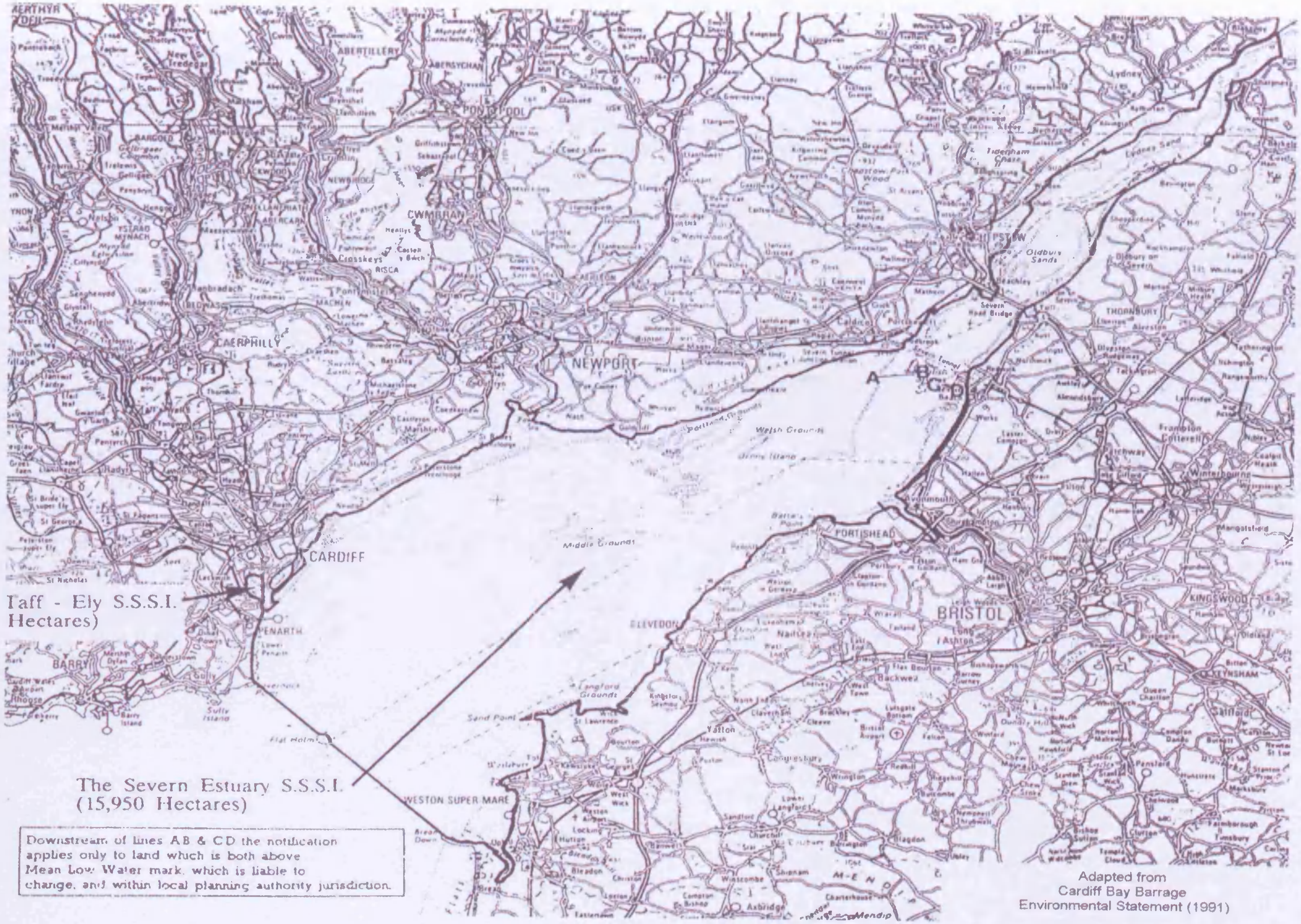

Adapted from
Cardiff Bay Barrage
Environmental Statement (1991)

EC Directive 79/409 on the Conservation of Wild Birds: Special Protection Area

SEVERN ESTUARY (GLOUCESTERSHIRE, AVON, SOMERSET, SOUTH GLAMORGAN, MID GLAMORGAN, GWENT)

The Severn Estuary is one of the largest estuaries in Britain and it has the second largest tidal range in the world. Its classic funnel shape and south-west orientation makes it susceptible to extreme weather conditions in the east Atlantic. There are large urban developments on the estuary including the cities of Bristol and Cardiff.

The Severn Estuary qualifies under Article 4.1 of the Birds Directive by regularly supporting an internationally important wintering population of Bewick's swan *Cygnus columbianus bewickii*, an Annex I species. During the period 1988/89 to 1992/93 a mean peak of 289 birds (1.7% of the north-west European population, 4.1% of the British wintering population) used the estuary.

The Severn Estuary qualifies under Article 4.2 as a wetland of international importance by regularly supporting in winter over 20,000 waterfowl. In the five year period 1988/89 to 1992/93 the average peak count was 68,026 waterfowl comprising 17,502 wildfowl and 50,524 waders.

The Severn Estuary also qualifies under Article 4.2 by regularly supporting in winter internationally important numbers of the following 5 species of migratory waterfowl (average peak means for the period 1988/89 to 1992/93): 3,002 European white-fronted goose *Anser albifrons albifrons* (1.0% NW European, 50.0% British), 2,892 shelduck *Tadoma tadoma* (1.2% NW European, 3.9% British), 330 gadwall *Anas strepera* (2.8% NW European, 5.5% British), 41,683 dunlin *Calidris alpina* (2.9% east Atlantic flyway (EAF), 9.6% British) and 2,013 redshank *Tringa totanus* (1.3% EAF, 2.6% British).

The Severn Estuary also supports nationally important wintering populations of a further 10 species: 3,977 wigeon *Anas penelope* (1.6% British), 1,998 teal *Anas crecca* (2.0% British), 523 pintail *Anas acuta* (2.1% British), 1,686 pochard *Aythya ferina* (3.8% British), 913 tufted duck *Aythya fuligula* (1.5% British), 227 ringed plover *Charadrius hiaticula* (1.0% British), 781 grey plover *Pluvialis squatarola* (3.7% British), 3,096 curlew *Numenius arquata* (3.4% British), 246 whimbrel N. phaeopus (4.9% British total) and 3 spotted redshank *Tringa erythropus* (1.5% British).

In addition, during passage periods, the estuary supports nationally important numbers of ringed plover (spring migration: 442 birds (1.4% British passage), autumn migration: 1,573 birds (5.2% British passage)), dunlin (spring: 3,510 birds (1.7% British passage), autumn: 5,500 birds (2.7% British passage)), whimbrel *Numenius phaeopus* (spring: 246 birds (4.9% British passage), autumn: 66 birds (1.3% British passage)) and redshank (autumn: 2,456 birds (2% British passage)).

The Severn Estuary also supports a nationally important breeding population of a migratory species. In 1993 2040 pairs of lesser black-backed gulls *Larus fuscus* bred on the islands of Steep Holm and Flat Holm within the estuary. This represents 2.5% of the British total.

SPA Citation
CAR
December 1993

Severn Estuary 'Ramsar' Designation

United Kingdom 7UK088

Site: Severn Estuary **Designation date:** 13/07/1995
Coordinates: 51°36'N, 002°40'W **Elevation:** no information **Area:** 24,701 ha
Location: The site lies in the southwest of the United Kingdom, between Wales and England in the Atlantic biogeographical region. The nearest town is Bristol.
Criteria: (1c, 2b, 2c, 3a, 3c): **1, 3, 4, 5, 6**
Importance: The immense tidal range (2nd highest in world) affects both the physical environment and biological communities. The site contains unusual estuarine communities, reduced diversity and high productivity. This site is important for the run of migratory fish between sea and river via estuary. Species include salmon *Salmo salar*, sea trout *S. trutta*, sea lamprey *Petromyzon marinus*, river lamprey *Lampetra fluviatilis*, Allis shad *Alosa alosa*, Twaite shad *A. fallax*, and eel *Anguilla anguilla*. It is also of particular importance for migratory birds during spring and autumn, including nationally important numbers of ringed plover *Charadrius hiaticula*, dunlin *Calidris alpina*, whimbrel *Numenius phaeopus* and redshank *Tringa totanus*. Over winter, the site regularly supports 65,555 waterbirds, including gadwall *Anas strepera* (an average of 282 individuals representing 0.9% of the Northwestern Europe population), dunlin *Calidris alpina alpina* (an average of 31,418 individuals representing 2.3% of the Northern Siberia/Europe/ Western Africa population), redshank *Tringa totanus* (an average of 2,110 individuals representing 1.2% of the Eastern Atlantic wintering population), white-fronted goose *Anser albifrons albifrons* (an average of 2,664 individuals representing 0.4% of the Northwestern Siberia/Northeastern & Northwestern Europe population), Bewick's swan *Cygnus columbianus bewickii* (an average of 280 individuals representing 1.6% of the Western Siberia/Northeastern & Northwestern Europe population) and shelduck *Tadorna tadorna* (an average of 2,552 individuals representing 0.9% of the Northwestern Europe population).
Wetland Types: G (84%), D (4.7%), H (4.7%), E (4.4%), Tp (1%), B (0.9%), F (0.2%)

A consequence of the large tidal range is the extensive intertidal zone, one of the largest in the UK, comprising mudflats, sand banks, shingle, and rocky platforms.
Biological/Ecological Notes: The tidal regime results in plant and animal communities typical of the extreme physical conditions of liquid mud and tide-swept sand and rock. The species-poor invertebrate community includes high densities of ragworms, lugworms and other invertebrates forming an important food source for passage and wintering waders. Glassworts and annual sea blite colonise the open mud, with beds of all three species of eelgrass occurring on more sheltered mud and sandbanks. Large expanses of common cord grass also occur on the outer marshes. Heavily grazed saltmarsh fringes the estuary with a range of saltmarsh types present. The middle marsh sward is dominated by *Puccinellia maritima* with *Glaux maritima* and *Triglochin maritima*. At the edge of the mudflats, there are monocultures of *Spartina anglica* and there are pools and depressions with *Phragmites australis* and *Bolboschoenus maritimus*. In the upper marsh, there is *Festuca rubra* and *Juncus gerardii*.
Hydrological/Physical Notes: The estuary's classic funnel shape, unique in Britain, is a factor causing the Severn to have the second highest tidal range in the world (after the Bay of Fundy, Canada). The soil and geology includes biogenic reef, clay, cobble, gravel, limestone, mud, peat, sand, sandstone and sediments. The site provides functions of sediment trapping, shoreline stabilisation and dissipation of erosive forces. The climate is rainy and temperate with a mild winter and periodic frost. The mean minimum and maximum temperatures are 8.6°C and 15.3°C, respectively. Mean annual rainfall is about 867 mm with a winter maximum.
Human Uses: Functional jurisdiction resides with the Department of the Environment, Transport and the Regions. The site and the surrounding area is in mixed ownership of the local municipality, national government, private property, private ownership and public land. The site itself is also partially owned by an NGO and in other tenure. Large-scale activities and uses

occurring on site include grazing, sewage treatment/disposal, a harbour/port and flood control. Small-scale activities on site include nature conservation, recreation, research, recreational fishing, gathering of shellfish, bait collection and recreational hunting. Other small-scale uses of the site include industrial water supply, industry, mining, a transport route and military activities. Large-scale activities and uses in the immediate vicinity include tourism, grazing, permanent pastoral agriculture, flood control and urban development. The surrounding area is also used for small-scale activities of industry and transport route. Numbers of migratory and wintering waders and wildfowl are monitored annually as part of the national Wetland Birds Survey (WeBS). There are some interpretation panels and hides at Bridgewater Bay. Walking, dog walking, and birdwatching are concentrated along the seawalls, saltmarsh and sandy beaches all year round. Bathing and beach recreation including windsurfing are practised on the sandy beaches and sea, mainly in summer. There are boat clubs/marinas in the sub-estuaries with sailboats, motorboats and jet skis.
Conservation Measures: The site is an EU Special Protection Area, a Site of Special Scientific Interest and a National Nature Reserve. The conservation of the site is affected by the tidal regime. Scouring of the seabed and strong tidal streams result in natural erosion of the habitats. The estuary is therefore vulnerable to large-scale interference, including human actions. These include land reclamation, aggregate extraction/dredging, physical developments such as barrage construction flood defences, pollution, eutrophication and tourism based activities and disturbance. These issues are being addressed through existing control measures and as part of the Severn Estuary Strategy. Since June 1995, the Severn Estuary Strategy has been working towards the sustainable management of the site, through the involvement of local authorities, interested parties and local people. This integrated approach is being further developed in conjunction with the EU Special Area of Conservation management scheme for the nature conservation interest of the estuary.
Adverse Factors: Dredging, erosion, eutrophication, pollution (industrial waste and oil) and disturbance through recreation and tourism are factors affecting the site.
Site Management: English Nature. Northminster House. Peterborough PE1 1UA.

Countryside Council for Wales. Plas Penrhos, Fford Penrhos Bangor, Gwynedd LL57 2LQ. Based on the 1999 Ramsar Information Sheet and the 2002 National Report to the Ramsar Convention.

Appendix 2.3

Gwent Levels Designations

GWENT　　　　GWENT LEVELS - NASH AND GOLDCLIFF SSSI

Newport Borough

Local Planning Authority: Newport Borough Council

Date of Notification: August 1987

National Grid Reference: ST 350850

O.S. 1:50,000 Sheet No: 171

1:25,000 Sheet No: ST 38

DATE OF NOTIFICATION
20 AUG 1987

Site Area: 954 hectares (2357 acres)

Description:

The Gwent Levels constitute the lowlands between Cardiff and Chepstow and are drained by an ordered network of drainage ditches. They are an example of one of the most extensive areas of reclaimed wet pasture in Great Britain which includes the Somerset Levels, Romney Marsh and the Pevensey Levels, and is the largest area of its kind in Wales. Together these Levels systems constitute a national series of sites each with its own special features.

The Gwent Levels reens are rich in plant species and communities, many of which are rare or absent in other Levels systems. This is due to the variety of reen types and their management regimes and the timing of the management which results in a staggered programme across the Levels. The regular maintenance of some reens provides conditions for submerged species such as hairlike pondweed (Potamogeton trichoides) and openwater emergents such as arrowhead (Sagittaria sagittifolia) an opportunity to flourish. Others are less intensively managed and some have become completely overgrown by weeds and hedges.

The aquatic invertebrate fauna is very diverse and the Gwent Levels compares well with similar areas in Britain. Many nationally rare or notable species are present such as Haliplus mucronatus and Hydrophilus piceus. The area is important in the Welsh context for its snails and dragonflies and includes the species Physa heterostropha and Brachytron pratense respectively. The large number of hedgerows add to the diversity of the area and together with the main reen banks provide a habitat for nationally important assemblages of terrestrial invertebrates such as Pipunculus fonsecai and Tomosvaryella minima.

The Nash and Goldcliff area forms an important part of the Gwent Levels system and is of particular botanical interest as it is the only area in Wales for the Least Duckweed (Wolffia arrhiza). There is also an interesting community where two species of hornwort (Ceratophyllum submersum and C. demersum) grow together.

The invertebrate interest is also high, as rare and notable species such as Odontomyia ornata, Oplodontha viridula and Hydaticus transversalis are present.

Remarks

New site.

The Gwent Levels - Nash and Goldcliff SSSI is one of a series of SSSIs within the area between Chepstow and Cardiff known as the Gwent Levels.

The Severn Estuary SSSI is contiguous with the southern boundary of this area.

Newport Borough

Local Planning Authority: Newport Borough Council

Date of Notification: 7 June 1988

National Grid Reference: ST 390840

O.S. 1:50,000 Sheet No: 171

1:25,000 Sheet No: ST 38

Site Area: 937.4 hectares (2316.4 acres)

Description

The Gwent Levels constitute the lowlands between Cardiff and Chepstow and are drained by an ordered network of drainage ditches. They are an example of one of the most extensive areas of reclaimed wet pasture in Great Britain which includes the Somerset Levels, Romney Marsh and the Pevensey Levels, and is the largest area of its kind in Wales. Together these Levels systems constitute a national series of sites each with its own special features.

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The aquatic invertebrate fauna is very diverse and the Gwent Levels compares well with similar areas in Britain. Many nationally rare or notable species are present such as Haliplus mucronatus and Hydrophilus piceus. The area is important in the Welsh context for its snails and dragonflies and includes the species Physa heterostropha and Brachytron pratense respectively. The large number of hedgerows add to the diversity of the area and together with the main reen banks provide a habitat for nationally important assemblages of terrestrial invertebrates such as Pipunculus fonsecai and Tomosvarvella minima.

The Whitson area is of particular importance for its large number of nationally rare and notable invertebrate species. A total of 65 of these rare invertebrates have been recorded in this area including Anthomyza bifasciata, Coptophlebia volucris and Hydrophilus piceus.

This area is also important for its botanical interest as it contains the nationally rare hairlike pondweed Potamogeton trichoides and is the only location in Gwent for the tussock sedge Carex elata. Arrowhead Sagittaria sagittifolia also grows in abundance in several main reens in this area.

Remarks

New site.

The Gwent Levels - Whitson SSSI is one of a series of SSSIs within the area between Chepstow and Cardiff known as the Gwent Levels.

The Severn Estuary SSSI is contiguous with the southern boundary of this area.

Appendix 3.1

Table showing the distribution of Subclasses within the classification hierarchy of the U.S. Department of the Interior's 'Classification of Wetlands & Deepwater Habitats of the United States' (Cowardin *et al.* 1979).

	System and Subsystem[a]										
	Marine		Estuarine		Riverine				Lacustrine		Palustrine
Class/Subclass	**ST**	**IT**	**ST**	**IT**	**TI**	**LP**	**UP**	**IN**	**LM**	**LT**	-
Rock Bottom											
Bedrock	X		X		X		X		X	X	X
Rubble	X		X		X		X		X	X	X
Unconsolidated Bottom											
Cobble-Gravel	X		X		X	X	X		X	X	X
Sand	X		X		X	X	X		X	X	X
Mud	X		X		X	X	X		X	X	X
Organic			X		X	X			X	X	X
Aquatic Bed											
Algal	X	X	X	X	X	X	X		X	X	X
Aquatic Moss					X	X	X		X	X	X
Rooted Vascular	X	X	X	X	X	X	X		X	X	X
Floating Vascular			X	X	X	X	X		X	X	X
Reef											
Coral	X	X									
Mollusk			X	X							
Worm	X	X	X	X							
Streambed											
Bedrock				X	X			X			
Rubble				X	X			X			
Cobble-Gravel				X	X			X			
Sand				X	X			X			
Mud				X	X			X			
Organic				X	X			X			
Vegetated								X			
Rocky Shore											
Bedrock		X		X	X	X	X			X	
Rubble		X		X	X	X	X			X	
Unconsolidated Shore											
Cobble-Gravel		X		X	X	X	X			X	X
Sand		X		X	X	X	X			X	X
Mud		X		X	X	X	X			X	X
Organic		X		X	X	X	X			X	X
Vegetated					X	X	X			X	X
Moss-Lichen Wetland											
Moss											X
Lichen											X
Emergent Wetland											
Persistent				X							X
Nonpersistent				X	X	X	X			X	X
Scrub-Shrub Wetland											
Broad-leaved Deciduous				X							X
Needle-leaved Deciduous				X							X
Broad-leaved Evergreen				X							X
Needle-leaved Evergreen				X							X
Dead				X							X
Forested Wetland											
Broad-leaved Deciduous				X							X
Needle-leaved Deciduous				X							X
Broad-leaved Evergreen				X							X
Needle-leaved Evergreen				X							X
Dead				X							X

[a]ST = Subtidal, IT = Intertidal, TI = Tidal, LP = Lower Perennial, UP = Upper Perennial, IN = Intermittent, LM = Limnetic, LT = Littoral.

Appendix 3.2

Key for defining habitat systems and classes, using the U.S. Department of the Interior's 'Classification of Wetlands & Deepwater Habitats of the United States', (Cowardin *et al.* 1979).

Artificial Keys to the Systems and Classes

Key to the Systems

1. Water regime influenced by oceanic tides, and salinity due to ocean-derived salts 0.5% or greater.

    2. Semi-enclosed by land, but with open, partly obstructed or sporadic access to the ocean. Halinity wide-ranging because of evaporation or mixing of seawater with runoff from land . . . . ESTUARINE

    2. Little or no obstruction to open ocean present. Halinity usually euhaline; little mixing of water with runoff from land 3

        3. Emergents, trees, or shrubs present . . . . ESTUARINE

        3. Emergents, trees, or shrubs absent . . . . .MARINE

1. Water regime not influenced by ocean tides, or if influenced by oceanic tides, salinity less than 0.5%

    4. Persistent emergents, trees, shrubs, or emergent mosses cover 30% or more of the area . . . . PALUSTRINE

    4. Persistent emergents, trees, shrubs, or emergent mosses cover less than 30% of substrate but nonpersistent emergents may be widespread during some seasons of year 5

        5. Situated in a channel; water, when present, usually flowing . . . . RIVERINE

        5. Situated in a basin, catchment, or on level or sloping ground; water usually not flowing 6

            6. Area 8 ha (20 acres) or greater . . . . LACUSTRINE

            6. Area less than 8 ha. 7

                7. Wave-formed or bedrock shoreline feature present or water depth 2 m (6.6 feet) or more . . . . LACUSTRINE

                7. No wave-formed or bedrock shoreline feature present and water less than 2 m deep . . . . PALUSTRINE

Key to the Classes

1. During the growing season of most years, areal cover by vegetation is less than 30%.

2. Substrate a ridge or mound formed by colonization of sedentary invertebrates (corals, oysters, tube worms). . . . . .REEF

2. Substrate of rock or various-sized sediments often occupied by invertebrates but not formed by colonization of sedentary invertebrates 3

3. Water regime subtidal, permanently flooded, intermittently exposed, or semipermanently flooded. Substrate usually not soil. 4

4. Substrate of bedrock, boulders, or stones occurring singly or in combination covers 75% or more of the area . . . . ROCK BOTTOM

4. Substrate of organic material, mud, sand, gravel, or cobbles with less than 75% areal cover of stones, boulders, or bedrock . . . . UNCONSOLIDATED BOTTOM

3. Water regime irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded, intermittently flooded, saturated, or artificially flooded. Substrate often a soil 5

5. Contained within a channel that does not have permanent flowing water (i.e., Intermittent Subsystem of Riverine System or Intertidal Subsystem of Estuarine System) . . . . STREAMBED

5. Contained in a channel with perennial water or not contained in a channel 6

6. Substrate of bedrock, boulders, or stones occurring singly or in combination covers 75% or more of the area . . . . ROCKY SHORE

6. Substrate of organic material, mud, sand, gravel, or cobbles; with less than 75% of the cover consisting of stones, boulders, or bedrock . . . . UNCONSOLIDATED SHORE

1. During the growing season of most years, percentage of area covered by vegetation 30% or greater.

7. Vegetation composed of pioneering annuals or seedling perennials, often not hydrophytes, occurring only at time of substrate exposure 8

8. Contained within a channel that does not have permanent flowing water . . . . STREAMBED (VEGETATED)

8. Contained within a channel with permanent water, or not contained in a channel . . . . UNCONSOLIDATED SHORE (VEGETATED)

7. Vegetation composed of algae, bryophytes, lichens, or vascular plants that are usually hydrophytic perennials 9

9. Vegetation composed predominantly of nonvascular species 10
10. Vegetation macrophytic algae, mosses, or lichens growing in water or the splash zone of shores . . . . .AQUATIC BED
10. Vegetation mosses or lichens usually growing on organic soils and always outside the splash zone of shores .MOSS-LICHEN WETLAND
9. Vegetation composed predominantly of vascular species 11
11. Vegetation herbaceous 12
12. Vegetation emergents .EMERGENT WETLAND
12. Vegetation submergent, floating-leaved, or floating . . AQUATIC BED
11. Vegetation trees or shrubs 13
13. Dominants less than 6 m (20 feet) tall. . . . SCRUB-SHRUB WETLAND
13. Dominants 6 m tall or taller . . . . .FORESTED WETLAND

Appendix 4.1

The results of a macrophyte survey of Cardiff Bays' saltmarshes, undertaken by P.F. Randerson in 1979 (Smith, 1979).

Description of the Area:

Zone A – *Puccinellia* dominant, *Aster, Triglochin, Atriplex, Spergularia media, Glaux*, and *Plantago maritima* common, *Limonium vulgare* is present. The zone represents the species rich upper-marsh. The general surface is flat, of firm mud and fully covered by plants. It slopes gradually seawards and is not grazed.

Zone B – *Spartina, Atriplex, Cochlearia, Suaeda*, and *Aster* co-dominant, some *Puccinellia*, Ground flat, of fairly firm mud, well covered by plants, merges with Zones A and C. Not Grazed.

Zone C – *Spartina* dominant, *Suaeda* present, *Salicornia* occasional at the seaward edge. Ground surface of soft mud at the landward edge, becoming softer and wetter seawards. This zone slopes gently seawards , ending as a mud cliff or more often, scattered clumps of *Spartina*, at the seaward edge.

Zone D – *Triglochin* dominant, also *Puccinellia* and the species of Zone A are found here. Ground flat, firm mud, fully covered by plants, sloping gently seawards.

Zone E – *Festuca* dominant, 1-5m wide zone, landward border of true marsh. Ground firm, higher than Zone A, sloping toward Zone A.

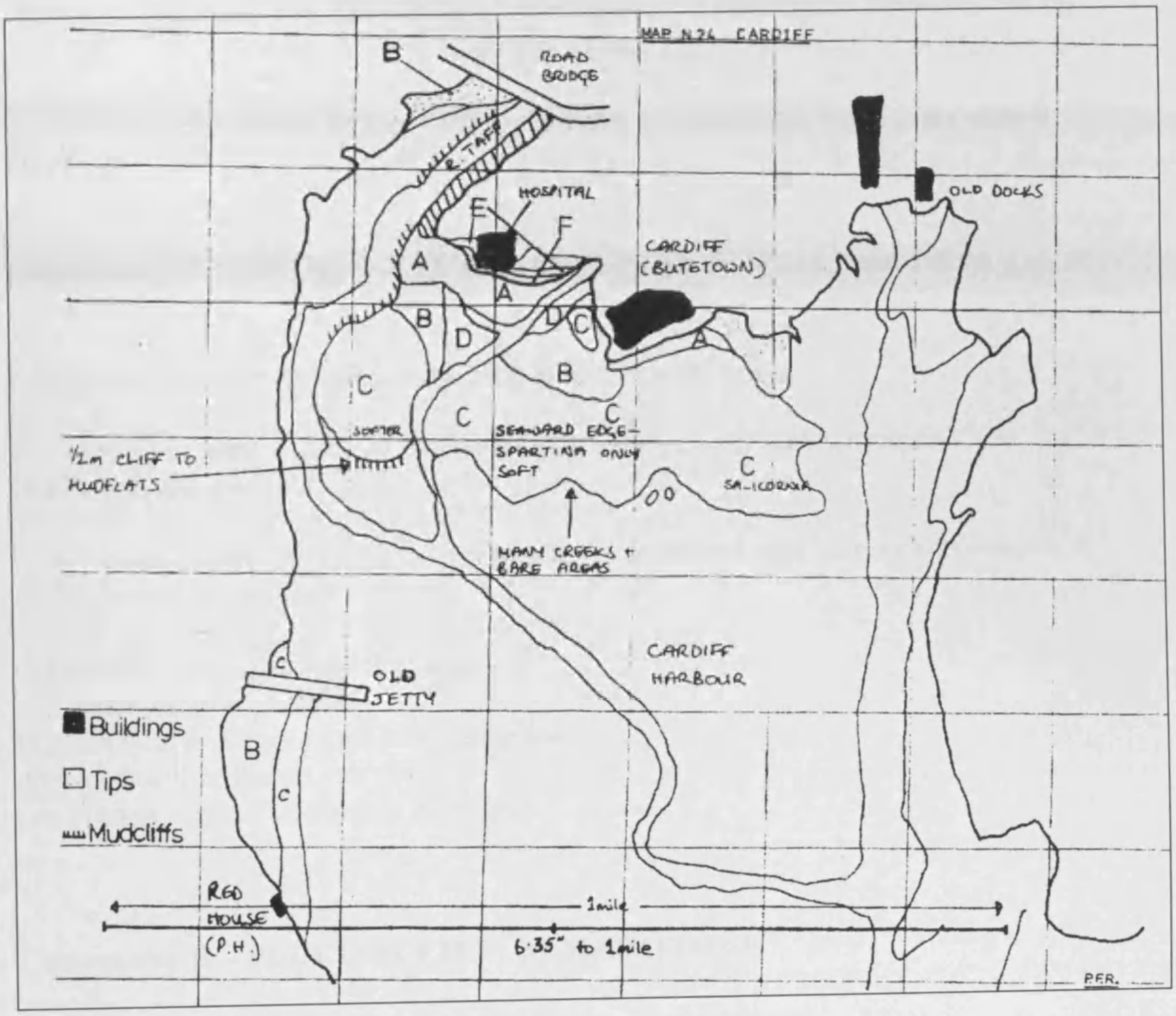
Zone F – *Juncus gerardii* forming a 1m wide zone at the landward edge of Zone A, forms the transition to Zone E, and is approx. at the tidal limit of the marsh.

Summary: At Cardiff Harbour:-

Zones A, D, E, F – 38,000m^2 – *Puccinellia, Triglochin, Festuca, Juncus*
Zones B, C – 256,399m^2 – *Spartina*

Informational Source: The area was surveyed by Dr P F Randerson.
Aster
Atriplex
Cochlearia
Festuca
Glaux
Juncus gerardii
Limonium vulgare
Plantago Maritima
Puccinellia
Salicornia
Spartina
Spergularia
Suaeda
Triglochin

Map of above Saltmarsh Communities (from Smith, 1979)



Appendix 4.2

Plant communities identified at Windsor Esplanade Saltmarsh by Kalejta (1984)

The Plant Communities of the Taff/Ely Saltmarsh (only sites 1 and 2 are shown here):

Community A – SPARTINETUM MARITIMAE (Emb. Et Regn.1926; Corillion,1953)

Dominant Species = Small Cord Grass *Spartina maritima*

Covered an extensive area of the entire saltmarsh, along with Common Cord Grass *Spartina anglica.*

- Associated species with community A at Sites 1 and 2 (wetlands reserve & Parc hamadryad):

Common Cord Grass *Spartina anglica*
Sea Aster *Aster tripolium*
English Scurvy Grass *Cochlearia anglica*
Annual Seablite *Sueda maritima*
Sea Manna Grass *Puccinellia maritima*

Community B – PUCCINELLIETUM MARITIMAE

Dominant Species = Sea Manna Grass *Puccinellia maritima*

- Associated species at Site 1 (wetlands reserve):

Sea Arrow Grass *Triglochin maritima*
Sea Lavender *Limonium vulgare*
Sea Plantain *Plantago maritima*
Spear Leaved Orache *Atriplex hastata*
Greater Sea Spurrey *Spergularia media*

- Associated species at Site 2 (hamadryad):

Sea Arrow Grass *Triglochin maritima*
Sea Aster *Aster tripolium*
English Scurvy Grass *Cochlearia anglica*
Sea Plantain *Plantago maritima*
Greater Sea Spurrey *Spergularia media*
Sea Milkwort *Glaux maritima*
Spear Leaved Orache *Atriplex hastata*
Sea Lavender *Limonium vulgare*

Community C – FESTUCETUM RUBRAE (Hepburn, 1952)

Dominant Species = Red Fescue *Festuca rubra*

- Associated species at Site 1 (wetlands reserve):

Lacks community but Festuca rubra is found locally on upper level of saltmarsh

- Associated species at Site 2 (hamadryad):

Brackish Mud-Rush *Juncus gerardii*
Creeping Bent *Agrostis stolonifera*
Common Couch *Elytrigia repens*

Community D

No formal classification, only present on Site 1.

- Associated species at Site 1 (wetlands reserve):

Sea Manna Grass *Puccinellia maritima*
Spear Leaved Orache *Atriplex hastata*
Annual Seablite *Sueda maritima*
Greater Sea Spurrey *Spergularia media*
English Scurvy Grass *Cochlearia anglica*
Sea Plantain *Plantago maritima*
Sea Milkwort *Glaux maritima*
Sea Aster *Aster tripolium*
Glasswort *Salicornia spp*
Common Cord Grass *Spartina anglica*

Community E – JUNCETUM GERARDII (Hepburn, 1952)

Dominant Species = Brackish Mud-Rush *Juncus gerardii*

- Associated species at Site 1 (wetlands reserve):

No community present except for in small stands

- Associated species at Site 2 (hamadryad):

Long-bracted Sedge *Carex extensa*
Sea Milkwort *Glaux maritima*

Community G – AGROPYRETUM PUNGENTIS

Dominant Species = Sea Couch *Elytrigia atherica* (*Agropyron pungens)*

- Associated species at Site 1 (wetlands reserve):

Found in dense strands along the sea wall.

Bermuda Grass *Cynodon dactylon*
Long-bracted Sedge *Carex extensa*
Buckshorn Plantain *Plantago coronopus*
Sea Mayweed *Matricaria maritima (Tripleurospermum maritimum)*
Rasberry *Rubus idaeus*
Mugwort *Artemisia vulgaris*
Dandelions *Taraxacum sp*

Common Reed *Phragmites australis* invades community in a small patch

- Associated species at Site 2 (hamadryad):

Red Fescue *Festuca rubra*
Creeping Bent *Agrostis stolonifera*

Stands of Broad Leaved-Pepperwort *Lepidium latifolium* are also present

Community H - No official name.

Present in the uppermost levels of Sites 1 and 2.

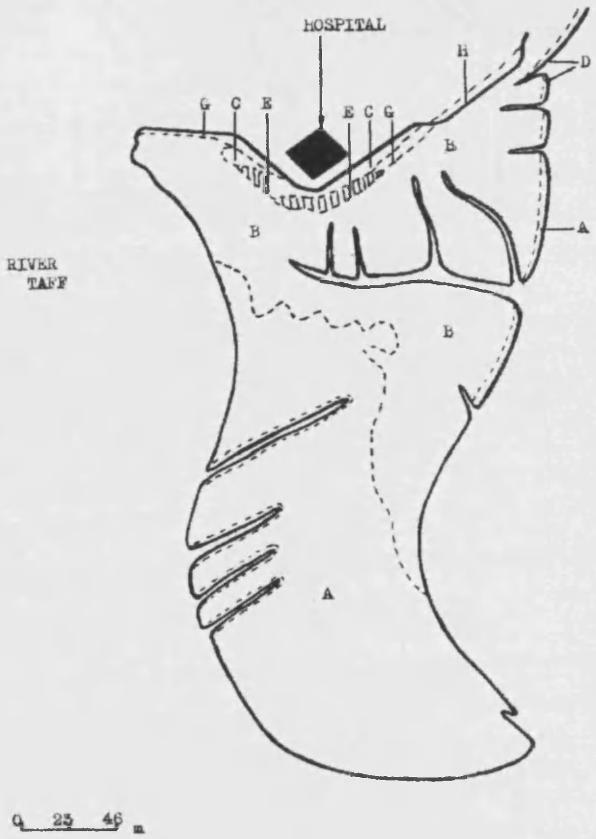
Creeping Bent *Agrostis stolonifera*
Sea Couch *Elytrigia atherica*
Spear Leaved Orache *Atriplex hastata*
Greater Sea Spurrey *Spergularia media*
Sea Plantain *Plantago maritima*
Mugwort *Artemisia vulgaris*
Sea Mayweed *Matricaria maritima (Tripleurospermum maritimum)*
Red Fescue *Festuca rubra*
Broad Leaved-Pepperwort *Lepidium latifolium (Dittander)*

Area Species List:

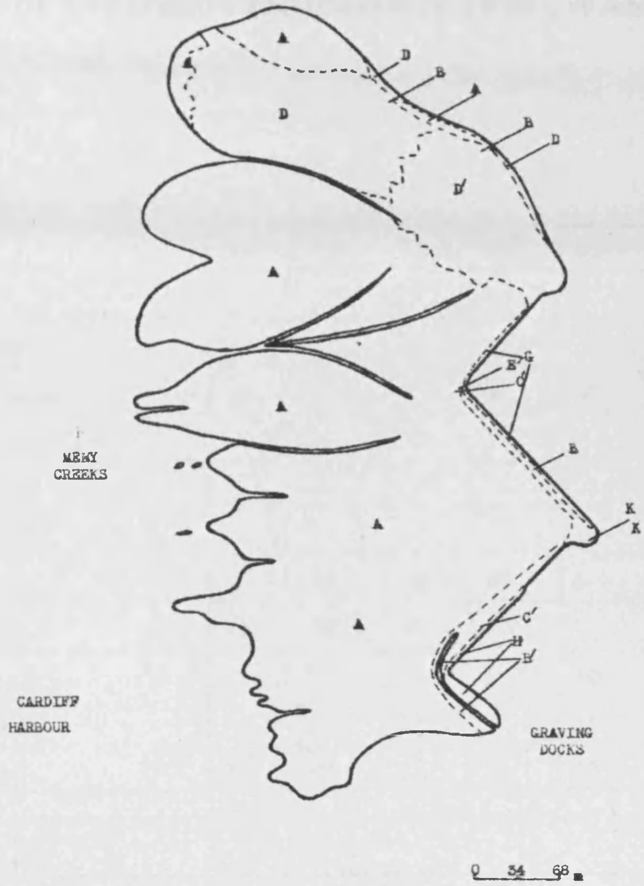
1. Annual Seablite *Sueda maritima*
2. Bermuda Grass *Cynodon dactylon*
3. Brackish Mud-Rush *Juncus gerardii*
4. Buckshorn Plantain *Plantago coronopus*
5. Common Cord Grass *Spartina anglica*
6. Common Couch *Elytrigia repens*
7. Common Reed *Phragmites australis*
8. Creeping Bent *Agrostis stolonifera*
9. Dandelions *Taraxacum sp*

10. English Scurvy Grass *Cochlearia anglica*
11. Glasswort *Salicornia spp*
12. Greater Sea Spurrey *Spergularia media*
13. Long-bracted Sedge *Carex extensa*
14. Mugwort *Artemisia vulgaris*
15. Rasberry *Rubus idaeus*
16. Red Fescue *Festuca rubra*
17. Sea Arrow Grass *Triglochin maritima*
18. Sea Aster *Aster tripolium*
19. Sea Couch *Elytrigia atherica*
20. Sea Lavender *Limonium vulgare*
21. Sea Manna Grass *Puccinellia maritima*
22. Sea Mayweed *Matricaria maritima (Tripleurospermum maritimum)*
23. Sea Milkwort *Glaux maritima*
24. Sea Plantain *Plantago maritima*
25. Small Cord Grass *Spartina maritima*
26. Spear Leaved Orache *Atriplex hastate*

Associated map of the Hamadryad Park area of the saltmarsh



Associated map of the Windsor Esplanade area of the saltmarsh



Appendix 4.3

The results of a series of quadrat surveys undertaken on the Windsor Esplanade saltmarsh in 1998 (WAS, 1999).

APPENDIX 2.

Quadrat Data

Edge	T1	T2	T3	T4	T5	T6	T7	T8
Grasses								
Puccinellia maritima			35					
Spartina x townsendii	10	5	5	6	30	15	10	2
Other monocotyledons								
Plantago maritima						2		
Dicotyledons								
Aster tripolium	30	40	18	65	5	50	25	60
Cochlearia anglica	40	20	40	2			5	
Salicornia sp.					10			
Suaeda maritima			2		15			
Bare ground	25	40	6	25	50	50	65	40

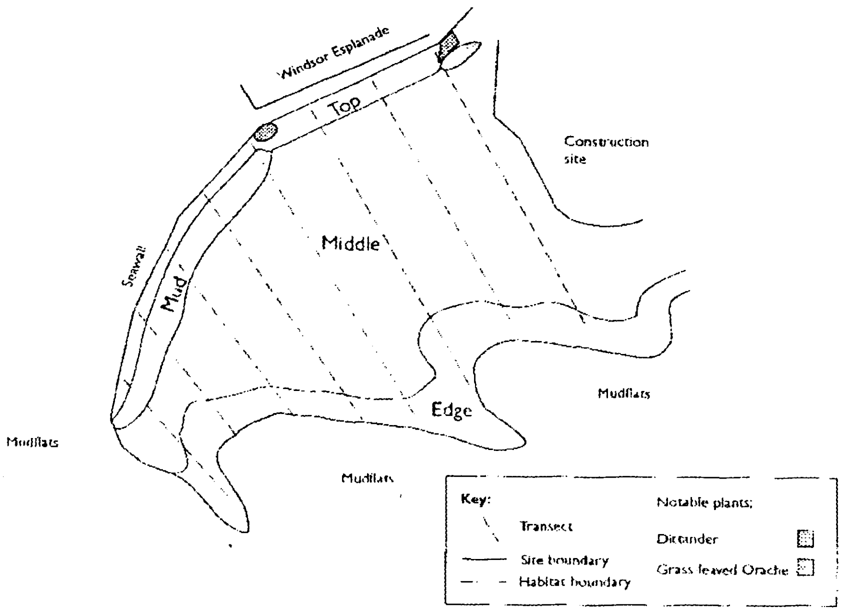
Middle	T1	T2	T3	T4	T5	T6	T7	T8
Grasses								
Puccinellia maritima		5						
Spartina x townsendii	45	100	40	80	40	25	70	55
Other monocotyledons								
Plantago maritima	15		6	5				
Triglochin maritimum				5				
Dicotyledons								
Aster tripolium			15	15	5	20		1
Cochlearia anglica	40		15		30	10	20	
Salicornia sp.						5		
Suaeda maritima	1		10		5	15		
Bare ground	20	0	15	0	30	20	35	75

Mud	T5	T6	T7	T8
Grasses				
Puccinellia maritima	1			
Other monocotyledons				
Plantago maritima	12	15		
Dicotyledons				
Aster tripolium	30	3	25	
Atriplex prostrata	2	15	20	
Cochlearia anglica	?	3	10	
Salicornia sp.	1	2	10	20
Spergularia media	2	10		
Suaeda maritima		1	30	10
Bare ground	60	60	20	80

Top	T1	T2	T3	T4	T5	T6	T7	T8
Grasses								
Agropyron pungens	10	100	85	45	20	15	10	2
Other monocotyledons								
Plantago maritima					10	10		5
Triglochin maritimum		1						
Dicotyledons								
Aster tripolium		1	10	15	10	10		2
Atriplex prostrata	1			1	1			
Beta vulgaris ssp. *maritima*						2		
Salicornia sp.					1			
Suaeda maritima					1			
Bare ground	90	0	5	50	65	65	90	95

Map of vegetation communities recorded during the WAS survey in 1998:

Figure 3. Map of vegetation communities



The **edge community** is along the boundary of the saltmarsh with the mudflats of Cardiff Bay. In

Appendix 4.4

Species recorded during Cardiff Naturalist Societies Survey of the Windsor Esplanade Saltmarsh Area in June and July of 2001 (Cardiff Naturalists Society, 2001).

N.B. Highlighted species indicate halophytic species

Genus/Species	Common Name
Acer pseudoplatanus	Sycamore
Alisma plantago-aquatica	Common Water-plantain
Alnus glutinosa	Alder
Alopecurus geniculatus	Marsh Foxtail
Angelica sylvestris	Wild Angelica
Antirrhinum majus	Snapdragon
Artemisia vulgaris	Mugwort
Aster tripolium	Sea Aster
Atriplex hastata	Hastate Orache
Atriplex littoralis	Grass-leaved Orache
Atriplex patula	Common Orache
Beta vulgaris subsp. maritima	Sea Beet
Buddleja davidii	Buddleja
Calystegia sepium	Hedge Bindweed
Campanula sp	Bellflower [undet] (escape)
Carex extensa	Long-bracted Sedge
Centaurea nigra	Common Knapweed
Cirsium arvense	Creeping Thistle
Cirsium vulgare	Spear Thistle
Cochlearia anglica	English Scurvygrass
Convolvulus arvensis	Field Bindweed
Crepis capillaris	Smooth Hawk's-beard
Cymbalaria muralis	Ivy Leaved Toadflax
Cyrtisus scoparius	Broom
Dactylis glomerata	Cock's-foot
Daucus carota	Wild Carrot
Elymus repens	Common Couch
Elytrigia atherica	Sea Couch
Endymion nonscriptus	Bluebell
Epilobium hirsutum	Great Willowherb
Fallopia japonica	Japanese Knotweed
Festuca rubra	Red Fescue
Filipendula ulmaria	Meadowsweet
Fraxinus excelsior	Ash
Galium aparine	Cleavers
Galium saxatile	Heath Bedstraw
Geranium robertianum	Herb Robert
Heracleum sphondylium	Hogweed
Holcus lanatus	Yorkshire Fog
Hypericum perforatum	Perforate St Johns Wort
Impatiens glandulifera	Hymalayan Balsam
Iris xiphium	Spanish Iris
Lactuca serriola	Prickly Lettuce
Lemna minor	Common Duckweed

Lepidium latifolium	Dittander
Linaria purpurea	Purple Toadflax
Lotus corniculatus	Birdsfoot Trefoil
Lycopus europaeus	Gipsywort
Melilotus sp	Meliot [undet]
Oenanthe crocata	Hemlock Water-dropwort
Parapholis strigosa	Hard Grass
Pastinaca sativa	Wild Parsnip
Persicaria amphibia	Amphibious Bistort
Persicaria hydropiper	Water Pepper
Phragmites australis	Common Reed
Picris echioides	Bristly Ox-tongue
Plantago coronopus	Buck's-horn Plantain
Plantago lanceolata	Ribwort Plantain
Plantago major	Greater Plantain
Plantago maritima	Sea Plantain
Poa trivialis	Rough Meadow Grass
Puccinellia distans	Reflexed Saltmarsh-grass
Puccinellia maritima	Common Saltmarsh-grass
Puccinellia rupestris	Stiff Saltmarsh Grass
Ranunculus acris	Meadow Buttercup
Ranunculus sceleratus	Celery Leaved Buttercup
Raphanus raphanistrum subsp. maritimus	Sea Radish
Reseda lutea	Wild Mignonette
Rosa sp	Rose (undet)
Rubus fruticosus agg.	Bramble
Rumex obtusifolius	Broad Leaved Dock
Salicornia sp	Glasswort [undet]
Secale cereale	Rye
Securigera varia	Crown Vetch
Senecio squalidus	Oxford Ragwort
Senecio vulgaris	Groundsel
Sonchus arvensis	Perennial Sow-thistle
Spartina anglica	Common Cord-grass
Spergularia sp	Sea Spurrey [undet]
Stellaria media	Common Chickweed
Suaeda maritima	Annual Seablite
Tagetes patula	French Marigold
Trifolium campestre	Hop Trefoil
Trifolium dubium	Lesser Trefoil
Trifolium pratense	Red Clover
Trifolium repens	White Clover
Triglochin maritima	Sea Arrowgrass
Tripleurospermum maritimum	Sea Mayweed
Tussilago farfara	Coltsfoot
Urtica dioica	Stinging Nettle
Vulpia myuros	Rat`s Tail Fescue

Appendix 5.1

Table of Revised BMWP Scores from Walley & Hawkes (1996 & 1997).

Common Name	Family	Original Score	Revised Score	Habitat Specific Scores		
				Riffles	Riffle/Pools	Pools
Flatworms	Planariidae	5	4.2	4.5	4.1	3.7
	Dendrocoelidae	5	3.1	2.3	4.1	3.1
Snails	Neritidae	6	7.5	6.7	8.1	9.3
	Viviparidae	6	6.3	2.1	4.7	7.1
	Valvatidae	3	2.8	2.5	2.5	3.2
	Hydrobiidae	3	3.9	4.1	3.9	3.7
	Lymnaeidae	3	3	3.2	3.1	2.8
	Physidae	3	1.8	0.9	1.5	2.8
	Planorbidae	3	2.9	2.6	2.9	3.1
Limpets and Mussels	Ancylidae	6	5.6	5.5	5.5	6.2
	Unionidae	6	5.2	4.7	4.8	5.5
	Sphaeriidae	3	3.6	3.7	3.7	3.4
Worms	Oligochaeta	1	3.5	3.9	3.2	2.5
Leeches	Piscicolidae	4	5	4.5	5.4	5.2
	Glossiphoniidae	3	3.1	3	3.3	2.9
	Hirudididae	3	0	0.3	-0.3	
	Erpobdellidae	3	2.8	2.8	2.8	2.6
Crustaceans	Asellidae	3	2.1	1.5	2.4	2.7
	Corophiidae	6	6.1	5.4	5.1	6.5
	Gammaridae	6	4.5	4.7	4.3	4.3
	Astacidae	8	9	8.8	9	11.2
Mayflies	Siphlonuridae	10	11	11		
	Baetidae	4	5.3	5.5	4.8	5.1
	Heptageniidae	10	9.8	9.7	10.7	13
	Leptophlebiidae	10	8.9	8.7	8.9	9.9
	Ephemerellidae	10	7.7	7.6	8.1	9.3
	Potamanthidae	10	7.6	7.6		
	Ephemeridae	10	9.3	9	9.2	11
	Caenidae	7	7.1	7.2	7.3	6.4
Stoneflies	Taeniopterygidae	10	10.8	10.7	12.1	
	Nemouridae	7	9.1	9.2	8.5	8.8
	Leuctridae	10	9.9	9.8	10.4	11.2
	Capniidae	10	10	10.1		
	Perlodidae	10	10.7	10.8	10.7	10.9
	Perlidae	10	12.5	12.5	12.2	
	Chloroperlidae	10	12.4	12.5	12.1	
Damselflies	Platycnemidae	6	5.1	3.6	5.4	5.7
	Coenagriidae	6	3.5	2.6	3.3	3.8
	Lestidae	8	5.4			5.4
	Calopterygidae	8	6.4	6	6.1	7.6
Dragonflies	Gomphidae	8				
	Cordulegasteridae	8	8.6	9.5	6.5	7.6
	Aeshnidae	8	6.1	7	6.9	5.7
	Corduliidae	8				
	Libellulidae	8	5			5
Bugs	Mesoveliidae *	5	4.7	4.9	4	5.1
	Hydrometridae	5	5.3	5	6.2	4.9

Common Name	Family	Original Score	Revised Score	Habitat Specific Scores		
				Riffles	Riffle/Pools	Pools
	Gerridae	5	4.7	4.5	5	4.7
	Nepidae	5	4.3	4.1	4.2	4.5
	Naucoridae	5	4.3			4.3
	Aphelocheiridae	10	8.9	8.4	9.5	11.7
	Notonectidae	5	3.8	1.8	3.4	4.4
	Pleidae	5	3.9			3.9
	Corixidae	5	3.7	3.6	3.5	3.9
Beetles	Haliplidae	5	4	3.7	4.2	4.3
	Hygrobiidae	5	2.6	5.6	-0.8	2.6
	Dytiscidae	5	4.8	5.2	4.3	4.2
	Gyrinidae	5	7.8	8.1	7.4	6.8
	Hydrophilidae	5	5.1	5.5	4.5	3.9
	Clambidae	5				
	Scirtidae	5	6.5	6.9	6.2	5.8
	Dryopidae	5	6.5	6.5		
	Elmidae	5	6.4	6.5	6.1	6.5
	Chrysomelidae *	5	4.2	4.9	1.1	4.1
	Curculionidae *	5	4	4.7	3.1	2.9
Alderflies	Sialidae	4	4.5	4.7	4.7	4.3
Caddisflies	Rhyacophilidae	7	8.3	8.2	8.6	9.6
	Philopotamidae	8	10.6	10.7	9.8	
	Polycentropidae	7	8.6	8.6	8.4	8.7
	Psychomyiidae	8	6.9	6.4	7.4	8
	Hydropsychidae	5	6.6	6.6	6.5	7.2
	Hydroptilidae	6	6.7	6.7	6.8	6.5
	Phryganeidae	10	7	6.6	5.4	8
	Limnephilidae	7	6.9	7.1	6.5	6.6
	Molannidae	10	8.9	7.8	8.1	10
	Beraeidae	10	9	8.3	7.8	10
	Odontoceridae	10	10.9	10.8	11.4	11.7
	Leptoceridae	10	7.8	7.8	7.7	8.1
	Goeridae	10	9.9	9.8	9.6	12.4
	Lepidostomatidae	10	10.4	10.3	10.7	11.6
	Brachycentridae	10	9.4	9.3	9.7	11
	Sericostomatidae	10	9.2	9.1	9.3	10.3
True flies	Tipulidae	5	5.5	5.6	5	5.1
	Chironomidae	2	3.7	4.1	3.4	2.8
	Simuliidae	5	5.8	5.9	5.1	5.5

Notes:

- * These families are now excluded from the list used for the calculation of the score.
- A blank indicates that there were insufficient records for the calculations.
- The Revised BMWP Scores are based on the analysis of frequency of occurrence of the families recorded in approximately 17,000 samples.
- The Habitat Specific Scores are based on the following substrate compositions:

Riffles: >= 70% boulders and pebbles Pool: >= 70% sand and silt Riffle/Pool: the remainder

Appendix 6.1

Winter Marsh Transect Record Sheet

Date:				Time:			
Transect 1	**Hab.**	**Transect 2**	**Hab.**	**Transect 3**	**Hab.**	**Transect 4**	**Hab.**

Habitats Key:
RB = Reed Bed; **RS** = Reservoir; **RD** = Reens & Ditches; **SS** = Shallow Scrapes; **I** = Raised Areas & Islands, **AW** = Alder & Willow Carr; **GR** = Gravel; **F** = Reserve Front; **OW** = Open Water/Bund; **THF** = Tall-herb Fen & Grassland.

Appendix 6.2

Breeding Bird Record Sheet

Date:							
Time:							
Map No.	**Species**	**Individuals**	**Pairs**	**Nests**	**Eggs**	**Young**	**Notes**
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							

Appendix 7.1

Small mammals of the Cardiff Bay Wetland Reserve

Introduction

Although there is an extensive North American literature on the small mammal populations of marine and freshwater wetlands (e.g. Shure 1970, 1971, Shanholtzer 1974, Kitchings & Levy 1981, Takegawa *et al.* 2003), these habitats have not often been surveyed in Great Britain. In fact, the only similar British study has been of sand dunes (Deshmukh & Cotton 1970).

One of the main hazards for small mammals in wetland areas is irregular and unpredictable flooding (freshwater marshes), or regular and predictable tidal inundation (saltmarshes). Most species seem to cope with such by remaining in air-filled burrows, or moving away from the flooded area and returning when the water recedes (Blair 1939, Ruffer 1961, Shure 1971, Andersen *et al.* 2000, Chamberlain & Leopold 2003, Jacob 2003). The Cardiff Bay wetland is typical of many freshwater marches in being subject to irregular and unpredictable flooding in this way when the barrage is closed and river levels are high.

Methods

The Cardiff Bay Wetland Reserve is an artificially modified area of shallow freshwater pools, ditches, reedbed, freshwater marsh and grassland (Fig. 1) created to enhance the wildlife interest of part of the Cardiff Bay freshwater lake formed by the construction of the Cardiff Bay barrage. The barrage impounded and inundated the formerly brackish estuaries of the rivers Taff and Ely. Final barrage closure occurred in late 1999 and the final stages of the construction of the wetland reserve were undertaken in 2004.

The reserve was constructed on the former Windsor Esplanade saltmarsh of the Taff Estuary, and some of the original saltmarsh surface of consolidated mud dissected by creeks still survives, albeit with the original *Spartina* vegetation replaced largely by Sea Couch *Elytrigia atherica*.

The reserve comprises an area of mowed short grassland and several public paths at its landward edge. This, together with a boardwalk that extends out into the Cardiff Bay lake at the eastern side of the marsh form the part of the reserve most intensively used by the public. Access to the rest of the reserve is discouraged by the presence of a water-filled ditch running roughly east-west along the middle of the marsh (Fig. 1). There are three separate pools in the marsh, one surrounded by reeds in the upper marsh and the other two in the lower marsh, including one planted with reeds, one shallow wader scrape, with a raised roosting island beside it. The lower part of the marsh comprises the remnant creeks of the old saltmarsh, colonised by rank grasses and alder carr, which lead down to part of the Cardiff Bay lake enclosed by a boom used to intercept floating debris. This part of the reserve is quite shallow because it has been built up below water level with stone to protect the marsh edge from erosion by wave action, and part of it has been planted with reeds for the same reason. Several of the old saltmarsh creeks lead to extensive water-filled inlets (Fig. 1).

For the purposes of this survey, the terrestrial portion of the marsh was divided up into nine broad habitat categories (Table 1). Rough grassland dominated by *Elytrigia atherica* was the main vegetation type, occupying over half of the total area of the reserve at low-, mid- and high-marsh levels (Fig. 1). Mowed grass was the second most abundant vegetation type, occupying a strip alongside the mud track (not the public track) running through the middle of the marsh, and an area in the NW corner of the upper marsh. In the latter area, some seating has been provided and some exotic vegetation (including pampas grass and palms) planted.

Alder and willow carr naturally colonised the lower part of the marsh, and some of this (22%) had been cut back to stools a few inches in diameter earlier in 2005. Grass still occupied the majority of the ground amongst the alder carr, though in the densest parts there was a bare litter layer. No distinction was made between untouched and felled alder since the ground layer vegetation was similarly grassy throughout.

Water levels were relatively low at the time the small mammal survey was carried out, and about 7% of the vegetation comprised dry reedbed. A further 0.246 ha of wet reedbed was present, but this was not included in the estimates of terrestrial vegetation cover. Rosebay willowherb formed some small dense patches at the eastern end of the upper marsh and there were also patchess of brambles in this area.

Ongoing management of the reserve involves halting ecological succession to woodland by rotational cutting of the Willow and Alder carr that propagates itself (both vegetatively and from seed) in the lower marsh, and regular cutting of the grass in the upper marsh.

The small mammal population of the marsh was investigated by Longworth live-trapping carried out by P.N. Ferns and M.I. MacIntosh during the winter of 2005/6. Fifty Longworth traps were set in a series of trap lines in different habitats. They were set in pairs, each member of a pair being about a metre apart, and the distance between pairs being 10 m. Each trap line was consequently 25 m long. The traps were provided with bedding in the form of hay, food in the form of mixed seeds and blowfly pupae. They were baited with mixed seeds, and no prebaiting was employed. Each line was deployed for two trap nights to minimise the chances of theft and vandalism, and two lines were deployed simultaneously during three separate catching sessions (10-11 November 2005, 20-21 December 2005 and 18-19 January 2006). The trap lines were located at six different sites in the marsh (Fig. 1), two in the grassy alder carr, two in rough grassland and two in mixed grass and shrub habitats in the upper marsh. Animals were weighed upon initial capture and marked by fur clipping.

The total numbers of individual animals of each species caught in each of the trap lines were compared using chi-square, based on the expectation that the numbers should have been equal in all lines. Exact probabilities were computed using StatXact 4.0.1. An attempt was made to estimate the total small mammal population of the marsh by making some assumptions about the area from which the 25 m long trap line sampled the population. The average home range diameter of *M. agrestis* was assumed to 8 m, based on Godfrey's (1954) estimate of home range size of 198 m^2. A strip of this diameter was added to the ends and to either side of each trap line (ending at the edge of any water body if one was reached) and the area so enclosed (usually 2198 m^2) was used as an estimate of the area from which the traps sampled this species. Areas of similar density were pooled, and separate estimates made for the numbers in each. If a similar logic is applied to *A. sylvaticus*, in which the home range diameter is about 25 m, based on Crawley's (1969) average home range area for both sexes of 2034 m^2, this suggests that a single trap line is capable of sampling individuals from the whole reserve, and so the best population estimate is probably the enumerated total number of individuals actually caught.

The dorsal coloration of *Apodemus sylvaticus* was slightly atypical in that the rump appeared to be of the usual colour in the midline (above the vertebral column), but on either side it was rather pale, making all individuals appear more darkly striped than normal. The colour was therefore measured using a Minolta CR221 Chroma Meter which records wavelengths in the 400-700 nm region, and has a spectral response matching that of the CIE 1931 Standard Observer curves. The LCH° colour system was used, in which Lightness (L) is a measure of the total amount of light reflected, regardless of wavelength, Chroma (C) is the extent of saturation with the dominant wavelength, and Hue (H°) is the dominant wavelength expressed in cylindrical co-ordinates, such that 0° = red, 90° = yellow, and 180° = green.

Since the abnormal coloration was on either side of the midline on the rump, it was decided to measure the colour of the pelage in three different areas. Firstly, in the middle of the crown on the head where the colour was normal. Secondly, to one side of the rump, where it was paler than normal, and thirdly, in the middle of the belly, which also appeared normal. The middle of the rump could not be satisfactorily measured because the skin would not lay flat beneath the sensor because of the underlying vertebrae. Six measurements were made in each of these three regions of each individual mouse, moving it away from the sensor between each reading. The measuring area was a circle of 3 mm diameter, illuminated at 45°. The instrument was calibrated using a certified standard white plate (CRA45) prior to the measurement of every mouse. The repeatability of the means based on the measurements of two different observers was high ($F_{44,45}$ = 375.6, $P < 0.0005$, $R = 0.997$).

Since three colour parameters were measured, in three different areas of the body, a standard Bonferroni correction was applied when testing for differences between the Cardiff Bay and control samples, and only relationships for which $P < 0.05/9 = 0.006$ were considered significant.

Results

Seventy one small mammals were captured in a total of 300 trap-nights (Table 1). These comprised 54 *Microtus agrestis*, 16 *Apodemus sylvaticus* and 1 *Mus domesticus*. In addition to these trapped mammals, both rats *Rattus norvegicus* and domestic cats were seen regularly on the marsh. No bank voles *Clethrionomys glareolus* or shrews *Sorex* spp. were captured.

There was a significant difference in the numbers of *M. agrestis* caught in different parts of the marsh (Table 2) ($\chi^2 = 14.33$, d.f. = 5, $P = 0.013$). This was clearly due to the small numbers caught in the higher parts of the marsh (high marsh and west marsh), since when these two lines were removed, the difference was no longer significant ($\chi^2 = 1.17$, d.f. = 3, $P > 0.200$). There was no significant difference in the numbers of *A. sylvaticus* caught in different parts of the marsh ($\chi^2 = 5.78$, d.f. = 5, $P > 0.200$).

Lincoln Index population estimates were calculated when sufficient captures and recaptures were made (Table 3). This was the case with all the alder and rough grassland lines for *M. agrestis*, but only one high marsh line for *A. sylvaticus*. The average of the four former estimates (± SD) was 30 ± 15, which was more than twice the actual numbers of individual voles caught (12 ± 4).

Approximate population estimates for the whole marsh were thus calculated separately for alder and rough grassland combined (65% of the total area of the marsh) and for the rest (35%). Since each trap line sampled about 0.220 ha for *M. agrestis* (and caught on average 12 of them), the 3.629 ha of alder and rough grass, contained approximately 198. The 1.946 ha of other habitats yielded an average of three, and thus contained approximately 27. This gives a total population estimate, based on the number of individuals actually caught of 225. If the Lincoln Index estimates are used instead of the numbers caught, then a figure more than twice as great (522) is arrived at. For *A. sylvaticus*, the enumerated population is just 16 individuals.

Using a GLM ANOVA on the recorded weights (Table 4), male *M. agrestis* were significantly heavier than females ($F_{1,48} = 4.48$, $P = 0.040$), but there was no significant difference in weight on the three different trapping occasions ($F_{1,48} = 1.43$, $P > 0.200$). Although the sample size of *A. sylvaticus* was very small (Table 4), the weight increase recorded in both sexes in January approached statistical significance ($F_{1,10} = 3.84$, $P = 0.058$), but in this species there was no significant sexual difference ($F_{1,10} = 0.03$, $P > 0.200$).

There was no significant difference in colour between male and female *Apodemus sylvaticus* at either site ($P > 0.200$ in all cases), and so the sexes were combined in order to compare sites. The only differences that were significant after Bonferroni correction showed that the mice from Cardiff Bay had significantly lighter rumps (Table 5, ANOVA, $F_{1,11} = 42.77$, $P < 0.0005$) with significantly yellower (but still very brown) pigment ($F_{1,11} = 27.37$, $P < 0.0005$). The colour of this area was 26% lighter and the dominant wavelength was shifted 6° away from red towards yellow. The net result of these statistically significant changes was to produce a mouse with a back showing greater contrast between the dark midline and the paler sides, than is present in the more familiar wild type. The Rhiwsaeson individuals were similar in colour to skins of individuals in a reference collection from Leckwith, Sully Island and several other sites in Wales and elsewhere in the UK.

The crown pelage was also lighter and yellower in the mice from Cardiff Bay, but in neither case did the significance of the statistical tests survive Bonferroni correction (ANOVAs: lightness, $F_{1,11} = 6.23$, $P = 0.030$; hue, $F_{1,11} = 9.52$, $P = 0.010$). None of the differences in colour saturation (chroma) even approached significance, but this is not surprising given the very low figures involved, these being a consequence of the high absorption of light by the dull brown melanin of the pelage.

Discussion

The estimated population of about 500 *M. agrestis* in 3.6 ha of rough grassland and alder carr at the Cardiff Bay wetland reserve in the winter 0f 2005/06 represents a population density of about 140 individuals per hectare. This is quite a high figure for grasslands in southern Britain. For example, it is higher than the peak density (128/ha) in the rank grassland in a young larch plantation in Devon (Ferns 1979), and about three or four times as high as the density on Sully Island in the 1970s (Ferns 1981). The major difference between the two Welsh habitats is the presence of a large rabbit *Oryctolagus cuniculus* population on Sully Island. Rabbit grazing significantly reduces the rankness of grasses on the island, reducing the suitability of the habitat for *M. agrestis*.

The weights of both *M. agrestis* and *A. sylvaticus* in the months of November and January were very similar to those recorded in these same months on Sully Island in 1973 - 1976 (Ferns 1981). This is despite the very different densities at the two sites and suggests a considerable degree of homeostasis in the winter weights of these species even though there were considerable differences in habitat quality. As is the case with many bird species, there is probably a trade-off at this time of year between the need to carry adequate body reserves in case of periods of food shortage and the need to reduce weight in order to escape predators with maximum efficiency (Steinlechner *et al.* 1983, Haftorn 1989, Korsland & Steen 2006).

Unusual pelage colour variants occur quite frequently in both *Apodemus sylvaticus* and *Microtus agrestis* (Ferns 1980, 1981) and hairless mutants of the former have also been recorded (Montgomery & Montgomery 1985). Colour variants seem to be especially common in small populations, such as that of *Apodemus sylvaticus* on Sully Island, where generally dark and pale variants, and a single individual with patches of greyish-white fur on the shoulders, were recorded in the 1970s (Ferns 1981). What is unusual about the wetland reserve population is that all captured individuals of *Apodemus sylvaticus* were of uniformly atypical coloration.

Paradoxically, the Cardiff Bay *Apodemus* appeared melanic because the paler sides to the back and rump made the midline appear darker, though the actual colour of the pelage in the midline could not be measured. The pelage of the crown was not darker in the midline region. It would be very interesting to know if this back and rump coloration is typical of *Apodemus* in the docks area of Cardiff generally, or is just a feature of the wetland reserve. Further trapping will be carried out to determine how widespread this morph is in the area.

Grinnell (1913) was the first person to notice that tidal marsh vertebrates tended to have apparently darker dorsal coloration than normal, and when the phenomenon was reviewed by Greenberg & Droege (1990), they also recorded a trend towards greyer hues rather than darker coloration. This is completely in accordance with the present observation that the animals appeared melanistic (i.e. darker), but when the colour was actually measured, it turned out that this was due to the presence of lighter grey pelage on either side of the dark dorsal midline stripe. Grenier & Greenberg (2006) recently described 11 species of North American bird in which saltmarsh populations (species or subspecies) are greyer or blacker.

Saltmarsh melanism has been recorded in the following shrews, voles and harvest mice in North America - *Sorex cinereus*, *S. ornatus*, *S. vagrans*, *Microtus californicus*, *M. pennsylvanicus* and *Reithrodontomys megalotis* (Grenier & Greenberg 2006, and other sources cited therein), as well as in a saltmarsh snake (*Nerodia sipedon*) (Conant *et al.* 1998). Some saltmarsh populations of snakes also tend to have different types of coloration pattern Greenberg & Maldonada (2006).

While terrestrial soils often have a reddish component due to the presence of iron oxides, iron in estuarine substrata is often reduced anaerobically to form grey iron sulphides. The need for darker and/or greyer dorsal coloration in order to remain camouflaged when foraging on darker substrata has been suggested as the explanation for saltmarsh melanism (Von Bloeker 1932). The latter author noted that it was mainly diurnally active small mammals that showed such melanism, and in that respect our nocturnal marshland population of *Apodemus sylvaticus* is atypical.

Although high water levels did not occur during our trapping sessions because we specifically avoided the high spring tide period when such inundation can occur, animals were trapped within a few yards of the water's edge, and they clearly used this area for foraging. It was noted, however, that the edges of the raised banks forming the wader roosting area near the wader scrape were riddled with the burrows of *Microtus agrestis*. This area would have provided an ideal refuge for animals in the east of the reserve when they were forced inland by rising water levels. Such inundation would constitute only a minor problem for the small mammal populations of the wetland reserve since it is limited in extent and occurs slowly enough to allow plenty of time for individuals to move inland in this way.

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Table 1. Area of broad vegetation categories into which the marsh was divided for trapping purposes.

Vegetation type	Area (ha)	% cover
Rough grass	3.026	54.3
Mowed grass	1.084	19.4
Alder carr	0.603	10.8
Dry reedbed	0.389	7.0
Exotic species	0.179	3.2
Rosebay willowherb	0.113	2.0
Bare mud	0.077	1.4
Brambles	0.063	1.1
Hawthorn	0.041	0.7
Total	5.575	

Table 2. Summary of the numbers of new and retrapped small mammals caught in single lines of 50 Longworth traps in each habitat in the wetland reserve (♂=adult male, ♀=adult female, J= juvenile).

Habitat	Species	Date	New ♂	New ♀	New J	Retraps ♂	Retraps ♀	Retraps J
Alder, low-marsh	*Microtus agrestis*	10/11/05	5	5	0			
		11/11/05	1	1	0	1	0	0
	Apodemus sylvaticus	10/11/05	1	1	0			
		11/11/05	0	0	0	1	1	0
Alder, mid-marsh	*Microtus agrestis*	10/11/05	4	4	2			
		11/11/05	2	3	0	2	1	0
	Apodemus sylvaticus	10/11/05	3	1	0			
		11/11/05	0	0	0	2	1	0
Grass, mid-marsh	*Microtus agrestis*	20/12/05	3	3	0			
		21/12/05	2	2	0	1	0	0
	Apodemus sylvaticus	20/12/05	0	0	0			
		21/12/05	0	0	0	0	0	0
	Mus domesticus	20/12/05	0	0	0			
		21/12/05	0	0	1	0	0	0
Grass, ditch-side	*Microtus agrestis*	20/12/05	4	4	0			
		21/12/05	2	1	0	2	3	0
	Apodemus sylvaticus	20/12/05	1	1	0			
		21/12/05	0	0	0	1	0	0
Grass and shrub, high-marsh	*Microtus agrestis*	18/01/06	0	1	0			
		19/01/06	0	0	0	0	1	0
	Apodemus sylvaticus	18/01/06	1	3	0			
		19/01/06	1	0	0	0	2	0
Grass and shrub, west marsh edge	*Microtus agrestis*	18/01/06	1	2	0			
		19/01/06	1	1	0	1	2	0
	Apodemus sylvaticus	18/01/06	2	0	0			
		19/01/06	1	0	0	2	0	0

Table 3. Total number of individuals captured in each habitat (Lincoln Index estimates of population size in brackets).

Habitat	*M. agrestis*	*A. sylvaticus*	*M. domesticus*
Alder, low-marsh	12 (50)	2	0
Alder, mid-marsh	15 (28)	4	0
Rough grass, mid-marsh	10 (30)	0	1
Rough grass, ditch-side	11 (13)	2	0
Short grass and shrub, high-marsh	1	5 (8)	0
Short grass and shrub, west marsh edge	5	3	0
Total	54 (117)	16 (19)	1

Table 4. Mean weights (g) of individuals caught at different times of year ± standard deviation (sample size in brackets).

Species	Date	Age and sex	Weight
M. agrestis	10-11/11/05	Adult male	22.6 ± 5.9 (12)
		Adult female	20.9 ± 3.5 (13)
		Juvenile	20.1 (2)
	20-21/12/05	Adult male	21.5 ± 2.8 (11)
		Adult female	18.8 ± 2.7 (10)
	18-19/01/06	Adult male	21.4 (2)
		Adult female	17.8 ± 2.9 (4)
Apodemus sylvaticus	10-11/11/05	Adult male	14.1 ± 1.6 (4)
		Adult female	15.9 (2)
	20-21/12/05	Adult male	16.6 (1)
		Adult female	15.1 (1)
	18-19/01/06	Adult male	18.0 ± 2.9 (4)
		Adult female	18.0 ± 2.7 (3)
Mus domesticus	21/12/05	Juvenile	9.1 (1)

Table 5. Average coloration of individual *Apodemus sylvaticus* from the Cardiff Bay wetland reserve and a control sample from Rhiwsaeson, Rhondda Cynon Taff (± standard deviation, sample size in brackets). Asterisks indicate a statistically significant difference in colour between sites after Bonferroni correction.

Site	Part of body	Colour parameter	Colour score
Cardiff Bay	Crown	Lightness	31.1 ± 2.1 (8)
		Chroma	9.6 ± 1.0 (8)
		Hue	69.7 ± 1.2 (8)
	Rump	Lightness	32.6 ± 1.7 (8)*
		Chroma	9.0 ± 0.9 (8)
		Hue	71.8 ± 0.9 (8)*
	Belly	Lightness	70.3 ± 5.1 (8)
		Chroma	4.7 ± 1.6 (8)
		Hue	89.9 ± 2.1 (8)
Rhiwsaeson	Crown	Lightness	28.5 ± 1.3 (12)
		Chroma	9.6 ± 1.4 (12)
		Hue	67.6 ± 1.1 (12)
	Rump	Lightness	25.7 ± 2.1 (12)*
		Chroma	7.1 ± 1.0 (12)
		Hue	66.2 ± 2.9 (12)*
	Belly	Lightness	72.7 ± 3.2 (12)
		Chroma	5.4 ± 2.2 (12)
		Hue	91.9 ± 4.5 (12)

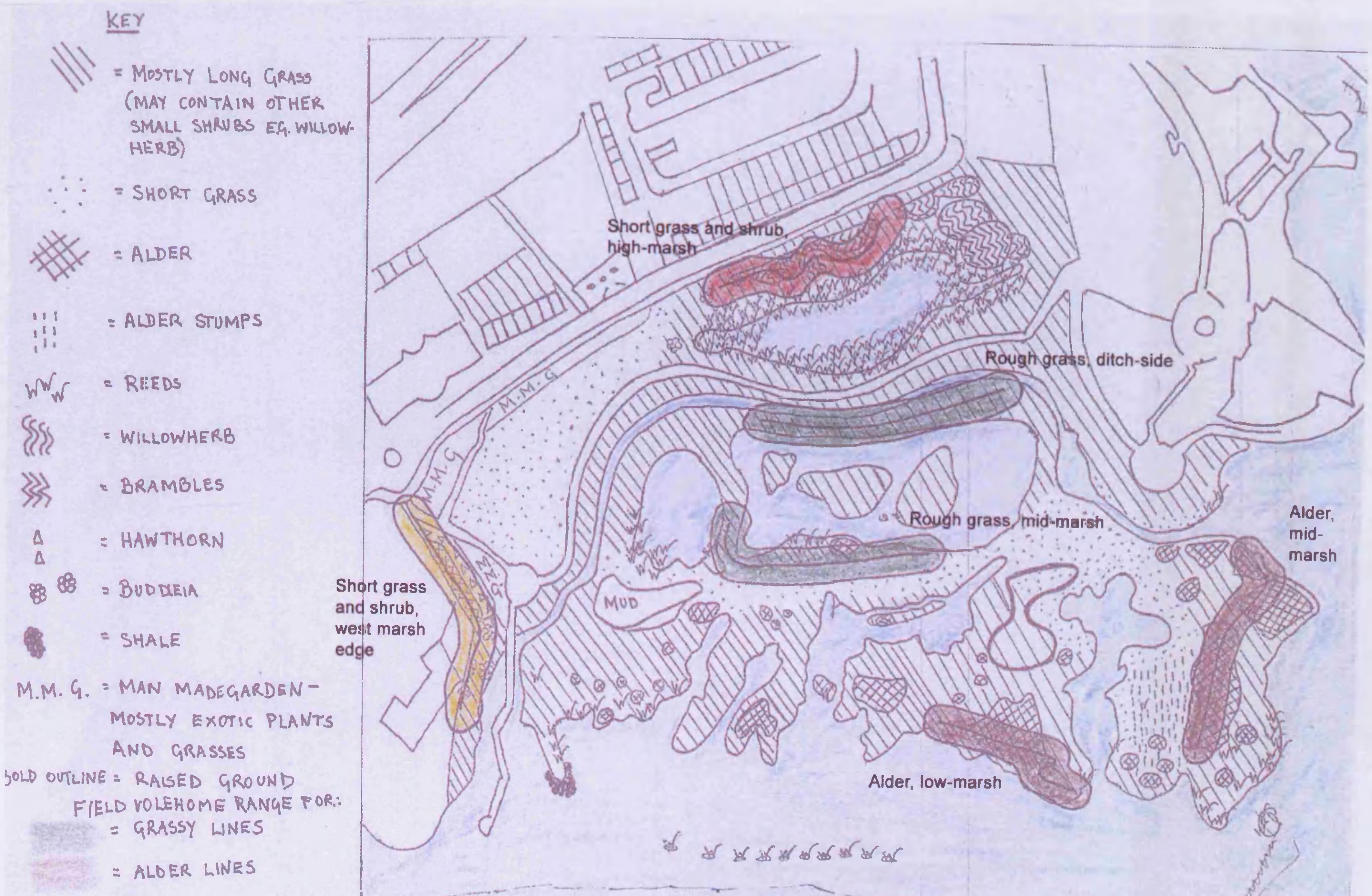

Fig. 1. Sketch map of the Cardiff Bay Wetland Reserve with position of trapping lines marked