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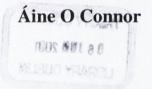
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The development of aquatic macroinvertebrate communities in two artificial wetlands on Irish cutaway bog, with particular reference to Corixidae (Hemiptera Heteroptera).

> A thesis submitted to the University of Dublin for the degree of Doctor of Philosophy



Department of Zoology University of Dublin Trinity College



#### **Candidate's Declaration**

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#### Summary

Two cutaway water bodies in mid-west County Offaly were studied. Turraun, created in 1990/1991, has an estimated area of 52-60 ha and an average depth of 0.5 to 1 m. The wetland sediment is predominantly peat with some shell marl and the macrophyte community is diverse and dense. Tumduff, created in 1995, has an area of c. 6 ha and an average depth of 1.5-2 m. Peat is the predominant pond sediment, with some blue silty clay and boulder clay and aquatic vegetation is sparse. The surface water levels fluctuated over time in both wetlands

Both ponds had above neutral pH, were coloured and had strong ground water influence. Conductivity, calcium concentration and alkalinity were highest in Tumduff indicating that the influence of ground water was greater at Tumduff than Turraun. Molybdate Reactive Phosphorus, total ammonia and nitrate concentrations were generally low. Nutrient analysis suggested that there was a pollution event at Turraun in July or August 1997. Analysis of total phosphorus and chlorophyll *a* in August 1999, suggested that Turraun was highly eutrophic to hypertrophic, and Tumduff was oligotrophic with high total phosphorus.

Macroinvertebrate taxon richness and diversity were greater at Turraun than Tumduff, with 108 aquatic macroinvertebrate taxa captured in Turraun and 71 in Tumduff between October 1996 and August 1999. Most lentic macroinvertebrate groups were represented in both wetlands. Heteropteran diversity was high, with 21 species in Turraun and 17 in Tumduff. Coleoptera were also reasonably diverse in Turraun with 38 species, while 16 were found in Tumduff. The macroinvertebrate communities included species typical of many different habitats and a number that have been previously recorded on exploited peatland. Most species identified are common in the British Isles, although, two notable coleopteran records were made, *Haliplus variegatus* Sturm, for which only one other record has been made since 1980, and *Gyrinus caspius* Ménétriés, which has a coastal distribution. 53 of the Turraun taxa and 36 Tumduff taxa occurred in less than 5% of samples and were considered rare in the wetlands.

Macroinvertebrate abundance was generally greater at Turraun than Tumduff, with an average catch per sample of 130 at Turraun and 85 at Tumduff between January 1997 and

February 1998 and a higher average monthly catch in all but two months. Corixidae followed by Mollusca and Trichoptera were the most abundant taxa in Turraun, while Diptera, followed by Trichoptera, Ephemeroptera and Corixidae dominated the Tumduff fauna. Temporal variations in abundance of some macroinvertebrate taxa suggested succession was occurring in the ponds.

Macroinvertebrate assemblage varied between sampling stations and between ponds and was influenced by habitat factors. Fine sediments supported high macroinvertebrate abundance. Structural diversity and density of macrophytes appeared to be major factors in macroinvertebrate taxon richness. Macroinvertebrate taxon richness also seemed to be affected by sediment texture and macrophyte species. Exposure, slope, depth and competition were considered to impact upon macroinvertebrate communities.

The corixid fauna of the cutaway wetlands was very diverse, with 13 species in Turraun and 12 in Tumduff. Specimens thought to be *Hesperocorixa moesta* (Fieber) were found in both wetlands, but as they were females they could not be confirmed. Corixid species composition did not clearly resemble that of other studied habitats and seemed to be governed by colonisation and habitat availability. Corixid abundance was extremely high, with corixids representing 34% of the macroinvertebrate population of Turraun and 12% of Tumduff between January 1997 and February 1998. Invasions appeared to be the most important factor contributing to corixid abundance. Other factors such as pond area, habitat variability, food availability and low parasite and predator numbers also appeared to favour high corixid abundance. Corixid abundance decreased between 1997 and 1999. Corixids appeared to colonise Turraun and Tumduff from regional sources.

Sex ratio in the corixids *Sigara dorsalis* (Leach), *S. distincta* (Fieber), *S. fossarum* (Leach) and *S. scotti* (Douglas & Scott) varied with season and the overall ratio was 1:1 or showed a slight dominance by females. Female *S. distincta*, *S. fossarum* and *S. scotti* were significantly longer than male, while no sexual dimorphism could be distinguished in *S. dorsalis*. Corixids were generally significantly longer at Tumduff than at Turraun, and length also varied within ponds. Parasitism of corixids by larval mites was reasonably low, with 1.24% of corixids infected at Turraun and 8.48% at Tumduff. *S. dorsalis* appeared to be more susceptible to infection than other species. Most corixids had only one attached larva and these were distributed around the corixid body.

Results of laboratory feeding trials indicated that *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* were omnivorous, capable of ingesting detritus, phytoplankton, periphyton and a variety of aquatic macroinvertebrates. Algae and biofilm were the most popular prey items and soft-bodied animals, such as oligochaete worms and chironomid larvae were acceptable prey. Some variation in diet was seen between species and between sexes.

Results of laboratory based corixid habitat selectivity experiments showed that *Sigara dorsalis* had a preference for *Myriophyllum* over open water, that *S. distincta* appeared to be associated with deeper water, that *S. fossarum* is found on or near the sediment and that *S. scotti* prefers shallow water. Field based habitat usage experiments indicated that corixid diversity and abundance was greater in *Myriophyllum* than *Hippuris* stands owing to the plants' differing influence on water turbulence and sediment stability. Many corixid species appear to prefer calm, undisturbed water.

Cutaway ponds increase the aquatic biodiversity of the Irish midlands and are considered worthy of conservation. Future development of wetlands should be managed to maximise macrophyte and macroinvertebrate diversity through variability of area, shoreline, slope, depth and sediments. A cohesive plan for the development of all future Bord na Móna cutaway is necessary.



Plate 1 The cutaway lake at Tumduff, June 2000.

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Chapter 1

## **INTRODUCTION**

#### **1.1 Introduction**

New ponds afford an invaluable opportunity to study aquatic macroinvertebrate colonisation and community development. Peat floored, alkaline ponds on cutaway raised bog introduce a unique set of interactions between macroinvertebrates and sediment, macrophytes and water chemistry. Monitoring macroinvertebrates in different habitats within cutaway ponds may prove useful in predicting community succession, as well as contributing to knowledge on the ecology of various species. Up to 35,000 ha of Bord na Móna cutaway may be developed into wetlands. Pioneer studies will prove pivotal to the planning and development of these vast areas, generating prescriptions on morphology and sediment manipulations. Such recommendations will be designed to promote high macroinvertebrate and macrophyte diversity, and hence, to increase the conservation value of cutaway wetlands.

Before conducting investigations on cutaway ponds, it is essential to understand the origin and types of peatland in Ireland, along with their history of exploitation. These topics are introduced below. Cutaway raised bog and artificial wetland creation are also described. Finally the choice of subject matter is explained, the aims of the thesis are detailed and the thesis structure given.

#### 1.2 Peatlands in Ireland

Peat develops in areas of waterlogging, where anaerobic conditions decrease the rate of decomposition. The result is an ecosystem where the rate of production of organic material greatly exceeds the rate of its consumption (Moore & Bellamy 1984). Most of the world's peatland is confined to the temperate zones of the Northern Hemisphere. There are nine predominant types of peatland in Western Europe and three are found in Ireland (Goodwillie 1980): fen, oceanic raised mire (or bog) and blanket mire (or bog). The few Irish fens remaining are restricted to the east of the country and differ from the other two peatland types by being groundwater fed or minerotrophic, thus having a greater concentration of nutrients. Raised and blanket bogs are described as ombrotrophic, receiving minerals from rainwater only. The two cutaway wetlands, which form the study sites, are located on oceanic raised bogs. This bog type is topogenous, developing in water

filled depressions (van Eck *et al.* 1984) and is typical of the Irish central plain (Bellamy 1986).

After the last Great Ice Age, which ended 11,000 yrs BP, the Irish central plain was covered by a series of shallow lakes. These were trapped by moraines and eskers left by the ice sheet, and were connected to the Shannon (Feehan 1994). Blue silty clay was commonly deposited in the deeper lakes, while calcium carbonate or shell marl was precipitated in the shallow, calcareous lakes (Feehan & O'Donovan 1996). The postglacial lakes were reduced in area and depth between 10,000 to 7,000 BP (Mitchell & Ryan 1997). Emergent vegetation encroached upon the shallow lakes and they rapidly became in-filled with reed swamp. This led to the deposition of reed-swamp peat and as the lakes became further in-filled, fen developed. Fen peat deposition began c. 8/9,000 BP. As the fen peat grew it gradually reached above the height of the water table, whereupon ombrotrophic, acid peat developed with the colonisation of *Sphagnum*, and raised bogs were formed. Raised bog *Sphagnum* peat had begun to form by 7,000 BP (Mitchell & Ryan 1997). At c. 2500 BP, the climate became wetter, increasing *Sphagnum* peat.

In a typical raised bog profile blue silty clay is often the lowermost sediment overlying the glacial deposits. Shell marl may overly the silty clay. A thin layer of gyttja (detrital or algal mud) lies between the lake sediments and peat (Feehan & O'Donovan 1996). The first peat is reed swamp peat, then fen peat, followed by strongly humified *Sphagnum* peat and finally lightly humified *Sphagnum* peat (Jessen 1949, Barry 1969). In places the formation of carr led to the deposition of woody fen peat at the edges of the former fen.

Raised bogs have a more or less domed surface and generally reach depths greater than 8m (Schouten 1981). The artificial wetlands involved in this study are situated in an extensive raised bog-complex known as the Bog of Allen, which once covered more than 300,000 ha in the Irish midlands (Egan 1998b). The term 'raised bog-complex' refers to a situation where a series of adjacent domes grow into one another (Feehan & O'Donovan 1996) with fen peat extending from lake basins to grow directly on moraine and eskers and acid peat developing subsequently.

Intact bogs are wet places, consisting of 95 to 98 % water (van Eck *et al.* 1984, Cross 1989). Most of this moisture is locked up in the peat, although, some standing water exists on intact bogs. These waterbodies range from water filled hollows and pools, to spring fed soaks and flushes, and bog lakes. Oceanic raised bogs typically contain networks of shallow pools separated by dry or hummocky areas (Schouten 1990) and may also have soak lakes at the top of the acrotelm. Pools and other standing water bodies on intact peatlands have been extensively described in terms of origin, development, morphology and vegetation by many authors (e.g. Schouten 1990, Lindsay *et al.* 1985, Glaser 1998, Karofeld 1998, Lindsay & Campagna Popolo 1998).

#### **1.3** Exploitation of peatlands

Peat represents a considerable resource in Ireland, with peatlands once covering 17.2 % or 1.18 million ha of the Republic of Ireland (Hammond 1979). 12.4% of Northern Ireland was covered by peatland (Taylor 1983). In the Republic, 92,500 ha was minerotrophic fen, 311,300 ha raised bog and the remainder blanket bog (Hammond 1979, van Eck *et al.* 1984). Of the original area of raised bog, 93% has been man modified by mechanical extraction, hand cutting or afforestation (Foss 1998).

Evidence suggests that peat has been used as a fuel for more than 2,000 years and that peat was harvested in Ireland as early as the seventh century AD (Feehan & O'Donovan 1996). Despite investigations by British governments into the potential uses of Irish bogs, large-scale industrial use did not commence until 1946, when Bord na Móna was established. This initiative was sparked by Ireland's economic and energy isolation during World War II (McNally 1998). Bord na Móna's remit was (and still is) to develop peatlands 'for the generation of electricity, the supply of domestic fuel and the supply of horticultural peat' (McNally 1994). Bord na Móna at first concentrated on turf production and sod peat was used by the ESB (Electricity Supply Board) to generate electricity. In the 1950s milled peat superseded sod peat and accounted for the majority of Bord na Móna's production. Today Bord na Móna continues to concentrate on milled peat production and most is sold to generate electricity, while briquettes and sod peat are produced for domestic heating and moss peat is sold for horticultural purposes.

Considerable private exploitation of peatland has also occurred and 68% of raised bogs have been cut away by private means (Foss 1998). For centuries private extraction was by traditional hand cutting. Mechanisation and grant aid under the Turf Development Act of 1986 increased private cutting (Foss 1998). Peatlands are also planted with forestry and large-scale afforestation, particularly of blanket bogs began in the 1950s.

#### **1.4** Milled peat production and the development of cutaway

The various forms of peatland exploitation (hand-cutting, mechanised sod peat extraction, Bord na Móna milled peat production and afforestation) have different end results. The study sites that are the focus of this thesis are located on Bord na Móna peatland used mainly for milled peat production. An understanding of the methods of extraction of milled peat is useful to appreciate the cutaway landscape.

Bord na Móna prepare the 'virgin' peatland by draining the entire bog (McNally 1994). In preparing for sod peat production, surface drains are dug, extending gradually from the bog edge to the centre, and are deepened yearly. The water from the bog drains either by gravity or is pumped into surrounding arterial drainage systems (McNally 1994). The bogs in the east midlands drain into the rivers Boyne and Barrow by gravity, and those in the west midlands are pumped into the river Shannon (McNally 1998). Bogs are drained for five to seven years before turf production can begin (McNally 1994). Most of the Bord na Móna bogs were initially prepared for sod peat extraction before being converted to milled peat production. Drainage of virgin bog for milled peat takes less time and can be as short as two years (Feehan & O'Donovan 1996).

After drainage, the bog is levelled and sloped towards the drains. For milled peat production, the peatland is laid out in a series of 15.2 m wide drying fields (van Eck *et al.* 1984) that can range from c. 730 to 1,100 m long (Feehan & O'Donovan 1996), with a drain separating each field. The milled peat methods used by Bord na Móna are those pioneered by Russians in the 1920s and 1930s. Milling machines have rotating drums fitted with spikes, which scarify or tear the surface into crumbs. A depth of between 4 and 13 mm is disturbed, depending on the drying conditions (van Eck *et al.* 1984, Feehan &

O'Donovan 1996). The dry peat is subsequently removed from the drying field and transported to a power station or briquette factory.

Bord na Móna generally harvest milled peat from mid April to mid September (Feehan & O'Donovan 1996). Each harvest cycle takes two to three days and an average of twelve harvests are completed each year (van Eck *et al.* 1984, Feehan & O'Donovan 1996). As a result it takes 10 years to remove 1 m of peat. Bord na Móna's policy is to remove as much peat as is economically possible (McNally 1994). A milled peat bog is in production for 40 or 50 years, as it is generally possible to take 4.5-5 m from a bog (McNally 1998).

When milled peat production has been completed the bog is known as cutaway. In this text, cutaway will be used to indicate industrially exploited bog, from which most of the peat has been removed and on which exploitation has ceased. Cutover refers to industrially exploited bog that is still in production or has the potential to be developed further, along with bogs that have been cut by hand.

Industrial cutaway is highly variable in terms of peat depths and types (McNally 1998). The residual peat left after milled peat production ranges from 0 to 1.5m (McNally 1994). The peat exposed at this cutaway level is generally minerotrophic and of reed swamp or fen origin. Woody fen peat is found over eskers and moraine, while reed swamp peat is found in the depressions (McNally 1998). At times the underlying substrata, such as glacial boulder drift, blue silty clay and shell marl, are exposed. All of these substrata are alkaline, but have different drainage features (McNally 1998).

The first of Bord na Móna's cutaways became available in mid 1950s (McNally 1994). Experiments were immediately established to assess the potential uses of cutaway, particularly with respect to agriculture and forestry. The success of the various projects is largely determined by the depth and properties of the residual peat layers. The use of cutaway for grassland and forestry will be returned to in Chapter 2.

As mentioned above, drainage water from peatlands in the west midlands often needs to be pumped into the surrounding arterial systems. Pumping is also necessary in some of the deeper depressions that formed the basins of postglacial lakes. The cutaway left in these areas is subject to periodic or permanent flooding and it is uneconomical to continue

pumping. Allowing these cutaways to flood and recolonise naturally is, economically and ecologically, the best option. Bord na Móna established the first experimental wetland on cutaway raised bog in 1991 and has continued to create artificial ponds ever since.

Preparation for the cutaway ponds involves the removal of further residual peat and the creation of a basin. The water bodies are allowed to fill naturally with ground and rain water or are filled by pumping water into the basin. The creation of the first artificial pond is described in detail in Chapter 2. Most of the cutaway wetlands are floored with reed swamp peat and fen peat, however, patches of shell marl, blue silty clay and glacial drift have been exposed. Macrophyte vegetation and aquatic invertebrates have colonised the water bodies.

Bord na Móna owns 88,000 ha of peatland, most of which is under production (Boora Enterprise Group 1994, McNally 1998). Approximately 80,000 ha of this is raised bog and includes 25% of midland raised bogs (McNally 1998). Currently 6,000 ha of Bord na Móna peatlands are cutaway. Estimates suggest that all of the Bord na Móna owned raised bog will be fully exhausted in the next 30 years (McNally 1994, Egan 1998a). McNally (1998) estimates that 20 to 30% of this cutaway will be developed as grasslands, 50 to 60% as forestry and 20 to 40% as wetlands.

Artificial water bodies on cutaway raised bog will cover substantial areas of land, and it is essential that existing cutaway wetlands are well researched and processes acting within them understood in order to maximise their usefulness for biodiversity and conservation purposes. Some of these cutaway ponds are being designated for recreational purposes such as fishing, although, most will be created to increase local biodiversity and maximise conservation importance. The high conservation value of cutover raised mire owing to the resident flora and fauna has been noted (Meade 1992). Abandoned and regenerating cutaway may form an 'oasis' for native biota in a 'desert' of agricultural land and peatland. This study represents one of the first limnological survey of these novel water bodies.

#### **1.5** Aquatic macroinvertebrates in cutaway wetlands

As the creation of water bodies on cutaway raised bog began in 1991, scientific research has been very limited and few observations have been published. No similar natural waterbodies exist. Kavanagh (1990, 1991, 1992 a and b, 1994, 1995) prepared a series of reports to Bord na Móna concentrating on plans for the development of the first artificial waterbody, surface water level fluctuations, sediments, vegetation and particularly bird life. Fay *et al.* (1996) conducted the first survey of aquatic macroinvertebrates in cutaway wetlands during the summer of 1996. Kaens (1996) reports on the entomostracan fauna of three cutaway ponds. A number of undergraduate theses at the University of Dublin, Trinity College, have also looked at elements of the macroinvertebrate fauna of cutaway wetlands.

Owing to the dearth of relevant research, many potential areas of study exist for cutaway wetlands. Aquatic macroinvertebrates provide an obvious starting point. Certain aquatic macroinvertebrates, particularly those capable of flight or with aerial adult stages, very rapidly colonise any new pieces of water (Fernando 1959, Barnes 1983, Friday 1987, Williams 1993). Species composition and abundance reflect many factors, such as basin morphology, sediment, water chemistry and macrophyte vegetation. Aquatic macroinvertebrates include both primary and secondary consumers and hence give an indication of both primary and secondary production. The macroinvertebrate fauna may also give an indication of the trophic status of a lake. Changes in macroinvertebrate populations are used to detect nutrient enrichment in rivers, where the presence of indicator species, or the absence of sensitive organisms, indicate organic pollution. The potential use of such bio-indicators in lakes has been investigated more recently (e.g. White 2000, Irvine *et al.* in press).

Aquatic macroinvertebrates have been studied in many habitats, including ponds (e.g. Macan 1965a, 1966, 1976, Palmer 1981, Williams 1993), ditches (e.g. Painter 1999), lakes (e.g. Tully *et al.* 1991, Bowman *et al.* 1993, Savage 1994, 2000) and especially flowing water (e.g. Frost 1942, Townsend & Hildrew 1994, Tham *et al.* 1997, Kelly-Quinn 1998). Study of the aquatic macroinvertebrate populations of cutaway wetlands allows comparison with other water bodies and aids in the understanding of the limnology of these new ponds.

#### 1.6 Aims of thesis

The main purpose of this survey was to assess the contribution of these artificial wetlands to the biodiversity of cutaway raised bog. A secondary aim was to evaluate the usefulness of various factors in promoting macroinvertebrate diversity, in order to influence future design of cutaway wetlands.

The water chemistry and aquatic macroinvertebrate assemblages were studied in two wetlands and eight habitats with different age, water depth, sediment type and vegetation, in order to investigate:

- 1) whether these novel ponds differ from natural water bodies in terms of water chemistry and macroinvertebrate populations, and as a result have a high conservation value,
- how macroinvertebrate assemblages varied with sediment and macrophyte vegetation within each wetland and
- short term successional changes within the wetlands and predict future developments and 'climax stages' for the study sites.

In Section A, Chapter 2, the two study sites are described. The history of exploitation at the sites, along with details of the creation, morphology, sediment and macrophytes of the cutaway ponds are given. Chapter 3 investigates the water chemistry of the study sites. Section B presents the results of a study of the aquatic macroinvertebrates at eight different sampling stations in the study sites. Details of the macroinvertebrates, other than Corixidae, are given.

Corixidae are the focus of Section C. Chapter 5 presents corixid results from the general macroinvertebrate survey and an extended survey. The remaining chapters are devoted to experiments and further field studies, designed to elucidate the role played by Corixidae in the cutaway wetlands. Factors influencing corixid diversity and abundance are considered. Sex ratio, length data and information on larval mite parasitism are explored in Chapter 6. Chapter 7 presents the results of corixid feeding trials and Chapter 8 examines laboratory and field based habitat selectivity experiments. Chapter 9 discusses all corixid results, while Chapter 10 makes some final conclusions and discusses the conservation value and biodiversity of cutaway ponds.

**Section A** 

# SITE DESCRIPTION, PHYSICAL ENVIRONMENT & WATER CHEMISTRY

#### Foreword

Section A describes the study sites in terms of their geographical location, history of development and physical and chemical environments. Chapter 2 details the selection of study sites. The industrial, social and environmental history of both sites is outlined. A description is given of the creation, flooding and subsequent development of one manmade pond selected for study. The context of these artificial cutaway wetlands in a contemporary landscape is discussed. Central to chapter 2 is the description of the geomorphology and hydrology of the two study wetlands. Substrata and lake sediments receive particular focus. Previous research on the study sites is outlined. Sampling stations within each wetland are introduced and described. The survey of aquatic macrophytes at each sampling station is reported.

Chapter 3 reports on a series of physical and chemical investigations undertaken at the two sites during the course of the study. The effect of surrounding natural and cultural environments upon the various physical and chemical parameters is described. The ionic and trophic status of both wetlands is discussed in detail. Chapter 3 also outlines the effects of the physical and chemical environments upon aquatic fauna.

Chapter 2

## **STUDY SITES**

#### 2.1 Introduction

The unusual nature of the study sites necessitates a history of their modification and a description of the surrounding environment, along with details of the morphology, sediment and habitats of the wetlands. Chapter 2 is divided into three main sections. In Section 2.2 the selection of two cutaway wetlands is detailed. Section 2.3 describes the Lough Boora Parklands in which the study sites lie. A site description of both wetlands is given, along with details of the creation of the ponds. The history of one wetland, Turraun, which has been well documented, is summarised. Section 2.4 describes the eight stations chosen for water and macroinvertebrate sampling in the two cutaway wetlands. The locations and sediments of the sampling stations are detailed, and the aquatic macrophytes are listed.

#### 2.2 Site Selection

Six cutaway wetlands were examined as potential study sites, between October 1996 and January 1997. These were Blackwater Lake (N 010 258) in west Co. Offaly; three wetlands in the Lough Boora Parklands (N 18 18) mid-west Co. Offaly, and Lullybeg Lake and Barnaran Pond in Lullymore bog (N 69 25) in Co. Kildare. Blackwater Lake was disregarded as it appeared to be affected by nutrient enrichment owing to intensive feeding of waterfowl. Boora Lake was also considered an atypical cutaway wetland as fish had been released into it. In contrast with the other four cutaway wetlands examined, Lullybeg Lake and Barnaran Pond were acid, with average pHs of 6.2 (n=3) and 5.77 (n=2) respectively (Kaens 1996). The two wetland sites in the Lough Boora Parklands, Turraun (N 172 230) and Tumduff (N 185 187), were chosen for water and macroinvertebrate sampling in early 1997. Turraun and Tumduff were also selected on the basis of their contrasting age, size, depth, macrophyte development and the diversity of sediments at each. Their proximity to each other was influential (Figure 2.1 shows the location of both wetlands).

#### 2.3 Lough Boora Parklands

The Lough Boora Parklands are located in mid-west County Offaly, about 16km west of Tullamore (N 340 250) (Figures 2.1 and 2.2). They consist of more than 2,000 ha of cutaway within the 8,100 ha Boora bog (Egan 1998a). The complex stretches from Cloghan (N 078 192) in the west, to Blueball (N 257 196) in the east; Pollagh lies at the northern edge and Kilcormac (N 182 138) at the southern one. The Parklands were named after the now drained lake and Mesolithic site, Lough Boora.

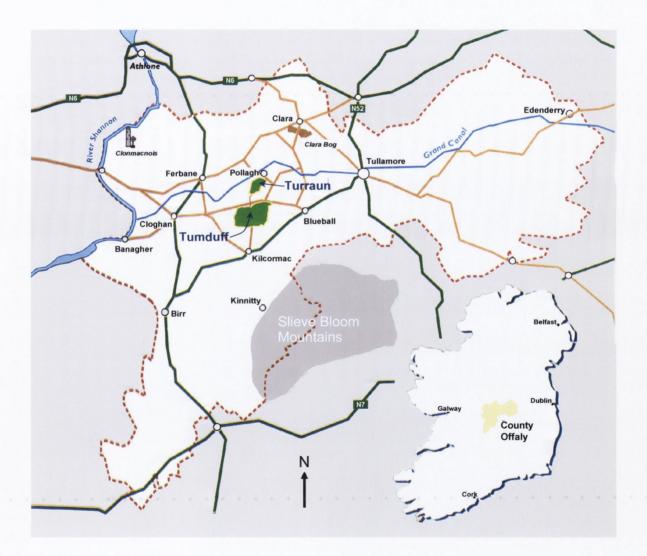


Figure 2.1 Map of County Offaly showing the location of the Lough Boora Parklands (shown in bright green).

Turraun bog, in which Turraun wetland lies, is separated from the rest of the Boora complex by a stretch of mineral soil. This bog has been exploited for almost two hundred years and has a well documented history. In the early 1960s Turraun bog began supplying peat to Ferbane power station and hence, became part of the Boora bog complex. In the 1990s it was included as part of the Lough Boora Parklands. The specific history and development of wetlands at Turraun are dealt with in Section 2.2.3.

Boora bog was one of the largest raised bogs in the midlands and a prominent Bord na Móna development. The Bord na Móna works at Boora opened in 1946 and the bog was initially prepared and drained to supply sod peat, but was converted to milled peat production in 1952. It was the first bog in the midlands to be commercially developed to produce milled peat for electricity generation (Egan 1998a) and supplied the ESB station at Ferbane. This power station, which opened in February 1957, was the first outside Russia to generate electricity from milled peat. Milled peat form Boora was also used to produce briquettes for the domestic market at the Derrinlough factory.

Peat fields were cut away rapidly at Boora. In the 1960s Bord na Móna and An Foras Taluntas (now Teagasc) began exploring potential uses of cutaway bog. Commercial applications were the focus of early attention and in the 1970s forestry and grassland trials were commenced at Boora. Many of these plots continue to be studied.

By 1994 more than 1,170 ha of the Boora bog-complex was fully exploited and abandoned as cutaway peatland. In 1998 2,000 ha was cutaway (Egan 1998a) and became known as the Lough Boora Parklands. With the aid of Bord na Móna, European funding, and the effort of local community groups, extensive plans were drawn up for the parklands. A mosaic of commercial forestry, grassland and various tourism and educational amenities was envisaged.

800 ha of the Parklands are currently planted with coniferous forestry (See Figure 2.2). The most important species is Sitka spruce. Lodgepole pine and Norway spruce were also planted. These trees proved unproductive, mainly because of late frost, competition with naturally invading species and nutrient deficiencies (Jones *et al.* 1998). Both Coillte and the Forest Ecosystem Research Group of University College Dublin are currently researching means of improving the productivity of plantations. Their investigations

include use of new species, different ground preparations and novel treatments. The potential of native tree species (1 ha) and mixed woodlands (15 ha) is being studied; 0.5 ha of willows have been planted for craft purposes (Egan 1998a).



Figure 2.2 Bord na Móna map of the Lough Boora Parklands, excluding Turraun. Note Tumduff wetland, with its bird hide and the adjacent Tumduff Brook.

By 1997 Bord na Móna had developed 350 ha of grassland in the Lough Boora Parklands. Most of this has been sold to 23 local farmers (Egan 1998a). Grassland experiments have been more commercially successful than afforestation, both in terms of production and employment. A number of problems, however, must be overcome in establishing grassland on cutaway. These include poor drainage, soil compaction, nutrient deficiency and difficulties in control of weeds (Feehan & O'Donovan 1996). Ongoing management of these grasslands is necessary to provide essential nutrients and to prevent physical deterioration of the land.

Wetlands form a central part of the Lough Boora Parklands. By 1997, four wetlands had been created, including Turraun and Tumduff. By 2000, there was more than 430 ha of permanent and periodically inundated wetland at more than eight sites within the Lough Boora Parklands (Tom Egan, personal communication). Deeper lakes have also been excavated and stocked with fish. Boora Lake, created in 1991, was the first experimental fishery (Caffrey 1998) and was stocked with brown trout. A smaller lake, Lough an Dochais, was developed to facilitate disabled anglers. At Finnamores bog, two lakes, of 4.8 ha and 3.6 ha (Egan 1998a), were excavated in 1996. These have been stocked with the coarse fish, carp, tench and bream (Caffrey 1998, Tom Egan personal communication). More than 40 ha of angling lakes are found in the Lough Boora Parklands (Tom Egan personal communication).

Over 140 ha of the parklands were allowed to recolonise naturally. Wild grass species were seeded around the wetlands and in other locations. Landscaping, including the planting of native tree species, is also a feature of the parklands. Populations of mallard and goose are maintained on Boora Lake. Extensive gravel walkways have been laid in appropriate locations around the parklands, bird hides have been built and a canoeing course constructed. The cutaway is also used for model aircraft flying and clay pigeon shooting.

Future plans for Lough Boora parklands include further wetlands, fishing lakes and natural re-colonisation areas, the construction of an interpretation centre and cycling tracks. It is envisaged that these types of amenities will constitute around 14 % of the parklands (Boora Enterprise Group 1994). Grasslands will continue to be developed on high, free draining areas, mainly on woody fen and boulder till (Egan 1998a). The parklands will eventually encompass more than 2,200 ha, all of which will be cutaway by 2012 (Boora Enterprise Group 1994).

Boora is notable for its wildlife. Bird life is diverse, with the grey partridge being by far the most celebrated species. This is considered 'endangered' (Whilde 1993) and with only 6-8 breeding pairs remaining in Ireland (Kavanagh *et al.* in press) is seriously threatened

with extinction. Partridge, traditionally a farmland bird, have survived on cutaway having suffered as a result of intensive agricultural methods elsewhere, which interfere with their breeding habits. The only remaining native breeding populations of grey partridge are at Boora and a second site in Kildare. Other notable species breeding on cutaway are merlin and nightjar (Kavanagh 1998), both of which are listed in the Irish Red Data book of threatened vertebrates (Whilde 1993). Skylarks, meadow pipits, reed buntings, lapwing and snipe breed at Boora, while lapwing, whooper swan and golden plover overwinter on the Parklands. Small numbers of Greenland white-fronted geese are regularly seen within flocks of swan (Kavanagh 1998).

#### 2.3.1 Tumduff: creation and site description

Tumduff wetland lies in the heart of the Lough Boora Parklands (Plate 1 and Figure 2.2). It is approximately 1 km south of the Bord na Móna works at Boora. The Boora-Kilcormac road allows easy access to the site. Double railway lines are located north of the pond, with Tumduff brook running parallel. There are privately owned grasslands to the south of the pond and abandoned peat fields and forestry plantations to the east, while the road, Lough Boora and the Mesolithic site lie to the west.

Tumduff was created on cutaway in October 1995. During development, much of the regenerating vegetation (including *Carex* spp. and *Eriophorum angustifolium* Honckeny) was retained. Small islands were raised. Before flooding a 3 m wide moat was built around the area to exclude predators such as foxes (Egan 1998a). It was originally proposed as a catch and release fishery for brown and rainbow trout but is now designated as a shallow excavation wetland (Tom Egan personal communication). The area immediately around the pond was reseeded with a wild grass mix and landscaped using deciduous trees. A raised circular bird hide was constructed adjacent to the road at the south of the pond.

Tumduff is approximately 6 ha in area. The underlying substratum is a combination of glacial boulder till and blue silty clay. The pond is shallow around the edge, then slopes sharply to depths of up to 2 m. A stream, with a constant flow of spring water, is piped underground into the centre of the pond. The basin surrounding Tumduff was small and direct precipitation and run-off would have been a minor water source. The full catchment

of the pond could not be estimated nor the input of water from drains calculated, as records of artificial drainage were not available. Tumduff is subject to fluctuations in water level. Peat is the predominant sediment, although, some blue silty clay and boulder clay are exposed to the south. Aquatic vegetation is sparse (see sections 2.3 and 2.4).

Tumduff has been used as a breeding site by black-headed gulls, grebes, mallard, tufted duck, lapwing, ringed plover and redshank (Kavanagh 1998). The pond is visited by many birds in winter, including whooper swan, curlew, lapwing and golden plover.

#### 2.3.2 Turraun: history, creation & site description

Turraun wetland is the largest in the Lough Boora Parklands (Plate 2 and Figure 2.3), and is situated approximately 5 km north of Turnduff wetland. The village of Pollagh (N 192 250), lies just north of Turraun. Access to the site is via a cul-de-sac running west from the village. The Grand Canal runs along the north and north-west perimeter of the site (see Figure 2.3). North and north-east of the site is predominantly farmland with small patches of woodland. Immediately east of the wetland, Cocta Hill, covered in regenerating woodland, rises out of the bog. To the west there are two further artificial waterbodies (See Plate 2). The Silt Lagoon was originally built to prevent peat sediment entering the Boora River and is now a designated coarse fishery. Torán is a small pond, constructed since 1997. Further west and to the south of the wetland lie a number of peat fields, which are gradually being phased out of production, as well as grasslands over peat.

#### 2.3.2.1 Site history

Turraun bog lies in mid-west Co. Offaly and originally covered 570 ha (Kavanagh 1990). It has had a long history of exploitation. Local people used the Grand Canal (which opened in 1804) to transport peat bricks and sod turf to market. The first industrial exploitation of peat began in 1850 under the innovation of local man Kieran Farrelly. He produced fuel peat and peat moss, along with brick clay and yellow ochre from below the bog (Trodd 1994). He sold the latter to the Dublin Gas Company (Feehan & O'Donovan 1996). In 1890 he opened a peat moss litter factory at Turraun. It is reported that he reclaimed cutaway for oilseed rape production (Trodd 1994, Feehan & O'Donovan 1996). In 1903 a rainstorm caused a breach in the canal and the ensuing flood destroyed Farrelly's stock and damaged his machinery. He lost all to his creditors and was evicted in 1905.

A creditor, Colonel Dropping foreclosed and took over the operation at Turraun (Feehan & O'Donovan 1996). He installed two engines on the bog and introduced machinery for cutting turf. Dublin was his main market and he persuaded the Canal Company to transport his products by motor boat rather than horse barge.



Plate 2 Aerial view of the cutaway wetland at Turraun (1998)

In 1924, Turraun was acquired by a Welshman, Sir John Purser Griffith, who invested £70,000 of his private fortune in developing the bog. He was an instrumental character in the development of bogs in Ireland. He drained 4,000 acres of bog, employed the most modern machinery in the exploitation and even built his own peat-fuelled power station (Trodd 1994). Machinery was electrically operated and current was distributed around the bog on overhead cables. Peat was transported from the bog to the canal by rail. He manufactured machine peat, peat moss litter, poultry peat and garden moss peat and employed 16 permanent and 50 seasonal workers (Feehan & O'Donovan 1996).

Sir John eventually handed over Turraun bog and all of his developments to the Turf Development Board for the sum of £4,500 in 1935. The Board moved into Turraun in 1936 and commenced large scale production in the 1940s in response to the Fuel Emergency of World War II, making Turraun one of the oldest bogs worked by Bord na Móna. During the war turf charcoal was produced in Turraun. In 1958, Turraun was the first bog to produce milled peat from cutover remaining after sod peat production. Thereafter, it became administratively part of the Boora-complex, which supplied Ferbane power station (N 135 195).

The bogs around Turraun are not only notable for their history of exploitation. The adjacent Pollagh bog was the only Irish site of the Rannoch Rush (Moore 1955). It is a plant, which forms floating mats in deep bog pools and is widespread in continental Europe. Fr Moore discovered the 'rush' in an extensive soak system in 1951. When the bog was developed in the 1950s, the plant was driven to extinction (O'Connell 1987).

#### 2.3.2.2 The creation of the wetland at Turraun

Peat fields in Turraun bog were among the earliest abandoned in Ireland. The first area of cutaway was abandoned at Turraun in 1973, when shell marl was exposed to the north of the bog. Further areas have been gradually phased out of production ever since. In 1990 Bord na Móna designated 118 ha of cutaway as a conservation area. All 118 ha had been cutaway for more than 20 years and included the original exposed shell marl. Natural vegetation regeneration had occurred at the site. Dr Brendan Kavanagh conducted a detailed baseline survey of the area in summer 1990, including investigations into substrata, vegetation and bird life. Dr Kavanagh supported the Bord na Móna initiative to

create their first artificial wetland at the site. He drew up a development plan for the area and was responsible for subsequent monitoring (Kavanagh 1992a).



Figure 2.3 Bord na Móna map of Turraun. This shows the Grand Canal and Boora River along with the Silt Lagoon (labelled 'coarse fishing lake'). Other notable features include the access roads, paths, bird hide and Cocta Hill.

In 1990, before the wetland was developed, the site was a low-lying area, with variable topography and a basin at the western end (Kavanagh 1991). Up to 1.2 m of peat were left owing to the undulating surface of the mineral substratum below the bog. The site was drained by a network of gravitational arterial drains with an outlet to the Boora River in the west. Springs in the south-west and east of the site resulted in small areas of permanently

waterlogged ground. Another spring discharged directly into the system of ditches half way along the north-west edge.

Development of the wetland began in October 1991. It was a complex procedure. Much of the remaining peat was removed from the chosen wetland basin and used to build embankments to the north. Excavation work exposed more marl, and this was used to cement the banks. Cocta hill was used as a natural boundary to the east, while a raised railway line formed the western perimeter. A high bank of fen peat formed the southern pond boundary. Within the western basin of the wetland, three islands were created in October/November 1991 (Kavanagh 1992b). This was accomplished by pushing peat (and in one case marl also) upwards to create an island while also deepening the surrounding pond bottom. Drains were cleaned and piped outflows blocked up. The original outflow to the west was sealed with the completion of the northern embankment on 15<sup>th</sup> November 1991, allowing water accumulation to begin. Initially, the wetland water level rose rapidly under the influence of the springs. Later the water level rose more gradually, as precipitation became the main water source. A podium outflow was built in the northern embankment. The level of water in the wetland has yet to reach that of the outflow.

#### 2.3.2.3 Site description

Turraun wetland has an estimated area of between 52 ha (Boora Enterprise Group 1994) and 60 ha (Egan 1998a and b). It is shallow, with average depth estimated as 1 m (Egan 1998a). There is a deeper area around the central islands (Brendan Kavanagh personal communication). Much of the wetland is very shallow, however, seldom exceeding 50 cm deep. Glacially deposited dry boulder till underlies the entire site. Roughly half of the Turraun site formed a post-glacial lake basin, having deposits of the lake sediments blue silty clay and shell marl. It has been estimated that approximately 15.5 m of shell marl overlies the silty blue clays (Egan 1998a).

The present day wetland sediments are a combination of peat and shell marl. Peat is the dominant sediment type directly underlying the new wetland. It covers more than 85% of the wetland bottom. This residual peat is variable, with woody fen peat, reed swamp peat and occasionally highly humified *Sphagnum* peat present. Much of the peat was naturally compacted as a result of the weight of overlying peat layers in the intact bog. Water movements within the wetland have led to the differential transport of peat particles and

consequently many former drains have been in-filled with very fine peat. These factors lead to a high degree of heterogeneity in the sediments. Shell marl is exposed to the north east of the wetland. An abundance of fossil shells of molluscs and crustacean exoskeletons can be seen in this marl.

The wetland appears to be predominantly rain fed, although at least three springs discharge into it. Seepage from surrounding drains also occurs. It is difficult to determine the exact catchment of the wetland owing to the lack of research into cutaway hydrology. Turraun is subject to fluctuations in water level. Changes in water surface level were monitored from 1991 to 1995 (Figure 2.4). When the wetland was created in December 1991 the water table was at 46.80 m ASL and by the end of that month it had risen to 47.18 m ASL (Kavanagh 1995). In winter 1992/3 it was around 47.50 m ASL, while in the wetter winters of 1993/4 and 1994/5 it was 47.70 m ASL. Kavanagh observed that the water level appeared to drop from April onwards, reaching lowest values around September.

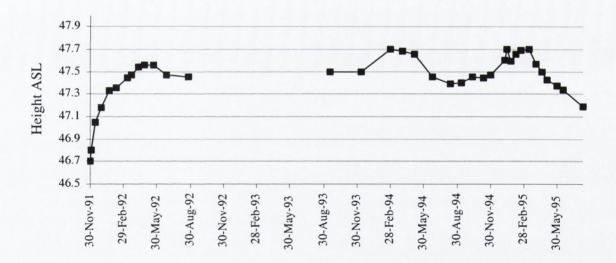


Figure 2.4 Water surface fluctuations in Turraun from 1991 to 1995 (after Kavanagh 1995).

As part of the current study, fluctuations in water level were measured from April to November 1997 (Figure 2.5). In this year water level was found to fall off after May, reaching the lowest point in July before rising gradually throughout the winter. The level fluctuated over a range of 20.3 cm during this time.

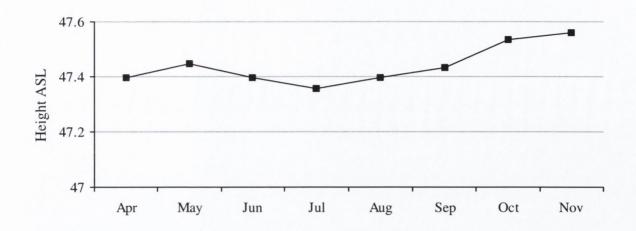


Figure 2.5 Water surface fluctuations in Turraun from April to November 1997.

Brendan Kavanagh and Bord na Móna undertook water chemistry analysis from 1991 to 1995 (Kavanagh 1995). Their results can be found in Table 2.1.

**Table 2.1** Water chemistry results at Turraun, 1991-5. Conductivity given in  $\mu$ S cm<sup>-1</sup>, pH in standard units. All others are given in mg l<sup>-1</sup>. (after Kavanagh 1995)

date	NO <sub>3</sub>	PO <sub>4</sub> -P <sup>-</sup>	Ca <sup>2+</sup>	CaCO <sub>3</sub>	Cond.	Mn	Fe	pH
Nov 1991	1.6	0.025	80.0	153	428	0.06	0.10	7.74
Apr 1992	2.0	0.05	52.7	136	337	< 0.02	0.03	7.70
Dec 1992	1.5	< 0.05	56.0	140	361	< 0.04	< 0.10	7.81
Aug 1994	0.8	< 0.05	52.9	149	335	0.05	0.09	8.40
Jan 1995	1.2	< 0.05	52.3	134	302	< 0.02	0.28	7.80
Jul 1995	1.5	0.06	72.9	116	274	< 0.02	< 0.05	8.50

Values for pH, alkalinity, calcium and calcium carbonate demonstrate Turraun is an alkaline wetland with a moderately high calcium concentration. Nutrient concentrations are relatively low. Conductivity values fell gradually between 1991 and 1995. The highest value ( $428 \ \mu \text{Scm}^{-1}$ ), recorded in 1991, was probably caused by the initial disproportionate influence of spring water. As precipitation became more important as a water source, the effect of the mineral rich ground water was diluted. pH appeared to rise gradually between 1991 and 1995. Plants in calcium rich waters can raise the pH through photosynthetic activity (Lewis 1962, Otsuki & Wetzel 1974, Flanagan 1992). The highest pH values were recorded in August 1994 and July 1995, when light intensity would have been highest for the year. Increased photosynthesis on bright days may have caused a temporary elevation

in pH. There may also have been an increase in pH over time as a result of the increasing abundance of phytoplankton and macrophytes in Turraun wetland.

Colonisation by macrophytes has been quite rapid and a diverse flora is found in the wetland (see also sections 2.3 and 2.4). Dramatic regeneration has also occurred on the peatland surrounding the wetland. Here, the vegetation is highly diverse (more than 160 species of flowering plants and fern) and reflects the variability in underlying peat, degree of waterlogging, pH and nutrient levels (Feehan & O'Donovan 1996). Plant communities include stands of *Betula* spp. and *Salix* spp., *Eriophorum angustifolium*, *Triglochin-Molinia* meadows with heather, rushes on damp ground and grassland (Kavanagh 1990).

Dr Brendan Kavanagh and local birdwatchers have monitored the avifauna of Turraun since 1990. Between 1990 and 1995, 96 bird species were recorded at Turraun including flocks of over 200 whooper swans (Kavanagh 1994, 1995). As this number represents more than 1% of the Irish whooper swan population, Turraun is listed as an internationally important wetland (Kavanagh 1992b). The number of whoopers, however, remains high for only a few weeks each winter before the birds form smaller groups and scatter (Kavanagh 1995). Mute and Bewick's swans have also been recorded. Some other rare waterfowl species have been recorded, such as garganey, goldeneye and gadwell. The main duck species found on Turraun are mallard, widgeon and teal, the most abundant waders are lapwing and snipe, while curlew and redshank are also present (Kavanagh 1995).

# 2.4 Habitat Selection

A variety of habitats could be identified within each wetland. In order to investigate spatial differences in the macroinvertebrate fauna, a number of these habitats were selected for regular sampling.

Five habitats were chosen as sampling stations at Turraun and three at Tumduff. These eight stations are described in terms of sediment type and dominant vegetation in Table 2.2. Stations were labelled one to eight, and given a letter to indicate which wetland they were in. Turraun stations are labelled T1 to T5 and are marked in Plate 2. As both wetland names begin with the same letter, Tumduff has been ascribed 'B', reflecting the name of the Boora bog complex in which it lies. Tumduff sampling stations are labelled B6 to B8. Plates 3-10 depict these stations in summer.

wetland	name	substratum	dominant vegetation
Turraun	T1	Peat	(None)
	T2	Peat	Typha latifolia
	T3	Peat	Polygonum amphibium
	T4	Shell Marl	Myriophyllum spp.
	T5	Peat	Carex rostrata
Tumduff, Boora	B6	Peat	flooded Agrostis stolonifera
	B7	Silty clay/Glacial drift	flooded Agrostis stolonifera
	<b>B</b> 8	Peat with CaCO <sub>3</sub> deposit	Juncus acutiflorus

 Table 2.2 Description of sampling stations at Turraun and Tumduff

Sampling stations T1, T2 and T3 lie on the western shore of Turraun, exposed to wave and wind action. The slope of this shore was very gradual and all three stations experienced periodic exposure during the dryer months. The peat at T1 was highly compacted and macrophytes did not colonise it readily. Calcium carbonate deposits were observed at T1 during 1998. T2 lay just north of T1 in a stand of *Typha latifolia* Linnaeus, with granular peat sediment. Beneath the aerial shoots of *Typha* there was a good diversity of aquatic angiosperms (see section 2.4 below). T2 was very shallow with almost no slope. T3 was the site of a former Bord na Móna drain. The peat was very fine-grained, probably as a result of resettlement of suspended fine particles. The fine peat was probably transported by currents from other locations within the wetland and deposited in the deep drain. *Polygonum amphibium* Linnaeus, *Sparganium erectum* Linnaeus and *Juncus* spp. dominated the flora at T3. Detritus and periphyton were very abundant here.

T4 was the north west corner of a sheltered bay overlying shell marl. The shell marl sediment was very soft and unconsolidated. It readily became suspended on disturbance. The slope of the bottom was steep. The area of water adjacent to the shore was colonised by a diverse emergent flora. *Myriophyllum* carpeted the remainder of the bay. A spring is known to enter the wetland at T4. Of all the sampling stations at Turraun, T4 was the most sheltered and suffered least as a result of the fluctuating water table. T5 lay on the eastern wetland shore at the base of Cocta Hill. It was adjacent the shell marl bay. The peat at T5 was of a fine texture. The sampling station was located in a dense stand of *Carex rostrata* Stokes and was exposed to wind and wave action.

B6 and B7 lay on the southern shore at Tumduff. Both sampling stations were exposed. The sediment at B6 was a fine textured peat, while that at B7 was a glacial deposit of blue silty clay. The vegetation at both stations was flooded *Agrostis stolonifera* Linnaeus and the slope was steep. B8 was located in a sheltered bay in the north west corner of the wetland. The slope was shallow. The peat had a fine texture and there were extensive calcium carbonate deposits on the sediment. There was a low density of *Juncus acutiflorus* Erh. ex Hoffm and *Glyceria fluitans* (Linnaeus) R. Br. at B8.

The vegetation changed at all sampling stations over the course of the study. Some *Juncus* spp., *Hippuris vulgaris* Linnaeus and *Alisma plantago-aquatica* Linnaeus slowly colonised T1. The area covered by *Typha* at T2 almost doubled between 1997 and 1999. *Polygonum* became less important at T3 and was replaced by more emergent macrophytes. The stand of *Myriophyllum* expanded rapidly at T4 during 1998 and 1999. *Carex rostrata* spread further at T5. At Tumduff macrophytes slowly colonised and increased their percentage cover of the wetland bottom.

Table 2.3 gives a detailed list of the aquatic macrophytes found at each of the eight sampling stations. Species are arranged in order of abundance, species with the highest percentage cover first and those with the lowest last (approximate). This data was gathered with the assistance of botanist, Sylvia Reynolds. A list of all macrophytes found in Turraun can be found in Appendix 2.4.

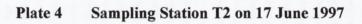
station	vegetation
T1	Bare, with slow encroachment of Alisma plantago-aquatica and Hippuris vulgaris (S)
T2	Typha latifolia, Juncus acutiflorus, J. effusus, Ramunculus flammula, Ramunculus aquatilis, Mentha aquatica, Polygonum amphibium (S), Alisma plantago-aquatica, Hydrocotyle vulgaris, Equisetum fluviatile, Veronica anagallis-aquatica, Glyceria fluitans, Myriophyllum spp (S)., Eriophorum angustifolium
Т3	Polygonum amphibium (S), Juncus acutiflorus, J. effusus, Sparganium erectum, Alisma plantago- aquatica, Myriophyllum spp. (S), Myosotis laxa, Galium palustre, Veronica anagallis-aquatica, Mentha aquatica
T4	Myriophyllum spp (S), Sparganium erectum, Juncus acutiflorus, Typha latifolia, Phragmites australis, Potamogeton natans (S), Equisetum palustre, Mentha aquatica, Alisma plantago- aquatica, Polygonum amphibium (S), Eriophorum angustifolium
T5	Carex rostrata, Eriophorum angustifolium, Scirpus lacustris, Glyceria fluitans, Equisetum fluviatile
B6	Agrostis stolonifera, Ramunculus spp.
B7	Agrostis stolonifera, Chara spp. (S), Mentha aquatica, Triglochin palustris, Cardamine pratensis, Potamogeton berchtoldii (S)
B8	Juncus acutiflorus, Glyceria fluitans, Chara sp. (S), Hydrocotyle vulgaris, Mentha aquatica, drowned terrestrial vegetation

# Table 2.3 Lake edge and aquatic macrophytes at the eight sampling stations. S indicates submerged species. S



Plate 3 Sampling Station T1 on 17 June 1997







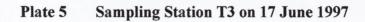




Plate 6 Sampling Station T4 on 17 June 1997



Plate 7 Sampling Station T5 on 17 June 1997



Plate 8 Sampling Station B6 on 17 June 1997



Plate 9 Sampling Station B7 on 17 June 1997



Plate 10 Sampling Station B8 on 17 June 1997

Chapter 3

# PHYSICAL AND CHEMICAL WATER PARAMETERS

# 3.1 Introduction

Among the many abiotic properties of a waterbody, some will have a profound effect on macroinvertebrate community structure. At Turraun and Tumduff, one physical and 11 chemical parameters were analysed. These not only illustrate the productivity and 'health' of the aquatic system, but also suggest the pond's capacity to buffer acids and to support plant and animal species. Water temperature and thermal structure affect the concentration of dissolved substances, the cycling of nutrients and the metabolism, physiology and behaviour of aquatic biota. Dissolved oxygen is crucial to the metabolism of both plants and animals. pH exerts a direct physiological effect on organisms, thereby influencing species composition. The concentration of dissolved ions (indicated by conductivity, alkalinity and concentration of individual ions) is of major importance to the maintenance of life, influencing productivity and osmoregulation. The availability of inorganic nutrients (e.g. phosphorus and nitrogen) is largely responsible for the productivity of a water body and measurement of factors such as total phosphorus or chlorophyll *a* tells much about the trophic status of a waterbody.

This chapter examines the chemical background to productivity of the studies wetlands. Results are presented and the physico-chemical properties of both wetlands are discussed.

# 3.2 Materials and Methods

A number of field and laboratory based measurements were selected for routine analysis. Water temperature, pH, dissolved oxygen conductivity and total dissolved solids were assessed in the field. Molybdate reactive phosphorus (MRP), total ammonia and nitrate were analysed in the laboratory as variables that indicated the availability of nutrients to the biota. From this routine chemistry, questions arose about the overall nutrient status and the nature of ions in the wetlands. In order to elucidate the productivity of the wetlands on a single date, water was sampled from both wetlands on 9<sup>th</sup> August 1999 and was analysed for total phosphorus and calcium. Chlorophyll *a*, pH, total alkalinity and colour were also measured for this date.

#### 3.2.1 Routine field measurements

Between June 1997 and February 1998 a Check Mate 90 Mettler-Toledo AG field kit with portable pH, conductivity, total dissolved solids and oxygen probes was used for routine field assessments. Measurements were made at all eight sampling stations (Section 2.3) on each occasion. Values for pH were recorded in June, July, August and September 1997. Dissolved oxygen concentration was measured in June and September. Conductivity and water temperature were recorded in June, July, August, September, October and November 1997, and in February 1998. Total dissolved solids were assessed in all months from June to November 1997. Replicate measurements were taken at each sampling station, unless precluded by time or other restrictions. Two to four replicate measurements were made. Measurements were made concurrent with macroinvertebrate sampling, between 10:00 and 16:00.

#### 3.2.2 Routine chemical analysis

Water samples for routine chemical analysis were taken from each of the eight sampling stations in Turraun and Tumduff on ten occasions, between January 1997 and February 1998. A single sample was obtained from Turraun in December 1996 in order to perform a trial analysis on nitrate and chloride. Water samples were taken on the same dates as macroinvertebrate samples (see section 4.2.2.1). The filtered samples were analysed for molybdate reactive phosphorus (MRP) and total ammonia in all months from March to

November 1997 and in February 1998. Nitrate and chloride analysis was done on December, March, April, June, July and August samples. Samples for May became contaminated and samples after August 1997 could not be analysed owing to the breakdown of the ion chromatography system.

Samples were obtained by hand from 5-10 cm below the surface in 250 ml polyethylene bottles. One sample was taken per station and a single bottle was assigned to each station. The bottles were rinsed a minimum of three times in the wetland water immediately before sampling. The samples were filtered within five hours using Whatman GF/C glass fibre filters in a hand held syringe. 50 ml of filtrate was transferred to digest bottles and stored below 4°C. The analysis was performed in the Environmental Sciences Unit laboratory, Trinity College Dublin. Analysis for MRP and total ammonia was conducted within a month of collection. Nitrate was stored for up to six months.

Molybdate reactive phosphorus was measured by the molybdenum blue method of Eisenreich *et al.* (1975). Absorbance was measured at 882 nm in a 5 cm cell. A Schimadzu UV-1601 spectrophotometer was used. All determinations followed calibration with five standards. The limit of detection was  $3 \mu g \Gamma^1 PO_4$ -P following Mackereth *et al.* (1989). Ammonia was determined using the indophenol method (Grasshoff *et al.* 1983). Absorbance was measured at 630 nm in a 1 cm cell on the above spectrophotometer. Calibration was carried out with between four and six standards. Occasionally MRP and total ammonia were measured with a 1 cm cell on a PYE Unicam SP6-350 spectrophotometer. The limit of detection for ammonia was approximately 0.04 mg  $\Gamma^1$  NH<sub>4</sub>-N. Nitrate and chloride concentrations were measured simultaneously by chemically suppressed ion chromatography (Dionex system). Determination followed calibration with five standards. Limits of detection were 0.011 mg  $\Gamma^1$  N for nitrate and c. 0.002 mg  $\Gamma^1$  Cl for chloride.

In order to investigate the influence of potential water sources on wetland nutrients, three other waterbodies were sampled. Water samples were obtained from the Silt Lagoon, which lies to the west of Turraun, in April, May, August, September, October and November 1997 and in February 1998. These samples were analysed for MRP and total ammonia. April and August samples were analysed for nitrate and chloride. The southern drain at Turraun was sampled in all months from July to November 1997. All samples were analysed for MRP and total ammonia, July and August samples for nitrate and

chloride. The southern inflowing stream at Tumduff was sampled and tested for MRP and total ammonia in April, October and November 1997. Nitrate and chloride were analysed in April.

#### 3.2.3 Further chemical analysis

On 9<sup>th</sup> August 1999, 5000 ml water samples were taken from each wetland in 1000 ml polyethylene bottles. Samples were recovered by hand from areas free of vegetation and as far from the shore as it was possible to wade. Water was taken from up-wind of the sampler, where sediment disturbance was minimal. Samples were returned to the laboratory and stored below 4 °C. The samples were analysed for total phosphorus and chlorophyll *a* in order to elucidate the nutrient status of the wetland. Total phosphorus was chosen over MRP as it is a better indicator of the overall productivity of a waterbody, and is frequently used in monitoring programmes. Colour was measured to indicate the concentration of dissolved humic materials (DHM). pH, total alkalinity, and calcium were analysed in order to understand the ionic status of the wetland. Analysis was performed in the Environmental Sciences Unit laboratory, Trinity College, Dublin between August 10<sup>th</sup> August. The filter paper was retained for Chlorophyll *a* assessment, placed in centrifuge tubes containing 10 ml of methanol and stored in darkness at 4 °C overnight.

pH was measured on 200 ml unstirred samples using a Jenway pH meter (model 3030) with a calibrated glass combination pH electrode. Alkalinity was determined, on duplicate 50 ml samples, by titration to pH 4.4 with 0.01 molar sulphuric acid using a Metrohm burette (E 485). Calculations were precise to 2% (Mackereth *et al.* 1989). Colour was read on 25 ml of filtrate at 455 nm using de-ionised water as a blank. Duplicate samples were measured. The concentration (mg l<sup>-1</sup> PtCo) was estimated directly by the HACH DR2000 spectrophotometer.

Chlorophyll *a* was determined using methanol extraction according to the Standing Committee of Analysts (1980). Two volumes were sampled for each wetland, 100 ml and 50 ml for Turraun and 1000 ml and 500 ml for Tumduff. Samples were brought to boiling point ( $\sim$ 75°C) for at least 20 seconds. After cooling the filter paper was removed and the samples centrifuged at 3500 rpm for 9 minutes. Absorbance was measured at 665 nm and

750 nm in a 5 cm cell. A Shimadzu UV-1601 spectrophotometer was used. The limit of detection of chlorophyll *a* was c. 0.5  $\mu$ g l<sup>-1</sup> (Flanagan & Toner 1975).

Total phosphorus determination followed Eisenreich *et al.* (1975). 25 ml of unfiltered sample was digested in 50 ml conical flasks. Water lost through evaporation was replaced with de-ionised water. 5 ml of sample was pipetted into test tubes. 1 ml of mixed reagent was added. After reaction absorbance was measured at 882 nm in a 5 cm cell. Triplicate samples were measured. Determinations followed calibration with five standards. A Shimadzu UV-1601 spectrophotometer was used. The limit of detection was 0.003 mg l<sup>-1</sup> P (Mackereth *et al.* 1989).

Calcium concentration was read on filtrate using a Perken Elmer atomic absorption spectrometer. Determinations followed calibration with four standards. 4 ml of lanthanum was added to 10 ml samples and 40 ml to 100 ml standards. Turraun samples were diluted by 10 and Tumduff samples by 20. Duplicate samples were analysed. The limit of detection was  $0.1 \text{ mg l}^{-1}$  Ca.

#### 3.2.4 Data analysis

Spreadsheets, calibration curves and all figures were generated on Microsoft Excel 97<sup>®</sup>. Correlation and non-parametric multisample statistical tests were performed using SPSS 8.0 for Windows<sup>®</sup>. Histograms, scatter plots, transformations and all other statistical tests were generated on Data Desk 6.0<sup>®</sup>.

#### 3.3 Results

#### 3.3.1 Routine field measurements

Water temperature is illustrated in Figure 3.1. Tables 3.1 to 3.4 give values for pH, oxygen concentration, conductivity and total dissolved solids at each station on the various sampling occasions. Where more than one reading was taken at the sampling station, the mean value and range are given.



Figure 3.1 Surface temperature profiles for Turraun and Tumduff over the sampling period from December 1996 to February 1998.

The seasonal trend in average water temperature in each wetland is illustrated in Figure 3.1. Similar trends were demonstrated at all stations. The highest average values were recorded in August 1997 in both wetlands, while the lowest values were recorded in November. Recorded temperatures reached 26 and 27 °C in July and August in both wetlands. Temperatures of 8 to 10 °C were recorded in November 1997 and February 1998. Ice sheets were rarely observed during the colder months. The lowest water temperature recorded was 2.1 °C in an ice covered Turraun on 6<sup>th</sup> December 1996.

Table 3.1 shows pH values over the sampling period. pH was high in both wetlands, reaching above 9 on occasion. The average value for pH was higher at Turraun than at Tumduff on most occasions, with the exception of  $22^{nd}$  September 1997.

Table 3.1pH values measured in the field. For dates when more than one measurement<br/>was taken at a sampling station, means and ranges are given.

date	T1	T2	T3	T4	T5	B6	B7	B8
17 <sup>th</sup> Jun 97								
Mean	9.18	9.02	9.01	8.95	8.90	8.29	8.34	8.18
Range	9.17-9.19	8.98-9.09	8.98-9.02	8.92-8.98	8.86-8.95	8.25-8.32	8.26-8.38	8.03-8.28
18 <sup>th</sup> Jun 97	8.83	8.71	8.70	8.57	8.59			
21 <sup>st</sup> Jul 97	9.01	9.08	9.06	8.78	8.56	7.99	8.17	7.99
18 <sup>th</sup> Aug 97	9.00	8.59	7.98	9.04	9.21	7.77	7.74	7.97
22 <sup>nd</sup> Sep 97	7.70	7.38	7.19	7.39	7.50	7.39	7.68	7.71

There was no obvious within-pond difference in pH between stations and between station trends were not constant. On the first three sampling occasions (June and July), T5 had the lowest pH of all the stations at Turraun. In August and September, T3 had the lowest pH. The highest values were recorded at T1 in June and September, T2 in July and T4 in August. No between station patterns emerged at Tumduff.

pH values in Turraun were generally higher in June and July than in August and September. A significant positive correlation (Pearson's r = 0.616, n = 38 and  $\alpha = 0.01$ ) was found between pH and temperature at Turraun, while no correlation was found at Tumduff.

Table 3.2 Dissolved oxygen concentration and % saturation measured in the field.Concentration is given in mg  $l^{-1} O_2$ . Duplicate concentration measurementswere made in June, means and ranges are given.

date	T1	T2	T3	T4	T5	B6	B7	B8
17 <sup>th</sup> Jun 97								
Mean Conc.	13.85	11.6	13.15	12.85	6.3	11.7	12.3	9.8
Range	13.8-13.9	10.1-13.1	13.1-13.2	12.8-12.9	6.3	11.7	11.9-12.7	9.7-9.9
Mean % Sat.	153	140	151	153	80	127	139	106
Range	151-156	135-146	150-152	151-155	76-87	127-128	134-141	105-107
22 <sup>nd</sup> Sep 97								
Conc.	8.4	7.9	7.8	7.5	9.7	8.9	9.8	9.2
% Sat.	82	79	78	76	103	92	103	97

The concentration of dissolved oxygen was very high in both wetlands in June but below saturation in September (Table 3.2). The data were too few to identify any seasonal trends or within or between wetland differences. In Turraun in June, the lowest oxygen value was recorded at station T5, while in September the highest value was recorded at T5. B7 had the highest dissolved oxygen concentration in Tumduff, in both months.

Conductivity measurements in Turraun ranged from 219 to 360  $\mu$ S cm<sup>-1</sup>, while those in Tumduff were consistently higher, between 420 and 587  $\mu$ S cm<sup>-1</sup> (Table 3.3). Differences in conductivity between Turraun and Tumduff were significant (F<sub>(7,102)</sub> = 109.4, at  $\alpha$  = 0.05, p  $\leq$  0.0001, LSD post-hoc test used to locate source of difference). No between-sampling station difference or trends were found in either wetland. On some sampling occasions (e.g. June, October), however, there was a considerable difference between the highest and lowest recorded values at Turraun.

**Table 3.3** Conductivity values measured in the field. Values given in  $\mu$ S cm<sup>-1</sup>. For months in which replicate measurements were made, means and ranges are given.

date	T1	T2	T3	T4	T5	B6	B7	B8
17 <sup>th</sup> Jun 97								
	200	201	210	201	202	570	5(0	577
Mean	299	301	310	291	302	579	568	577
Range	295-303	298-309	309-311	290-291	298-306	578-579	566-570	562-591
18 <sup>th</sup> Jun 97	360	316	315	289	298	579	581	587
21 <sup>st</sup> Jul 97								
Mean	324	282	283	275	277	526	524	528
Range	323-326	282-283	283-284	274-276	277	525-527	522-527	528
18 <sup>th</sup> Aug 97								
Mean	219	223	225	225	220	508	498	508
Range	218-221	221-225	224-227	223-228	217-223	508-509	496-500	507-509
22 <sup>nd</sup> Sep 97	315	318	330	346	328	497	496	459
20 <sup>th</sup> Oct 97	361	305	327	320	325	464	465	420
29 <sup>th</sup> Nov 97								
Mean	314	323	314	326	326	479	478	447
Range	310-319	323-324	313-316	325-328	325-327	476-483	477-480	446-449
18 <sup>th</sup> Feb 98	329	338	347	334	333	528	511	507

The same seasonal trend in conductivity was demonstrated at all stations in Turraun. Values fell from June to July and reached their lowest values of the sampling period in August. Conductivity rose dramatically again from August to September and remained more or less constant for all subsequent months. A different trend was found at the Tumduff stations, with conductivity falling gradually between June and October before rising in November and February.

date	T1	T2	T3	T4	T5	B6	B7	B8
17 <sup>th</sup> Jun 97	148	155	156	151	149	289	286	291
18 <sup>th</sup> Jun 97	171	158			151			
21 <sup>st</sup> Jul 97	157	140	143	139	140	266	263	265
18 <sup>th</sup> Aug 97	107	116	115	116	114	255	253	255
22 <sup>nd</sup> Sep 97	158	159	168	168	165	251	248	234
20 <sup>th</sup> Oct 97	151	152	163	159	160	230	230	210
29 <sup>th</sup> Nov 97	160	162	158	165	166	226	239	243

**Table 3.4** Total dissolved solids measured in the field. Values, based on single measurements, are given in mg  $l^{-1}$  solids.

Total dissolved solids measurements range from 107 to 171 mg  $l^{-1}$  in Turraun and from 210 to 291 mg  $l^{-1}$  in Tumduff (Table 3.4). These figures reflect conductivity values in terms of between wetland patterns and seasonal trends.

#### 3.3.2 Routine chemical analysis

Concentrations of Molybdate Reactive Phosphorus (MRP), total ammonia, nitrate and chloride on the various sampling dates are given in tables 3.5 to 3.8. Table 3.9 reports the nutrient concentrations in the Silt Lagoon, the southern drain at Turraun and the inlet stream to Tumduff. Ideally, nutrients (MRP, NO<sub>3</sub>-N and NH<sub>3</sub>) should be analysed within a day of sampling. With this in mind, results reported below should be treated with some caution.

Given the limit of detection, trace concentrations of MRP (Table 3.5) were recorded in both wetlands on most occasions. Some Turraun sampling stations, however, demonstrated very high MRP concentrations on certain dates, e.g. T3 and T5 in March, T3 in May. All Turraun stations had highly elevated concentrations in August, when the extremely high value of 204  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P was recorded at T3. In Tumduff the highest concentration of 34  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P was recorded at B8 in November. In all months with the exception of November, MRP average values at Turraun exceeded those at Tumduff.

date	T1	T2	T3	T4	T5	ave	B6	B7	B8	ave
18 <sup>th</sup> Mar 97	3	4	20	2	23	10.4	5	3	4	4.0
18 <sup>th</sup> Apr 97	2	4	3	3	4	3.2	2	2	2	2.0
19 <sup>th</sup> May 97	4	4	63	5	5	16.2	3	3	3	3.0
17 <sup>th</sup> Jun 97	4	6	4	4	4	4.4	3	4	3	3.3
21 <sup>st</sup> Jul 97	10	6	8	6	8	7.6	4	2	2	2.7
18 <sup>th</sup> Aug 97	17	16	204	12	36	57.0	2	2	2	2.0
22 <sup>nd</sup> Sep 97	4	4	13	6	5	6.4	1	2	2	1.7
20 <sup>th</sup> Oct 97	4	5	6	5	5	5.0	5	2	6	4.3
29 <sup>th</sup> Nov 97	3	6	4	3	3	3.8	2	2	34	12.7
18 <sup>th</sup> Feb 98	2	2	6	2	9	4.2	2	2	2	2.0

Table 3.5MolybdateReactivePhosphorus(PO<sub>4</sub>-P)valuesmeasuredinthelaboratory.Values given in  $\mu g l^{-1} PO_4$ -P.Average figures are given for each<br/>wetland.

Total ammonia concentrations (Table 3.6) ranged from low (e.g. 0.01 mg  $l^{-1}$  N at T2 and B8 in June) to very high (e.g. 0.73 mg  $l^{-1}$  N at T3 and 0.88 mg  $l^{-1}$  N at B7 in August) in the wetlands. There was no clear difference in concentration between the wetlands. The highest monthly concentration in Turraun was at T3 in April, May, June and August and at T1 in October. The concentration at T5 was high in August, October and November. Concentration was occasionally high at each of the Tumduff stations (e.g. at B7 and B6 in August and October and at B8 in August). Averaging the data for each wetland, similar seasonal trends emerge, with peaks in May and October and the highest average concentration recorded in August. This trend can be seen at all Tumduff stations, although, it is only truly demonstrated at T5 in Turraun.

Table 3.6Total ammonia ( $NH_4^+$  &  $NH_3$ ) values measured in the laboratory. Values<br/>given in mg l<sup>-1</sup> N. ave = wetland average. § March readings can be considered<br/>estimates, as standard concentration were too high.

date	T1	T2	Т3	T4	T5	ave	B6	B7	B8	ave
18 <sup>th</sup> Mar 97 §	0	0	0	0	0	0	0.1	0.1	0	0.07
18 <sup>th</sup> Apr 97	0.04	0	0.16	0.02	0.03	0.05	0.04	0.06	0.04	0.05
19 <sup>th</sup> May 97	0.20	0.20	0.33	0.23	0.12	0.22	0.29	0.28	0.17	0.25
17 <sup>th</sup> Jun 97	0.00	0.01	0.04	0.03	0.03	0.02	0.05	0.06	0.01	0.04
21 <sup>st</sup> Jul 97		0.11		0.15		0.13	0.17	0.21	0.11	0.16
18 <sup>th</sup> Aug 97	0.33	0.17	0.73	0.20	0.42	0.37	0.55	0.88	0.65	0.69
22 <sup>nd</sup> Sep 97	0.09	0.08	0.09	0.06	0.01	0.07	0.05	0.03	0.08	0.05
20 <sup>th</sup> Oct 97	0.65	0.06	0.04	0.06	0.13	0.19	0.50	0.60	0.38	0.49
29 <sup>th</sup> Nov 97	0.04	0.03	0.04	0.02	0.06	0.04	0.44	0.36	0	0.26
18 <sup>th</sup> Feb 98	0.05	0.05	0.04	0.05	0.01	0.04	0.16	0.11	0.04	0.10

Nitrate concentration (Table 3.7) was generally low in Turraun, with the exception of July when concentrations were relatively high at all stations. Concentration at Tumduff was relatively high in March and April, but low in July and August. Between wetland differences in average concentration varied, being higher in Turraun in July and in Tumduff in March, April and August. Owing to the small number of data points, it was difficult to elucidate seasonal trends. Nitrate concentration was low in March in Turraun; it increased slightly during the summer months, reaching peak values in July and dropped considerably in August. At Tumduff, the concentration dropped sharply from March to July before increasing slightly in August.

**Table 3.7** Nitrate (NO<sub>3</sub><sup>-)</sup> values measured in the laboratory. Values given in mg  $l^{-1}$  N

date	T1	T2	T3	T4	T5	B6	B7	B8
6 <sup>th</sup> Dec 96				0.076				
18 <sup>th</sup> Mar 97	0.048	0.049	0.000	0.045	0.000	1.366	1.397	1.412
18 <sup>th</sup> Apr 97	0.067	0.069	0.062	0.087	0.097	0.926	0.950	0.999
17 <sup>th</sup> Jun 97	0.071	0.108		0.049				
21 <sup>st</sup> Jul 97	0.305	0.218	0.196	0.213	0.206	0.044	0.044	0.037
18 <sup>th</sup> Aug 97	0.036	0.000	0.000	0.030	0.000	0.079	0.076	0.080

Table 3.8 shows chloride concentrations. The range in concentration was 13.70 to 22.83 mg  $I^{-1}$  Cl in Turraun and 15.69 to 18.39 mg  $I^{-1}$  Cl in Tumduff. There was no obvious difference between wetlands in chloride concentration. No clear seasonal trend was apparent at the Turraun stations, although, concentrations generally fell in spring before rising again in summer. In Tumduff, chloride concentration increased from March to July, before dropping slightly in August.

Table 3.8	Chloride (Cl <sup>-</sup> )	values measured	in the laboratory.	Values given	n in mg l <sup>-1</sup> C	1
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date	T1	T2	Т3	T4	T5	B6	B7	B8
6 <sup>th</sup> Dec 96				18.33				
18 <sup>th</sup> Mar 97	14.16	13.97	13.70	13.99	14.09	15.91	15.69	15.71
18 <sup>th</sup> Apr 97	15.50	15.57	15.77	15.68	16.19	17.22	17.49	17.91
17 <sup>th</sup> Jun 97	16.13	16.43		16.12				
21 <sup>st</sup> Jul 97	17.85	16.85	17.39	17.16	17.83	18.39	18.22	17.96
18 <sup>th</sup> Aug 97	21.51	17.53	22.83	16.47	16.85	17.15	17.21	17.15

Table 3.9 details the nutrient chemistry of the Silt Lagoon, the southern drain at Turraun and the inlet stream at Tumduff. MRP concentration was generally low at the three sites, ranging from 1 to 4  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P in the silt lagoon, from 4 to 11  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P in the

southern drain and from 2 to 19  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P in the Tumduff inlet stream. Total ammonia concentrations varied among the three sites and were very high in the southern drain (ranging from 0.87 to 1.7 mg l<sup>-1</sup> N). Nitrate values at all three sites were low and chloride concentrations were similar to those of the wetlands.

**Table 3.9** Nutrient concentrations in the Silt Lagoon and Drain and Turraun and in Tumduff inlet stream. MRP is in  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P, total ammonia in mg l<sup>-1</sup> N, nitrate mg l<sup>-1</sup> N in and chloride in mg l<sup>-1</sup> Cl.

date	Silt Lagoon			Turraun Drain				Tumduff Inlet				
	PO <sub>4</sub> -P	$\mathrm{NH}_3$	$NO_3$	Cl	PO <sub>4</sub> -P	NH <sub>3</sub>	NO <sub>3</sub>	Cl	PO <sub>4</sub> -P	NH <sub>3</sub>	NO <sub>3</sub>	Cl
18 <sup>th</sup> Apr 97	2	0.01	0.07	16.17					19	0.46	0.07	17.74
19th May 97	4	0.02										
21 <sup>st</sup> Jul 97					6	0.87	0.16	11.76				
18 <sup>th</sup> Aug 97	2	0.19	0.27	17.24	6	1.62	0.21	12.61				
22 <sup>nd</sup> Sep 97	1	0.23			5	1.71		9.8674				
20 <sup>th</sup> Oct 97	2	0.13			11	1.61			2	0		
29 <sup>th</sup> Nov 97	2	0.41			4	1.58			2	0.01		
18 <sup>th</sup> Feb 98	2	0.24										

### 3.3.3 Further chemical analysis

Samples taken from Turraun and Tumduff wetlands on the 9<sup>th</sup> August 1999 were analysed between 10<sup>th</sup> and 13<sup>th</sup> August 1999 (Table 3.10). As replicate measurements proved more or less identical for all analyses, average figures are quoted.

parameter	unit	Turraun	Tumduff	
pН		8.45	8.34	
Total alkalinity	mg l <sup>-1</sup> CaCO <sub>3</sub>	104	193.8	
Colour	mg l <sup>-1</sup> PtCo	53	63	
Chlorophyll a	$\mu g l^{-1}$	110.0	2.5	
Total phosphorus	mg l <sup>-1</sup> P	0.076	0.016	
Calcium	mg l <sup>-1</sup> Ca	44	106	

Table 3.10 Analyses of water sampled 9<sup>th</sup> August 1999

The pH in both wetlands was high on 9<sup>th</sup> August. Turraun was moderately alkaline while Tumduff was highly alkaline. The waters were markedly coloured, Tumduff being more coloured than Turraun. Chlorophyll *a* concentration was extremely high in Turraun and low in Tumduff. Total phosphorus was very high in Turraun and moderately high in Tumduff. Calcium concentration was moderately high in Turraun and extremely high in Tumduff.

#### **3.4 Discussion**

The discussion attempts to explain the origin of and seasonal trends in the reported physico-chemical data, and to elucidate some of the processes acting within the wetlands. Owing to the absence of analogous water bodies in Ireland, comparative water chemistry data was unavailable. Whilst recognising the differences in chemical processes between the artificial wetlands and large natural lakes, data for Irish rivers and lakes is quoted throughout the discussion in order place the study sites within an Irish context. Where possible, chemical values from the Norfolk Broads, England, and the Loosdrecht Lakes, the Netherlands, are noted. Both of these areas originated from mediaeval peat excavations and have suffered from eutrophication in recent years.

#### 3.4.1 Routine field measurements

As expected water temperature was highest during the summer months and lowest during The summer temperatures recorded in Turraun and Tumduff were the winter. unexpectedly high. The normal temperature range in Irish waters is 0 to 25 °C, with values of 25 °C only occasionally encountered (Flanagan 1992). Both study wetlands exceeded 25 °C in summer 1997. The dark sediments may have readily absorbed irradiation and heated the shallow water column rapidly. Both wetlands were also subject to ice formation, Turraun much more so than Tumduff. An extensive sheet of ice, 3-4 mm thick, covered most of the surface of Turraun on 9<sup>th</sup> January 1999. On the same date, a thin ring of ice stretched for c. 1 m from the shoreline at Tumduff. Ice formation could be a result of the very low volume to surface area ratio, which allowed the wetland to lose, as well as gain, heat rapidly. The wide temperature ranges in Turraun and Tumduff could preclude temperature sensitive fauna from inhabiting the wetlands. Increasing temperature decreases the concentration of oxygen that a given body of water can hold and this can have directly harmful effects on macroinvertebrates and fish. At higher temperatures a greater percentage of ammonia is de-ionised to the toxic form (NH<sub>3</sub>) (Flanagan 1992).

The pH of both wetlands was highly alkaline, both in routine field measurements and laboratory analysis, with values generally above the equilibrium (pH 8.3) for calcareous groundwater (Norman Allott personal communication). Values were similar to those found in the Norfolk Broads, where the average pH was c. 8.0 and the maximum rarely exceeded 9 (Moss 1983).

pH was very high in June and July, particularly in Turraun and was strongly correlated with temperature at Turraun but not at Tumduff. This would suggest that pH was elevated by photosynthetic activity in Turraun, where macrophytes and phytoplankton were more abundant than at Tumduff. Increased solar irradiance on water leads to an increase in both temperature and photosynthetic rate. As photosynthesis increases, so too does the consumption of CO<sub>2</sub>. In alkaline waterbodies CO<sub>2</sub> is produced in reactions involving bicarbonate, with the eventual release of hydroxyl ions (OH<sup>-</sup>) and a corresponding increase in pH (Otsuki & Wetzel 1973, 1974). Despite the photosynthetically elevated pH in Turraun, the pH range in both lakes was narrow, suggesting a large buffering capacity. A similar situation is found in the Norfolk Broads, but in the English Lake District photosynthesis can cause pH to rise to 10 or 11 (Moss 1983). The pH in both wetlands was considerably lower in September than in earlier months. This was probably because of a reduction in photosynthesis, combined with the dilution of the calcareous groundwater with rainwater.

The water in both wetlands was found to be saturated with dissolved oxygen during the day on 17<sup>th</sup> June 1997 and slightly below saturation on 22<sup>nd</sup> September 1997. The large surface area to volume ratios, the wide fetches, the lack of surrounding shelter and the frequent wave action, would have aided the exchange of atmospheric oxygen in the wetland waters. Excess dissolved oxygen, however, is generally indicative of an enriched waterbody, with a high algal biomass (Flanagan 1992). High rates of algal photosynthesis in summer release large quantities of oxygen to the water. At night, drops in oxygen can occur when photosynthesis ceases and respiration by bacteria, phytoplankton, macrophytes and animals takes over. However, no oxygen measurements were made at the study sites at night.

The conductivity readings for both wetlands were relatively high. Conductivity is proportional to the concentration and extent of dissociation of dissolved salts and in hard waters is closely proportional to the concentrations of the major cations (Otsuki & Wetzel 1974). In Turraun and Tumduff, which had relatively hard water (Table 3.10), the dominant cations were probably calcium (Ca<sup>2+</sup>) and to a lesser extent magnesium (Mg<sup>2+</sup>). The higher conductivity in Tumduff may be explained by the greater calcium concentration in that wetland (see section 3.3.3).

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Conductivity increases with increasing temperature, although, in both wetlands the conductivity decreased during the summer months and increased during the autumn/winter. This suggests that the seasonal trend was closely linked to changes in calcium concentration. The summer decreases in conductivity reflected the loss of calcium ions from the epilimnion owing to calcite precipitation. Calcium carbonate (CaCO<sub>3</sub>) precipitation was observed on many occasions as a tufaceous crust on the sediment of both wetlands. Precipitation can be initiated by high temperatures reducing the solubility of calcium or by high rates of photosynthesis (Otsuki & Wetzel 1973, 1974, Kleiner 1990, Stewart & Wetzel 1981a). Reduced inflow of calcium rich groundwater may also have contributed to the low summer conductivity. In Turraun the lowest conductivity values were encountered in August. In that same month temperature, and possibly also planktonic productivity, was highest and probably led to the greatest calcium carbonate precipitation The dramatic increase in conductivity from August to September in Turraun rates. concurred with the decrease in pH. This may indicate a reduction in photosynthesis and the cessation of calcium carbonate precipitation. In Tumduff, the lowest conductivity values were recorded in October. High rainfall leading to dilution of the ion rich water in Tumduff is the most likely explanation for this.

Gray (1999) quotes a range of 10 to 1000  $\mu$ S cm<sup>-1</sup> for natural rivers and lakes. The conductivity at Turraun is below the median of this range and that at Tumduff, median or slightly above. Figures quoted for Irish waterbodies suggest that conductivity at Turraun and Tumduff was high. Flanagan and Toner (1975) reported a range of 50-500  $\mu$ S cm<sup>-1</sup> in Irish lakes, with central limestone lakes generally greater than 250  $\mu$ S cm<sup>-1</sup>. The mean conductivity for the Grand Canal was 501  $\mu$ S cm<sup>-1</sup> (Lucey *et al.* 1999). Sea spray influenced, acid streams in Galway and Mayo ranged from 177 to 293  $\mu$ S cm<sup>-1</sup> (Reynolds *et al.* 1994).

Total dissolved solids are a measure of all solids, including ions and organic matter, dissolved in the water (Gray 1999). As the probe used calculated TDS directly from conductivity, no information further to that discussed above was elucidated.

#### 3.4.2 Routine chemical analysis

The long storage period prior to analysis for Molybdate reactive phosphorus (MRP) means the results are not entirely reliable. Because of the method of sampling, sediment may have been stirred up and sediment release of nutrients could have led to erroneous values. MRP was generally low (2-10  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P) in Turraun, with occasional high concentrations recorded at various stations. The extremely high concentrations (e.g. 204  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P in T3) recorded in August 1997 are above normal for temperate freshwaters and may be erroneous. MRP was very low in Tumduff (1-6  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P), with only one high measurement (34  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P) made at B8 on the 29<sup>th</sup> November.

MRP is predominantly composed of orthophosphate (Gary Free personal communication). It is often considered to represent the biologically available phosphorus fraction (Flanagan 1992), although it does not take into account rapid transformations and flux rates of phosphorus (Ken Irvine personal communication). It appears that most of the MRP was bioavailable at Turraun, leading to the algal bloom observed from March/April to late October. Phosphorus is generally considered the limiting nutrient in freshwaters (Vallentyne 1974, Wetzel and Likens 1991, Jeffrey 1998, Gray 1999) and as a result MRP is normally encountered in very low concentrations. The high concentrations encountered in Turraun may indicate a recent artificial release of MRP or phosphorus release from the sediments. Phosphorus may not always have been the limiting nutrient in Turraun. In Ireland, Flanagan and Toner (1975) state that orthophosphate is rarely found in concentrations > 17  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P in the absence of artificial enrichment and that values in excess of 10  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P can lead to excessive production of algae. Concentrations > 30  $\mu$ g l<sup>-1</sup> PO<sub>4</sub>-P were recorded in Turraun in May and August. An algal bloom was observed at Turraun along with extensive periphyton growths at T3 (which demonstrated some of the highest MRP concentrations). Both of these are indicative of excessive phosphate in Irish waters (Flanagan 1992).

Total ammonia concentration was very variable. The seasonal trend in both wetlands indicated summer peaks in concentration. This is contrary to the expected trend in freshwaters, which is year-round low concentrations of total ammonia (because it is readily oxidised to nitrate), with possible decreases during the growing season. Concentrations of ammonia greater than 0.1 mg  $I^{-1}$  N, usually indicate pollution (Flanagan 1992). The high values encountered in both Turraun and Tumduff in August may represent pollution

incidents. Anecdotal evidence indicated that a slurry tank was washed out on the western shore of Turraun during summer 1997. Alternatively,  $NH_4^+$  may have been released from the sediments during summer.

Measurement of total ammonia includes both free, non-ionised ammonia (NH<sub>3</sub>) and saline ammonia (ammonium NH<sub>4</sub><sup>+</sup>). Unionised ammonia is very harmful to aquatic life and the Freshwater Fish Directive (78/659/EEC) gives a maximum allowable concentration of <0.025 mg l<sup>-1</sup> NH<sub>3</sub>. The percentage of total ammonia available in the unionised form is dependent on both pH and water temperature (Wetzel & Likens 1991, Flanagan 1992). It was found that total ammonia concentrations for both wetlands in August all contained non-ionised ammonia far in excess of >0.02 mg l<sup>-1</sup> NH<sub>3</sub>. There may have been excessive amounts of NH<sub>3</sub> on other occasions (e.g. T3 in May, T1 in October and B6 in November), but pH values were not available for these dates.

The concentration of ammonia in a sample can change markedly in a short space of time (Wetzel and Likens 1991), and samples not analysed rapidly may generate misleading results. Whilst it is possible that some total ammonia concentrations may be erroneous, owing to the delays in analysis and difficulties establishing a relevant standard curve, the values were generally quite high. The analysis of August samples (which suggested a domestic or agricultural pollution incident) was rapid and proceeded without difficulty.

Nitrate was generally low in Turraun, indicating much of the available nitrogen was assimilated by phytoplankton, periphyton and macrophytes. Relatively high concentrations of nitrate were recorded in July. Concentration fell dramatically after July and only trace amounts were detected in August. Nitrate is normally detectable in freshwater and trace concentrations in Irish waters often indicate artificial enrichment (Flanagan & Toner 1975). MRP concentrations were high in Turraun in August and nitrate may have been the limiting nutrient at that time. At Tumduff, the gradual decline in nitrate from March to July was more typical of the seasonal pattern in productive waterbodies, where nitrate is often markedly reduced in concentration during the growing season (Flanagan & Toner 1975).

The author received reports of a slurry tank being washed out in Turraun during summer 1997, and nutrient analysis suggests this occurred in July or early August. It is also

possible that sediment release of MRP and total ammonia occurred at this time, but this was not measured as the topic is beyond the scope of the thesis.

Chloride levels were low for freshwater, which is not surprising in an area overlying limestone, removed from the influence of sea spray. The natural range in chloride is 15 to 35 mg l<sup>-1</sup> Cl (Flanagan 1992) and midland lakes generally have concentrations <20mg l-1 (Flanagan & Toner 1975). August values of 22.8 and 21.5 mg l<sup>-1</sup> Cl, recorded in T3 and T1 respectively, were considerably higher than concentrations recorded on other dates and at other Turraun stations on that date. This may indicate a discharge of sewage or slurry (Flanagan 1992) between these adjacent sampling points.

MRP and total ammonia concentrations in the Silt Lagoon at Turraun were generally as low as or lower than concentrations in the main wetland. Nitrate values in August were high. MRP was moderately low in the southern drain at Turraun, but the total ammonia concentrations were extremely high. Water from the Silt Lagoon may have percolated into Turraun through the peat. Water from the southern drain flowed directly into Turraun at times of high precipitation. There is no evidence that either the Silt Lagoon or the southern drain represented a source of enrichment to Turraun. MRP and total ammonia concentrations in the Tumduff inlet in April were relatively high and may have caused a degree of enrichment in the wetland. Nutrient concentrations were otherwise very low in the stream.

#### 3.4.3 Further chemical analysis

On the 9<sup>th</sup> August 1999, total alkalinity at Turraun was moderate to high, while that at Tumduff was very high. The concentrations indicate that both wetlands have a high buffering capacity. High alkalinity is mainly caused by the presence of bicarbonates  $(HCO_3^{-})$  and is reflected by high concentrations of cations, particularly calcium. The alkalinity values at Turraun and Tumduff were, concurrent with moderately and extremely high calcium concentrations respectively. The availability of large concentrations of bicarbonate allows the photosynthetic elevation in pH, through the following equations:

$$\mathrm{H}^{+} + \mathrm{HCO}_{3}^{-} \leftrightarrow \mathrm{H}_{2}\mathrm{CO}_{3} \left[\mathrm{H}_{2}\mathrm{O} + \mathrm{CO}_{2}\right] \tag{1}$$

(2)

$$H^+ + CO_3^{2-} \leftrightarrow HCO_3^{--}$$

(Otsuki & Wetzel 1974). Equation 1 releases carbon dioxide necessary for photosynthesis.

While natural rivers in Ireland may have total alkalinity concentrations as high as 400 mg  $\Gamma^{1}$  CaCO<sub>3</sub> (Flanagan 1992), this is atypical. Flanagan and Toner (1975) recorded a range of 10 to 240 mg  $\Gamma^{1}$  CaCO<sub>3</sub> for Irish lakes. Irish lakes with alkalinity similar to Turraun included Loughs Corrib, Lene, Owel and Rea and alkalinity similar to Tumduff was found in Loughs Inchiquin, Cara, Derg and Ballycullinan (Flanagan & Toner 1975, Allott *et al.* 1998). Alkalinity in Turraun falls within the range found in some of the Norfolk Broads (e.g. Hickling Broad, 80-155 mg  $\Gamma^{1}$  CaCO<sub>3</sub>; Hoevton Great Broad, 85-215 mg  $\Gamma^{1}$  CaCO<sub>3</sub>) (Moss 1983).

Both wetlands were highly coloured on the 9<sup>th</sup> August 1999. This colour was almost certainly owing to the release of humic substances from peat within and surrounding the wetlands and indicates the presence of significant concentrations of dissolved humic material (DHM). Similar values were recorded in Lough Bray (56 mg l<sup>-1</sup> PtCo), Lough Doo (69 mg l<sup>-1</sup> PtCo), Lough Easky (62 mg l<sup>-1</sup> PtCo), Lough Lettercraffroe (50 mg l<sup>-1</sup> PtCo) and Lough Poulaphuca (64 mg l<sup>-1</sup> PtCo) (Allott *et al.* 1998). Many of these waterbodies lie in peaty catchments. Colour of 130 Hazen units (roughly equivalent to mg l<sup>-1</sup> PtCo) was recorded for hypertrophic for Lough Ramor, Co. Cavan and for Lough Fada, which lies in the midst of Roundstone Atlantic blanket bog (McGarrigle *et al.* 1990). As colour is generally higher in winter, when the degradation rate of colloidal material is not as high (Gary Free personal communication), the water at the study sites may have been even more highly coloured in winter.

Chlorophyll *a* concentration was extremely high in Turraun on 9<sup>th</sup> August 1999, but low in Tumduff. The high values at Turraun reflect the presence of an extensive phytoplankton bloom. The water at Turraun had a characteristic red-brown hue, indicating a plankton bloom from March/April to late October 1997, and for long periods in the two subsequent years. Phytoplankton blooms were not observed at Tumduff during sampling. It was not possible to apply the O.E.C.D. trophic classification scheme for lakes (O.E.C.D. 1982), nor the EPA modified version (Lucey *et al.* 1999) to these data, as annual means and maximums are required. The single chlorophyll *a* measurements suggested that primary productivity in Turraun is high (hypertrophic) and that in Tumduff is low (oligotrophic). Lucey *et al.* (1999) recorded only four Irish lakes (Loughs Ramor, Oughter, Sillan and White) with maximum chlorophyll *a* concentrations equal to or greater than that recorded in August at Turraun. Of 31 lakes studied by Allott *et al.* (1998), only Lough Ramor had a

higher maximum chlorophyll *a* value. The chlorophyll *a* concentration in Tumduff was similar to that in Kylemore lake (2.4  $\mu$ g l<sup>-1</sup>) (McGarrigle *et al.* 1990) and Lough Easky (1.7-2.6  $\mu$ g l<sup>-1</sup>) (Flanagan & Toner 1975), both of which are considered oligotrophic.

Total phosphorus was very high in Turraun and moderately high in Tumduff. While the data were too few to allow trophic classification, the values suggest Turraun is highly eutrophic to hypertrophic and Tumduff is mesotrophic (Lucey et al. 1999). The high total phosphorus concentration at Turraun was matched by high chlorophyll a values. TP concentration on 9<sup>th</sup> August 1999 at Turraun fell within the range found in the artificially enriched Norfolk Broads (e.g. Brundall Gardens Broad, 0.02-0.105 mg l<sup>-1</sup> P; Wroxham Broad, 0.059-0.253 mg l<sup>-1</sup> P) (Moss 1983). It is interesting to note that the moderately high total phosphorus value in Tumduff did not lead to a high algal biomass. In this respect Tumduff is similar to Lough Akibbon, Co. Donegal (total phosphorus 0.012-0.028 mg l<sup>-1</sup> P, chlorophyll a 1.1-1.2  $\mu$ g l<sup>-1</sup>), which is a shallow, soft water oligotrophic lake in a peaty catchment (Flanagan and Toner 1975). Many authors have found that coloured lakes with high concentrations of dissolved humic materials have high total phosphorus concentrations that are not reflected by high productivity nor high concentrations of MRP (e.g. Hutchinson 1975, Flanagan & Toner 1975). This appears to be because of the presence of phosphorus in non-bioavailable, DHM-orthophosphate complexes (Stewart & Wetzel 1981a, Francko 1986, Jones 1990, McGarrigle & Kilmartin 1992).

Calcium concentration was moderately high in Turraun and extremely high in Tumduff. This fact was supported by higher conductivity values throughout the year at Tumduff, along with higher alkalinity. As stated in section 3.3.3, calcium precipitation was observed to occur in both wetlands. This may be initiated by either elevations in temperature, or photosynthetic activities of phytoplankton. Increases in temperature rapidly decrease the solubility of both carbon dioxide and calcium carbonate, leading to precipitation by the following equation in saturated waters:

 $Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$ 

(Otsuki & Wetzel 1974). Photosynthesis induces precipitation as following:

 $Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$ 

leading to the release of carbon dioxide, which is utilised in photosynthesis, and an increase in pH (Otsuki & Wetzel 1973).

Summer decreases in conductivity indicated that calcium was lost from both wetlands, either through precipitation or reduced inflow of ground water. Calcium carbonate precipitation is very important as it removes dissolved humic material from the water column by adsorption and incorporation into the crystal during nucleation (Otsuki & Wetzel 1973, 1974, Kleiner 1990, McGarrigle & Kilmartin 1992, Wetzel 1993). Calcium can also co-precipitate MRP (Francko & Heath 1982, Jeffrey 1998). Stewart & Wetzel (1981a) demonstrated that DHM (particularly fulvic acid) could inhibit calcium carbonate precipitation. Inhibition will not occur where temperature and productivity are very high, when DHM is photolysed to carbonates and water or when the DHM does not contain inhibitory fractions (McGarrigle & Kilmartin 1992).

#### 3.4.4 General discussion and conclusions

Both wetlands were coloured owing to dissolved humic materials (DHM) supplied by the peat sediment. As mentioned in section 3.4.3, coloured waterbodies often have high total phosphorus concentrations. Turraun and Tumduff had large concentrations of total phosphorus on the 9<sup>th</sup> of August, but the origin of that phosphorus was uncertain. MRP, total ammonia and nitrate concentrations for August, along with anecdotal evidence, suggested Turraun suffered artificial enrichment between late July and early August. August chloride values suggested that the pollution may have been released from a point source, somewhere between stations T3 and T1. Alternatively bacterial mineralisation of peat and/or nutrient release from the sediments may have occurred.

Biologically available phosphorus in peaty waters, slowly adsorbs to DHM (McGarrigle & Kilmartin 1992). Orthophosphate can interact with DHM in two ways, it can form a DHM-PO<sub>4</sub> complex, or a DHM-Fe<sup>3+</sup>-PO<sub>4</sub> complex (Francko & Heath 1982, Francko 1986, Jones 1990, McGarrigle & Kilmartin 1992). The former is highly stable and effectively means the loss of the phosphorus from the system, while the later may be regenerated. Orthophosphate regenerative mechanisms have been the subject of much study (Francko 1986). UV-induced release has received particular focus (Francko & Heath 1982, McGarrigle & Kilmartin 1992). It is thought to be brought about by the photoreduction of ferric iron (Fe<sup>3+</sup>) to ferrous iron (Fe<sup>2+</sup>) with the consequent release of orthophosphate from the DHM-Fe<sup>3+</sup>-PO<sub>4</sub> complex. Two other possible orthophosphate regenerative mechanisms are polycondensation of various phosphorus fractions and hydrolysis of

phosphorus fractions by phosphatase enzymes (Francko 1986). DHM-Fe<sup>3+</sup>-PO<sub>4</sub> complexes can have the effect of maintaining orthophosphate in the epilimnion of lakes (McGarrigle & Kilmartin 1992). Jones (1990) believed that the DHM-Fe<sup>3+</sup>-PO<sub>4</sub> complex had a buffering capacity, releasing phosphorus when all freely available PO<sub>4</sub>-P was used up. This would have the effect of allowing a more sustained phytoplankton bloom, as witnessed at Turraun.

Calcium interferes with DHM and  $PO_4$ -P in a number of ways. As mentioned in section 3.4.3, calcium carbonate can co-precipitate  $PO_4$ -P, however, it will preferentially bind to high molecular weight DHM (Stewart & Wetzel 1981b). DHM can either be incorporated into the calcite crystal during nucleation or can adsorb onto the surface (Otsuki & Wetzel 1973, Kleiner 1990). DHM, particularly fulvic acid, can actually inhibit calcium carbonate precipitation (Stewart & Wetzel 1981a), although certain factors can reduce this effect (see section 3.4.3). Interactions between phosphorus, calcium, iron and DHM cannot be elucidated from the reported data, but represent an interesting area for further study.

Calcium precipitation in Turraun was probably triggered by the high photosynthetic activity of the plankton bloom. Precipitation led to the release of carbon dioxide for photosynthesis and an increase in pH. The very high calcium concentration in Tumduff suggested calcite precipitation resulted from supersaturation with calcium and was initiated by high temperature reducing the solubility of calcium and carbon dioxide.

Plankton biomass was high at Turraun and was maintained for most of the year. The large surface area and shallow depth of the wetland probably encouraged high rates of photosynthesis. Photosynthesis by algae led to increases in pH during the summer months, although the lake appeared to have a large buffering capacity. Nutrients seem to have come from a combination of natural and anthropogenic enrichment. The relative contribution of these factors is currently unknown. The data gathered suggested that Turraun is a moderately hard, coloured, highly eutrophic to hypertrophic, groundwater wetland.

It appears that Tumduff, on the other hand, fits the typical model of a coloured waterbody with high total phosphorus and low primary productivity. The phosphorus appeared not to be bioavailable and may have been derived from decomposition of peat in the sediment and/or catchment. Plankton blooms were not observed at Tumduff during the period of the study. Tumduff can be considered a hard, oligotrophic ground water pond.

The results of investigations into physical and chemical properties suggest macroinvertebrates may encounter a number of difficulties in the study wetlands. High temperatures and toxic concentrations of ammonia may damage or limit the aquatic fauna. Eutrophication at Turraun may also have a number of negative effects on the wetland. High primary productivity causes night-time depletion of dissolved oxygen and has a direct impact on the fauna. Eutrophication can lead to compositional, structural and abundance changes in the invertebrate fauna. This is often an indirect effect, with water chemistry generating changes in the photosynthetic communities, which have an knock-on effect on the fauna (Moss 1983). Loss of macrophytes can cause a decrease in macroinvertebrate diversity and abundance (Moss 1983).

The wetland contains an abundance of nutrients and ions essential to the growth of macroinvertebrates. Calcium concentration is high and this is not only important in terms of conductivity, alkalinity, water hardness and pH, but is also an essential element for growth and health of macroinvertebrates such as Mollusca and Crustacea. The macroinvertebrate communities found in Turraun and Tumduff will now be discussed in Section B.

**Section B** 

# MACROINVERTEBRATE POPULATIONS OF TURRAUN & TUMDUFF

#### Foreword

Macan (1965a) stated that whether the purpose of a community study is academic or applied, the following fundamental information is required:

- 1. What species are present
- 2. What the life histories of these species are
- 3. How the number of each species varies
  - a) spatially within the water body
  - b) throughout the lifecycle
  - c) with time.

Section B presents this fundamental information for the macroinvertebrate communities of the study sites, Turraun and Tumduff.

In Chapter 4, the macroinvertebrates of the wetlands are described in terms of temporal changes between January 1997 and February 1998, and spatial variations among eight sampling stations. Lists of all species captured over the study period (October 1996 to August 1999) are also included. The two wetlands, Turraun and Tumduff, and eight sampling stations are compared in terms of species present, taxon richness and abundance, diversity and temporal changes. These results are related to habitat factors (sediments and macrophytes), wetland age and morphology. Temporal and spatial variations in Corixidae between January 1997 and April 1999 will be returned to in detail in Section C, Chapter 5.

Chapter 4

# SPATIAL & TEMPORAL VARIATIONS IN MACROINVERTEBRATES AT TURRAUN & TUMDUFF

#### 4.1 Introduction

While pools and ponds are common on exploited peatlands in Ireland, there have been few published accounts of their macroinvertebrate populations. Whelan (1996) studied the macroinvertebrate fauna of acid pools created by hand cutting on midlands raised bog, and found they were characterised by low macroinvertebrate species richness and abundance. A number of undergraduate reports and theses at the Zoology Department, Trinity College, Dublin studied aspects of the macroinvertebrate fauna of Bord na Móna cutaway ponds (e.g. Fay *et al.* 1996, Kaens 1996).

Biogeographical studies of certain aquatic macroinvertebrate orders, such as Odonata, Heteroptera and Coleoptera have made mention of the fauna of Irish cutover and cutaway habitats (Bilton 1988, O'Connor & Murphy 1988, Nelson *et al.* 1989, Bilton & Lott 1991, Foster *et al.* 1992, Nelson 1995). Species richness is often found to be high in these artificial habitats (Foster *et al.* 1992, Nelson 1995, Foster & Bilton 1998).

Artificial ponds on peatland have also been studied in Great Britain and The Netherlands. Macan (1938, 1965a and b, 1966, 1973, 1976) spent many years studying the macroinvertebrates and especially Corixidae of Tarns (notably Hodson's Tarn), which are small, generally artificial ponds over peat in the Lake District. These studies concentrated on the composition, abundance and distribution of species in relation to fish predation. Griffiths (1973a) investigated the structure of the macroinvertebrate community in an upland, acid, peat reservoir in relation to macrophytes and water depth. Griffiths (1973b) examined trophic relationships in the same water body.

The Norfolk Broads in south east England originated because of peat excavation between the 9<sup>th</sup> and 13<sup>th</sup> centuries (Moss 1983). The 46 shallow, peat based 'Broads' have suffered severely as a result of nutrient enrichment from agriculture and sewage, and now have among the highest total phosphorus concentrations in world freshwaters (Moss 1983). The eutrophication problem has been extensively studied, in relation to water chemistry, phytoplankton, macrophyte vegetation and restoration (e.g. Moss 1983, Moss *et al.* 1986, Balls *et al.* 1985, 1989, Bales *et al.* 1993). Microcrustacean communities were found to change with the decline in macrophytes, from a diverse cladoceran-rich community to a copepod-rotifer dominated zooplankton (Moss 1983). The invertebrate community of the Broadland fens and submerged plants was very diverse, however, the impact of nutrient enrichment has not been well studied (Moss 1983). Chironomid larvae and oligochaetes tend to dominate the sparse benthic fauna, where macrophytes have been eliminated (Moss 1983).

The Loosdrecht Lakes in the Netherlands were also created by mediaeval peat excavation and studied owing to problems of eutrophication. The research topics included water and sediment chemistry, algae and macrophytes (e.g. Best *et al.* 1984, de Kloet *et al.* 1984, Kromkamp & Gons 1984, Roijackers & Verstraelen 1988), however, aquatic macroinvertebrates do not appear to have been investigated. van Duinen *et al.* (2000) reported on Odonata in re-wetted Dutch raised bog remnants and suggested that peatland restoration methods do not restore all species characteristic of ombrotrophic bog centres.

The invertebrate fauna of intact bog has generally received little attention, especially when compared to the volumes of vegetation research available and Reynolds (1990) stated that 'ecosystem-level studies are rare'. During the 1950s and 1960s, Crisp and Heal investigated the Corixidae, Gyrinidae and Cladocera of 25 lakes and pools on the Roundstone blanket bog complex (Crisp & Heal 1958, 1998, Crisp 1959). Results showed that corixid and cladoceran species richness and species composition varied with pH, size of the water body and habitat diversity. In the early 1970s invertebrate communities (mainly terrestrial) of a blanket bog in Glenamoy, Co. Mayo were studied as part of the tundra biome project. This lead to two theses (Swan 1973, McCall 1976) and five publications (Blackith 1974, Blackith 1975, Nixon *et al.* 1975, Behan-Pelletier & Hill 1983, Speight & Blackith 1983).

In 1983, a working group from the Zoology Department, Trinity College, Dublin, compiled baseline invertebrate information for midland raised bogs. A series of publications arose from these faunistic surveys detailing species of Araneae, Opiliones, Chilopoda (Higgins 1984), Lepidoptera (Bond 1984), Odonata, aquatic Hemiptera and Trichoptera (Reynolds 1984), Dixidae (Ashe 1985) and terrestrial insect groups (Good 1985). Reynolds (1984) sampled the marginal ditches, shallow drains, pools and soak systems, and found forms with no clear preference for water type alongside those typical of acid uplands. Reynolds (1985a) described the macroinvertebrates of Lough Roe, a soak lake on Clara bog, as being invertebrates of base rich sites, ponds and acid moorland habitats. During the early 1980s

a Dutch team studied aquatic fauna in a number of Irish raised and blanket bogs (de Leeuw 1986). Duigan (1987) examined the Cladocera of some raised bog habitats.

Reynolds (1990) reviewed work on invertebrates in Irish peatlands and described interactions between aquatic, neustonic and terrestrial habitats. He stated that while few tyrphobiont species have been identified, some species or species assemblages may be typical of certain bog habitats, and that the invertebrates of intact ombrotrophic peatlands are recognised as generally having a high species diversity. The fauna of aquatic bog habitats, however, is considered impoverished (McLachlan & McLachlan 1975, Kaens 1996). Foster & Bilton (1998) state that while beetles are often the most diverse and abundant taxonomic group in mire pools, overall the beetle fauna of bog pools is impoverished.

A number of British studies have looked at ecological aspects of bog fauna. McLachlan & McLachlan (1975) demonstrated associations between two chironomid larval species and different sediment textures in a small, shallow, acidic English bog lake. Standen *et al.* (1998) and Standen (1999) studied the macroinvertebrates of open and forested pools in the Sutherland Flows. Shallow, temporary pools were dominated by species with short life cycles and good dispersal rates; deeper, permanent pools contained a higher taxon richness, and it could not be concluded that afforestation affected the macroinvertebrate communities (Standen *et al.* 1998, Standen 1999). A current research project at the University of Edinburgh is attempting to unravel the community and food web structure in a bog pool complex. The gap in understanding of the functional relationships of aquatic mire fauna has long been recognised (Crisp & Heal 1998), and the apparent overrepresentation by predators in acid, bog pools has intrigued researchers (Kasprzak 1993, Crisp & Heal 1998).

As many waterbodies on intact and cut-over peatlands are acid and oligo- or dystrophic, their fauna is not directly comparable with that found in the alkaline cutaway wetlands. Perhaps the best approximation of the new artificial wetlands would be areas of open, alkaline water in fens. Although little work has been done on macroinvertebrate communities of fen wetland systems, the diversity of fen invertebrates is generally considered high as nutrients are not limiting. The marginal vegetation of lakes may also offer a comparable natural situation to that found in cutaway wetlands.

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between macroinvertebrate communities and macrophytes have been studied in many lakes and ponds (e.g. Voigts 1976, Palmer 1981, Friday 1987, Lodge 1985, Carpenter & Lodge 1986, Cyr & Downing 1988, Hanson 1990, Jacobsen & Sand-Jensen 1992).

Macroinvertebrate colonisation of artificial water bodies has been studied by a number of authors. Barnes (1983) investigated the macrophyte and macroinvertebrate populations of artificial ponds on the Isle of Purbeck, Dorset. These resulted from open-cast mining of ball-clay and ranged in age from six months to fifteen years. She found a general increase in the number of species with age in neutral or alkaline ponds, and evidence of succession in both macrophytes and macroinvertebrates. Friday (1987) investigated the range of factors affecting the numbers of macrophyte and macroinvertebrate species in ball-clay ponds, and concluded that pH was the most influential factor with respect to macroinvertebrates. Williams (1993) studied corixid and notonectid colonisation of ponds formed as a result of land subsidence owing to subterranean coal mining, and found that the number of species increased with age of the pond over a long period of time.

#### 4.2 Materials and Methods

#### 4.2.1 Preliminary survey

Between October 1996 and January 1997 six newly created cutaway wetlands were sampled to identify the most suitable study sites in which to investigate invertebrate community development. Turraun (N 172 230) was sampled on 18<sup>th</sup> October and 6<sup>th</sup> December 1996. Tumduff (N 185 187), Boora Lake (N 180 187) and Blackwater (N 05 25) were sampled on 18<sup>th</sup> October 1996. Lullybeg (N 75 20) and Barnaran Pond (N 75 20) were sampled on 11<sup>th</sup> November 1996. A hand-held pond net with 1 mm mesh was used to obtain a sample representative of the wetland fauna by means of qualitative sweep sampling, sweeping back and forth through a variety of habitats (macrophytes, open sediment). The samples were returned to the laboratory where they were sorted and stored in 90% industrial methylated spirit (IMS). Macroinvertebrates were subsequently identified to operational taxonomic units (OTUs), usually either genus or family, to estimate macroinvertebrate diversity and investigate the general similarities/differences between wetlands.

#### 4.2.2 Survey of artificial cutaway wetlands at Turraun and Tumduff

#### 4.2.2.1 Sampling dates

Two study sites, Turraun and Tumduff, were selected for detailed regular sampling, because of differences in their age, size and habitat development (Chapter 2). Sampling was conducted over 13 months, between January 1997 and February 1998. Each wetland was sampled for macroinvertebrates on 11 occasions, between 13<sup>th</sup> January 1997 and 18<sup>th</sup> February 1998.

In January 1997, three sampling stations (B6, B7 and B8) were selected at Tumduff. As vegetation was scarce in the pond, the stations were chosen to cover the range of substrata present. B6 and B8 had peat sediment and B7 was underlain with glacial drift sediment. B6 and B7 were located on steep slopes, were very exposed and had little macrophyte vegetation. B8 was a shallow, sheltered bay with a gradual slope, calcite precipitation and *Juncus acutiflorus*.

Three sampling stations (T1, T3 and T4) were chosen at Turraun in February. This number was increased to five in March. These five stations were chosen as representative of the main habitat types at Turraun. T1, T2 and T3 lay on the western shore of the wetland and had peat sediment and very gradual slopes. T1 had no vegetation, T2 was a *Typha* stand and T3 was dominated by *Polygonum amphibium* and *Sparganium erectum*. T4 had shell marl sediment, was very sheltered and had a diverse flora dominated by *Myriophyllum* spp. T5 was a peat sampling station on the eastern shore, with *Carex rostrata*. Detailed descriptions of all eight sampling stations, including macrophyte vegetation are given in section 2.4.

Exact sampling dates are recorded in Table 4.1. Samples were not taken from T3 on 18 April 1997 owing to difficulties in accessing the station.

date	T1	T2	T3	T4	T5	B3	B2	B3
13 <sup>th</sup> Jan 1997				3		М	М	М
7 <sup>th</sup> Feb 1997	М		М	М				
18 <sup>th</sup> Mar 1997	М	М	М	М	М	М	М	М
18 <sup>th</sup> Apr 1997	М	Μ		Μ	Μ	Μ	Μ	Μ
19 <sup>th</sup> May 1997	М	Μ	Μ	М	Μ	Μ	Μ	Μ
18 <sup>th</sup> Jun 1997	М	Μ	Μ	Μ	Μ	Μ	Μ	Μ
21 <sup>st</sup> Jul 1997	Μ	Μ	Μ	Μ	Μ	Μ	Μ	Μ
18 <sup>th</sup> Aug 1997	М	Μ	Μ	Μ	Μ	Μ	Μ	Μ
22 <sup>nd</sup> Sep 1997	М	Μ	Μ	Μ	Μ	Μ	Μ	Μ
20 <sup>th</sup> Oct 1997	Μ	Μ	Μ	Μ	Μ	Μ	Μ	Μ
29 <sup>th</sup> Nov 1997	М	Μ	Μ	Μ	Μ	Μ	Μ	Μ
18 <sup>th</sup> Feb 1998	М	Μ	М	Μ	Μ	Μ	Μ	Μ

 Table 4.1
 Macroinvertebrate sampling dates.
 M indicates samples were taken.

#### 4.2.2.2 Sampling method

A hand-held pond net with a 250 x 250 mm square frame and a 1 mm mesh net was used. Macroinvertebrate samples were taken from the shallow littoral zone at a depth limited by wellington-boot/wader height (10 to 40 cm deep). Sweep sampling was employed in order to catch a representative sample of the fauna, while avoiding large volumes of the peat substratum.

Each sample consisted of five standard sweeps. The net was swept sideways through one metre for the duration of one second and then back along the disturbed path for one second. The procedure was repeated five times, taking one step forward between each

standard sweep. The area covered in a full sample was approximately  $1.25 \text{ m}^2$  of bottom. Five replicate samples were taken at each of the eight sampling stations using this semiquantitative method. Samples were placed in separate bags and transported to the laboratory where they were stored at below 10 °C.

#### 4.2.2.3 Sorting, storage and identification

Samples were sorted live in the laboratory as soon as possible after collection. The presence of peat particles, along with more recent plant remains, made sorting a laborious process, taking on average two weeks to sort all 40 samples. The animals were transferred to 90% alcohol in labelled storage jars. As the animals were being sorted their numbers were recorded as OTUs (Operational Taxonomic Units). Identification to OTU was to a level facilitated by the naked eye and limited by the time constraints of sorting.

The animals were subsequently identified under a dissection microscope, using recognised Freshwater Biological Association (FBA) and Field Studies Council keys. Identification concentrated on Hirudinea, Crustacea, Mollusca, Odonata, Heteroptera, Trichoptera and Coleoptera. Diptera were not identified to species as a near contemporaneous study concentrated on the dipteran fauna of Turraun (Wayne Todd personal communication). Elliott and Mann (1979) was used to identify freshwater leeches. Malacostraca were identified from Gledhill *et al.* (1976). A key to British gastropods by Macan (1977) was used to distinguish Mollusca.

Elliott *et al.* (1988) was used to identify ephemeropteran nymphs. Odonate nymphs were identified using a combination of three keys (Gardner 1983, McGeeney 1986, Miller 1987). Dr Colm Roynane, who also provided information on species ecology, confirmed voucher specimens. Savage (1989) was used to identify aquatic Heteroptera. The heteropteran fauna of Turraun and Tumduff was discussed with Dr Brian Nelson and Dr Alan A. Savage, and Brian Nelson also examined a *Hesperocorixa ?moesta* (Fieber) specimen. Trichoptera were identified using Wallace *et al.* (1990) and Edington & Hildrew (1981). Adult Coleoptera were identified with Friday (1988) and larvae with Richoux (1982). Professor Garth Foster confirmed coleopteran voucher specimens and provided information on distributions. Authorities follow these keys (refer to Appendix 4.3.2.1 for list with authorities).

#### 4.2.3 Data processing and statistical analysis

Absolute and proportional abundance data were saved as Microsoft Excel 97® Worksheets. Data were sorted, subtotals calculated and graphs plotted on Microsoft Excel 97®. Statistical tests were performed using Data Desk 6.0® and SPSS 8.0 for Windows®.

A Shannon (H') and a Simpson's ( $\lambda$ ) diversity index was calculated for every sample (Ludwig & Reynolds 1988, Begon, Harper & Townsend 1996). Index values were converted into Hill's numbers for ease of interpretation and to aid comparison. Hill's numbers are N0 (total species richness, S), N1 ( $e^{H'}$ , the exponential of the Shannon Index) and N2 (1/ $\lambda$ , the reciprocal of the Simpson's Index) (Ludwig & Reynolds 1988, McCune & Mefford 1997). The units for Hill's diversity numbers are species or taxa and values indicate the number of abundant or dominant species or taxa in a sample. The more species are abundant, the more diverse the community (Ludwig & Reynolds 1988). These diversity measures were calculated as a means of comparing between wetlands and sampling stations. As the Indices were calculated using a combination of species and other taxa (see section 4.2.2.4 above for description of identification levels) they may not prove comparable to other studies.

The nature of the data was complex, having information on the abundance of a number of species for every sampling unit, and in order to elucidate patterns, multivariate statistics were used. A large number of multivariate methods exist, although there are no generally accepted 'best' techniques (Manly 1994). It was decided to concentrate on one method of classification (TWINSPAN) and one method of ordination (DCA) used widely in ecological literature (Foster *et al.* 1990, 1992, Death 1995, Brodersen *et al.* 1998). These were performed on PC Ord Version 3.18<sup>®</sup>. Hierarchical clustering and Non-metric MDS were used for comparison purposes and these were generated on SPSS 8.0 for Windows<sup>®</sup> and PC Ord Version 3.18<sup>®</sup>.

Classification techniques were used to produce relatively homogenous groups of samples. Both techniques chosen are polythetic, comparing samples on the basis of a number of variables (i.e. all taxa are used), and hierarchic, with each smaller group of samples being an exclusive subgroup of groups at higher levels (i.e. no samples overlap between concurrent groups) (Ludwig & Reynolds 1988). Two-way indicator species analysis or TWINSPAN (Hill 1979a, Gauch & Whittaker 1981) is a divisive method of hierarchical classification based on reciprocal averaging, designed specifically for ecological data. Samples and species are classified simultaneously. The output includes data that can be used to construct a sample dendrogram and an ordered two-way table. One major advantage of TWINSPAN is that it lists the species/taxa upon which each division was based and hence, outputs are more interpretable. The program used is a modified version of TWINSPAN (Hill 1979a) with remedies for the instabilities caused by reciprocal averaging. The pseudo-species cut-off levels chosen were 0, 2, 10, 20, 50 and 100, as these were most appropriate to the absolute abundance data used. The maximum number of indicators per division was five and the maximum number of divisions six. All TWINSPANs were run using absolute abundance data.

Hierarchical clustering is an agglomerative form of classification based on distance/dissimilarity data. This means that classification begins with all samples as separate entities and combines the most similar samples, forming successively larger groups of samples. A number of algorithms may be used to calculate distance/dissimilarity data. Squared Euclidean Distance was chosen here. Samples were combined on the basis of average between–group linkage. Proportional abundance data were used in order to eliminate problems in scaling which may occur with a large range in values.

Ordination involves the production of axes against which samples and/or species can be plotted (Manly 1994). It is used to elucidate biological and environmental factors controlling community structure (Ludwig & Reynolds 1988). It was used in this text to plot the distribution of samples. Both ordination techniques used are polythetic.

Detrended Correspondence Analysis (DCA) (also known as reciprocal averaging) is an objective ordination technique based on species composition. DCA was developed specifically for ecological data, described by abundance measures. Species scores are derived iteratively from the average scores of the samples in which they occur. Several orthoganal axes can be derived, with Axis 1 accounting for the largest variation between samples, Axis 2, the second largest variation and so on. DCA eliminates the arch problem found with other ordination techniques such as Principal Components Analysis (PCA), which results from non-linear relationships between species (Ludwig & Reynolds 1988).

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DCA was performed using a modified version of DECORANA (Hill 1979b). All DCAs were run using absolute abundance data.

Although DCA is popular in ecology, some authors believe it lacks robustness and may perform erratically (McCune & Mefford 1997). Non-metric Multidimensional scaling (NMDS or NMS) is an alternative technique well suited to non-normal data (McCune & Mefford 1997). NMDS uses an iterative method to rank and place a number of samples on a specified number of dimensions, continuing until stress cannot be further reduced. NMDS requires the pre-specification of the number of dimensions and does not generate species scores. NMDS plots were generated using proportional abundance on PC Ord Version 3.18<sup>®</sup>. Distance data were calculated using Euclidean distance. The number of dimensions was chosen on the basis of the lowest stress values.

DCA is considered an appropriate method for situations where species responses are near linear, while NMDS is used with more non-linear relationships (Ludwig & Reynolds 1988). The former occurs when the environmental gradient sampled is narrow and/or when species are tolerant of a broad range of conditions (Ludwig & Reynolds 1988). NMDS is more appropriate when a wide environmental gradient is sampled. As the environmental gradient consisted of the littoral zones of two similar and adjacent ponds, DCA was the main method employed here.

#### 4.3 Results

#### 4.3.1 Preliminary survey of six artificial wetlands on raised bog

Between 13 and 34 taxa were captured in each of the six cutaway wetlands during the preliminary survey. Table 4.2 shows the number of taxa found in each of the major groups for Turraun, Blackwater Lake, Lullybeg Lake, Barnaran Pond, Boora Lake and Tumduff. Appendix 4.3.1 contains a more detailed list of the taxa recorded in these Blackwater Lake, Lullybeg Lake, Barnaran Pond and Boora Lake.

Table 4.2Total number of taxa (OTUs) captured in Blackwater, Boora and<br/>Lullybeg Lakes and Barnaran Pond during the preliminary survey. The<br/>total number of individuals captured (Abundance) is also given. Abundance<br/>data for Turraun are those collected on 18<sup>th</sup> October 1996.

		number of taxa					
		Turraun	Blackwater	Lullybeg	Barnaran	Boora	Tumduff
Phylum	Group		Lake	Lake	Pond	Lake	
Annelida		2	2	1	1	1	1
Mollusca		5	4	1	0	1	0
Chelicerata	Hydracarina	1	0	1	0	0	0
Crustacea		3	3	2	1	2	1
Insecta	Ephemeroptera	2	2	2	1	2	2
	Odonata	2	1	1	0	2	1
	Corixidae	6	5	1	4	5	1
	Other Heteroptera	1	2	1	1	1	0
	Trichoptera	1	1	1	1	0	1
	Diptera	4	4	2	2	0	2
	Coleoptera	7	7	4	4	0	3
Vertebrates		2	1	2	0	0	1
To	tal	36	32	19	15	14	13
Abundance		533	630	201	86	119	109

34 taxa were recorded at Turraun in both October and December 1996, totalling 36 taxa over the two dates. The snail, *Potamopyrgus jenkinsi* (Smith), was very abundant at Turraun in October. Corixids, particularly *Sigara dorsalis* (Leach), *S. distincta* (Fieber) and *S. scotti* (Douglas & Scott) were also numerous. Seven species of Heteroptera and seven species of Coleoptera were recorded in Blackwater Lake on 18<sup>th</sup> October 1996. Mollusc species, *Asellus aquaticus* (Linnaeus), chironomid larvae and Hirudinea species were the most abundant taxa recorded.

In Lullybeg Lake on 11<sup>th</sup> November 1996, oligochaetes, trichopteran larvae and Asellus aquaticus were abundant. On the same date chironomid larvae and coleopteran species

were the most abundant taxa in Barnaran Pond. Zygopteran and ephemeropteran nymphs, and corixids were the most abundant taxa at Boora Lake, while baetid mayfly nymphs and chironomids were numerous at Tumduff.

The total catch was highest at Blackwater with 630 individuals, intermediate at Lullybeg Lake and Boora Lake with 201 and 119 respectively, and lowest at Barnaran Pond with 86 individuals.

#### 4.3.2 Survey of artificial cutaway wetlands at Turraun and Tumduff

#### 4.3.2.1 Species lists

In total, 108 taxa were recorded in Turraun and 71 in Tumduff over the full period of the study (between January 1997 and February 1998, 90 taxa were recorded in Turraun and 59 in Tumduff). A total of 85 insect taxa were found in Turraun, while 57 were found in Tumduff. Most lentic aquatic macroinvertebrate groups were represented in both wetlands. Detailed lists of all species captured at Turraun and Tumduff between October 1996 and August 1999 are given in Appendix 4.3.2.1. Table 4.3 summarises the number of species/taxa in the major macroinvertebrate groups.

Turraun had a greater number of species of Hirudinea, Mollusca, *Gammarus*, Corixidae, other Heteroptera and Coleoptera than Tumduff. Ten species of trichopteran larvae were encountered in each wetland. Three species of Ephemeroptera were recorded in Tumduff, although only one individual of *Leptophlebia vespertina* (Linnaeus) was captured there. Three species of anisopteran nymphs were recorded in Tumduff, and only one was recorded in Turraun. Females believed to be of *Hesperocorixa moesta* were captured in both wetlands and while this species has been included in the lists, its presence cannot be entirely confirmed.

Lymnaea stagnalis (Linnaeus), which was very abundant at Turraun (see Section 4.3.2.2 below), *Planorbis* species and *Gammarus duebeni* Stock & Pinkster were not captured in Tumduff. Sialis was also present in Turraun, but absent from Tumduff. There were a number of differences in trichopteran larvae between the wetlands. *Ecnomus tenellus* (Rambur), *Agrypnia obsoleta* (Hagen) and *A. varia* (Fabricius) were only caught in Turraun. *Lasiocephala basalis* (Kolenati)/ *Lepidostoma hirtum* (Fabricius), *Ylodes*/

*Triaenodes* spp. and possibly *Mystacides azurea* (Linnaeus) were found only in Tumduff. Chaoboridae, Dixidae and Sciomyzidae larvae were collected in Turraun but not in Tumduff. *Hydrobius fuscipes* (Linnaeus) was the only species of Coleoptera found in Tumduff but not in Turraun.

		Numbe	r of taxa	
Phylum	Group	Turraun	Tumduff	
Cnidaria	Hydra spp	1	1	
Annelida	Oligochaeta	1	1	
	Hirudinea	6	1	
Mollusca		8	5	
Chelicerata	Hydracarina	1	1	
Crustacea		4	3	
Insecta	Collembola	1	1	
	Ephemeroptera	2	3	
	Anisoptera	2	3	
	Zygoptera	2	2	
	Corixidae	14	13	
	Other Heteroptera	7	4	
	Megaloptera	1	0	
	Trichoptera	10	10	
	Diptera	8	5	
	Coleoptera	38	16	
Vertebrates	Gasterosteidae	2	2	
Tota	1	108	71	

## Table 4.3Total number of taxa caught in Turraun<br/>and Tumduff over the entire sampling<br/>period, October 1996 to August 1999.

#### 4.3.2.2 Total catch and species abundance

Figure 4.1 illustrates the monthly average total catch of macroinvertebrates per semiquantitative sample at each wetland (i.e. the summed total catches were averaged for 25 samples at Turraun and 15 at Tumduff). All abundance data refers to the sampling period January 1997 to February 1998. Average catch was generally higher in Turraun, however, Tumduff had a higher average catch in April and August. During the summer months, average total macroinvertebrate catch per month was high at Turraun and low at Tumduff. The trend in total catch between August 1997 and February 1998 was similar in both wetlands, with relatively low catches in October and February, and high catches in September and November. A total of 33,833 animals was captured in Turraun and 14,114 in Tumduff during the sampling period, January 1997 to February 1998 (Table 4.4). 260 samples were taken from Turraun and 165 from Tumduff. Appendix 4.3.2.2 gives details of the total number of individuals of each taxon captured over the sampling period. Table 4.4 summarises these data. It presents the total number of individuals of each group collected between January 1997 and February 1998. The proportional abundance of each group is given in terms of percentage abundance. In order to compare the numbers of animals captured in each wetland average catch per sample has been calculated for each group.

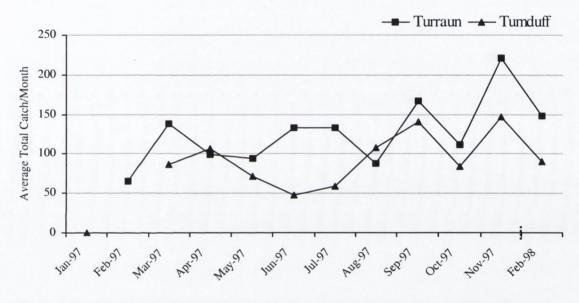


Figure 4.1 Average total catch per sample per month for the sampling period January 1997 to February 1998.

The most abundant groups at Turraun were Corixidae and Mollusca. Trichoptera, Diptera, *Gammarus* spp., Ephemeroptera and Oligochaeta were also numerous. The most abundant groups at Tumduff were Diptera, Trichoptera and Ephemeroptera. Corixidae and Mollusca were also abundant. This information is illustrated in Figure 4.2, which shows the percentage abundance of the main taxa.

Total catch per taxonomic group was generally greater at Turraun (260 samples) than at Tumduff (165 samples), although more Hydracarina, Ephemeroptera, Anisoptera and Diptera were captured at Tumduff. These five groups, and Trichoptera, also had greater percentage abundance at Tumduff than at Turraun. Corixidae, along with annelids, *Gammarus* spp., Ostracoda, other Heteroptera, Coleoptera and sticklebacks had greater

relative abundance at Turraun than Tumduff. In terms of average catch per sample, there were more trichopteran larvae at Tumduff than at Turraun but similar numbers of zygopteran nymphs.

		total catch	mean ca	tch/sample	% abundance		
	Turraun	Tumduff	Turraun	Tumduff	Turraun	Tumduff	
Hydra spp.	66	0	0.25	0.00	0.2	0.0	
Oligochaeta	1905	191	7.33	1.16	5.6	1.4	
Hirudinea	157	4	0.60	0.02	0.5	0.0	
Mollusca	5451	919	20.97	5.57	16.1	6.5	
Hydracarina	139	284	0.53	1.72	0.4	2.0	
Gammarus spp	2234	4	8.59	0.02	6.6	0.0	
Asellus aquaticus	263	61	1.01	0.37	0.8	0.4	
Ostracoda	222	5	0.85	0.03	0.7	0.0	
Collembola	6	0	0.02	0.00	0.0	0.0	
Ephemeroptera	2078	2590	7.99	15.70	6.1	18.4	
Anisoptera	10	14	0.04	0.08	0.0	0.1	
Zygoptera	770	446	2.96	2.70	2.3	3.2	
Corixidae	11482	1700	44.16	10.30	33.9	12.0	
Other Heteroptera	88	3	0.34	0.02	0.3	0.0	
Megaloptera	34	0	0.13	0.00	0.1	0.0	
Trichoptera	4758	3405	18.30	20.64	14.1	24.1	
Diptera	2625	4320	10.10	26.18	7.8	30.6	
Coleopteran adults	783	69	3.01	0.42	2.3	0.5	
Coleopteran larva	113	19	0.43	0.12	0.3	0.1	
Curculionidae	18	1	0.07	0.01	0.1	0.0	
Gasterosteidae	631	79	2.43	0.48	1.9	0.6	
Total catch	33,833	14,114	130.13	85.54	100	100	
Total number of samples	260	165	1	1	260	165	

Table 4.4	Total number of individuals captured in Turraun and Tumduff between
	January 1997 and February 1998.

*Theromyzon tessulatum* (Müller) was the most abundant species of leech at Turraun (0.4%) and the only species present in Tumduff (0.3%) (see Appendix 4.3.2.2). *Lymnaea stagnalis* (7.6%) and *Pisidium* spp. (6.6%) were the most important mollusc species at Turraun, while *L. palustris* (Müller) (5.6%) was the most important at Tumduff.

The same four species dominated the corixid fauna in both wetlands between January 1997 and February 1998. *Sigara fossarum* (Leach) (16.4%) and *S. distincta* (8.3%) were the most abundant corixid species at Turraun, while *S. scotti* and *S. dorsalis* were also reasonably abundant. *S. dorsalis* was the most abundant species at Turrduff having the same percentage abundance, 2.8%, as at Turraun.

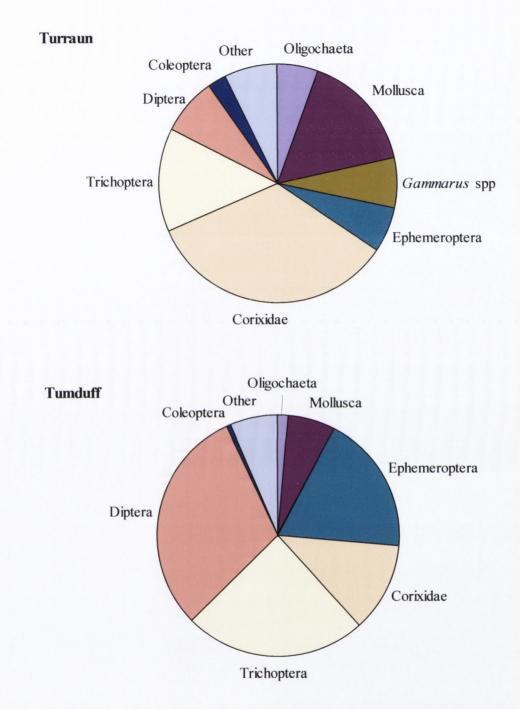


Figure 4.2 Relative abundance of main taxa in Turraun and Tumduff for the sampling period January 1997 to February 1998.

*Caenis luctuosa* (Burmeister) was the most abundant ephemeropteran nymph in both wetlands, but it showed a much greater relative abundance at Tumduff (17.1%) than at Turraun (5.3%). *Mystacides longicornis* (Linnaeus) was the most abundant trichopteran species in both wetlands representing 7.4% of the fauna at Turraun and 17.9% at Tumduff.

Chironomid larvae were the most abundant Diptera at Turraun (6.2%). Ceratopogonid and tabanid larvae were also important (0.6% each). Chironomids were very abundant at Tumduff, representing 29.7% of the fauna.

The most abundant coleopteran species at Turraun was *Noterus clavicornis* (Degeer) (1.2%). At Tumduff it was *Helophorus brevipalpis* Bedel (0.2%). Coleopteran numbers were much lower at Tumduff than at Turraun.

A large number of *Gammarus* individuals were juvenile and could not be identified to species. Based on a subsample of 80 out of a total of 193 samples containing *Gammarus* spp., *Gammarus duebeni* (0.6%) was more abundant than *G. lacustris* Sars (0.2%) at Turraun. Only four *Gammarus* individuals were found in Tumduff.

#### 4.3.2.3 Rare or occasional taxa

Rare taxa are defined here as those that occur in less than 5% of samples. 53 taxa were considered rare between January 1997 and February 1998 in Turraun, and 36 were rare in Tumduff. Appendix 4.3.2.3 lists the rare taxa recorded in Turraun and Tumduff. Table 4.5 summarises the number of rare taxa in each major macroinvertebrate group. Most of the taxa classified as rare had low total abundance as well as low frequency of occurrence (refer to Appendix 4.3.2.2), although 66 individuals of *Hydra* were captured in eight samples at Turraun.

It was notable that Hirudinea species other than *Theromyzon tessulatum* were rare at Turraun. Eleven species of Heteroptera were rare at Turraun, while ten were rare at Tumduff between January 1997 and February 1998. With respect to Coleoptera, 22 of the 38 taxa at Turraun and 13 of the 16 taxa at Tumduff were rare.

The nymphs and larvae of some forms were rarely encountered during the survey. At Turraun *Hydrometra* nymphs and Hydrophilidae, *Ilybius* and *Noterus* beetle larvae were rare. *Gerris* nymphs were also rare at Turraun, although, 36 individuals were captured. Larvae of Dytiscidae, *Haliplus* and Hydrophilidae were rare at Turnduff.

Over the sampling period January 1997 to February 1998, there were 21 species for which only one individual was recorded at Turraun and 13 such species at Tumduff (see table of

total abundance over sampling period, Appendix 4.3.2.2). For Turraun, these included two Hirudinea species (*Erpobdella octoculata* (Linnaeus), *Glossiphonia heteroclita* (Linnaeus)), five heteropteran species (*Gerris lacustris* (Linnaeus), *Gerris thoracicus* Schummel, *Arctocorisa germari* (Fieber), *Hesperocorixa linnaei* (Fieber), *Sigara lateralis* (Leach)), three trichopteran species (*Agrypnia varia, Ecnomus tenellus, Limnephilus vittatus* (Fabricius)), and 11 beetles (*Chaetarthria seminulum* (Herbst), *Donacia simplex* Fabricius, *Elmis aenea* (Müller), *Gyrinus marinus* Gyllenhal, *Gyrinus substriatus* Stephens, *Haliplus fluviatilis* Sturm, *Haliplus lineatocollis* (Marsham), *Hydraena rufipes/britteni/riparia, Hydroporus gyllenhalii* Schiödte, *Hydroporus pubescens* (Gyllenhal) and *Limnebius truncatellus* (Thunberg)). There may have been greater numbers of *Agrypnia varia* and *Limnephilus vittatus*, as a large number of trichopterans were first or second instars which could not be identified to species.

		number	r of taxa	
Phylum	Group	Turraun	Tumduff	
Cnidaria	Hydra spp	1		
Annelida	Hirudinea	5		
Mollusca	Gastropoda	2	1	
Crustacea	Gammarus spp.		2	
	Ostracoda		1	
Insecta	Collembola	1		
	Ephemeroptera		1	
	Anisoptera	2	3	
	Corixidae	5	9	
	Other Heteroptera	6	1	
	Trichoptera	5	3	
	Diptera	4	2	
	Coleoptera	22	13	
Total		53	36	

Table 4.5Rare taxa in Turraun and Tumduff over<br/>the sampling period, January 1997 to<br/>February 1998.

The 13 species, for which only one individual was captured at Tumduff, included *Leptophlebia vespertina* (Linnaeus), *Aeshna grandis* (Linnaeus), *Arctocorisa germari, Hesperocorixa linnaei, Sigara falleni* (Fieber), *Sigara lateralis, Lasiocephala basalis* /*Lepidostoma hirtum, Agabus nebulosus* (Forster), *Hydrobius fuscipes, Laccobius minutus* (Linnaeus), *Ochthebius minimus* (Fabricius), *Porhydrus lineatus* (Fabricius) and Family Curculionidae. Again, there may have been more *Aeshna grandis*, as a number of anisopteran nymphs could not be identified to species. Two females of the genus

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*Hesperocorixa* may have been *H. moesta*. The presence of this typically upland and relatively rare corixid could not, however, be confirmed without a male specimen.

#### 4.3.2.4 Diversity

The seasonal changes in average Hill's N1 ( $e^{H'}$ , the exponential of the Shannon Index) per sample per month are plotted in Figure 4.3. This suggests that diversity was higher in Turraun than Tumduff in all months, except November. The highest average diversity occurred in March in Turraun (H'=2.24, N1=9.89), while the lowest was in September and October (H'=1.7, N1=5.8). The highest diversity in Tumduff was in August (H'=1.82, N1=6.57) and the lowest in January 1997 (H'=0.12, N1=1.17). In terms of seasonal trends, diversity appeared to be higher in summer at Tumduff. The trend was erratic at Turraun, appearing to decrease steadily over the sampling period. Diversity was particularly low from September to November.

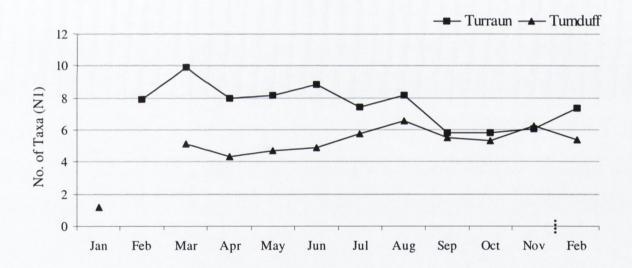


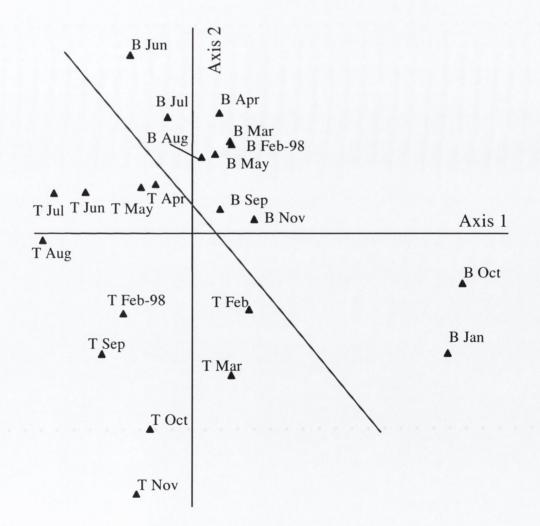
Figure 4.3 Average Hill's N1 per sample per month between January 1997 and February 1998. Hill's N1 (No. of taxa) is the exponential of H', the Shannon Diversity Index

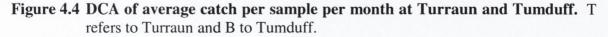
The average Shannon Diversity Index over the sampling period (January 1997 to February 1998) was 1.94 and 1.54 for Turraun and Tumduff respectively. These correspond to average N1 values of 7.58 for Turraun and 5.22 for Tumduff. The average Simpson's index was 0.23 (N2 = 5.41) for Turraun and 0.34 (N2 = 3.77) for Tumduff. The total number of taxa used in these calculations (i.e. taxon richness, S or N0) was 90 for Turraun

and 59 for Tumduff. These numbers were the total captured between January 1997 and February 1998 in each wetland. Pooled t-tests indicated that the difference between the wetlands in terms of N1 and N2 was significant ( $\alpha = 0.001$ ,  $p \le 0.0001$ ).

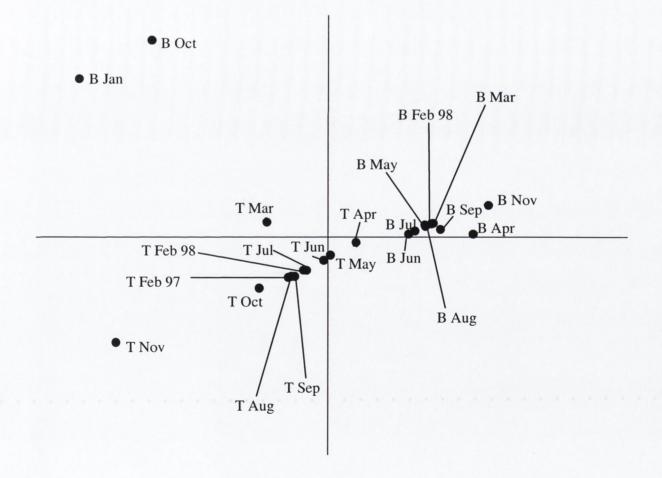
#### 4.3.2.5 Multivariate statistics

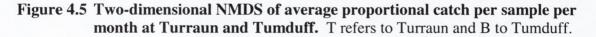
Using the average catch per sample per month, Detrended Correspondence Analysis (DCA) was conducted. A three dimensional plot was generated. Two dimensions are shown in Figure 4.4. The average proportional catch (or relative abundance) per sample per month was used in two-dimensional Non-metric Multi Dimensional Scaling (NMDS) and these results are given in Figure 4.5. Both plots clearly separate Turraun (T) and Tumduff (B) samples.





Both plots also show January and October samples from Tumduff distant from all other samples. January samples had only four species and 1.3 animals per catch on average. October samples had more typical species richness and average total abundance, although, *Lymnaea palustris* dominated with over 52 individuals per sample. All other Tumduff samples clustered together, particularly in Figure 4.5. Turraun samples were located to the lower left-hand side of both plots. Turraun April and May samples lie closest to the Tumduff samples in each figure. These, along with August had the lowest average catch per sample at Turraun. 'Turraun November' is the furthest removed from Tumduff samples. It had the highest average total abundance per sample of all months and the lowest species richness per month at Turraun. November was also the month of greatest abundance at Tumduff and this sample separated well in Figure 4.5.





#### 4.3.2.6 Breeding populations

Although the study was not designed to investigate invertebrate life histories, the presence of larvae, nymphs and juveniles suggested that certain species were breeding in the cutaway wetlands. At Turraun a number of large individuals of *Theromyzon tessulatum* were observed with tens of juveniles attached to their undersides. Egg masses of *Lymnaea stagnalis* were found attached to macrophytes at Turraun. Young molluscs of *Lymnaea* spp. and *Potamopyrgus jenkinsi* were captured at both wetlands.

A large number of *Gammarus* juveniles were recorded at Turraun. Trichopteran larvae and ephemeropteran and odonate nymphs were recorded at both wetlands. Heteropteran nymphs were found in both wetlands. Corixid nymphs formed 4% of the total catch at Turnduff, and 2.4% of the total catch at Turraun (see Appendix 4.3.2.2).

Coleopteran larvae were found in both wetlands. *Haliplus* larvae were the most abundant larva in Turraun and adults of the genus *Haliplus* were numerous. *Haliplus* larvae were also found in Tumduff. Although *Noterus clavicornis* was the most abundant coleopteran species in Turraun and many tenerals were observed, only two *Noterus* larvae were captured. There were a number of Dytiscidae species present at Turraun, but larvae numbers were relatively low. Only two adult *Ilybius fuliginosus* (Fabricius) (Coleoptera, Dytiscidae) were captured in Turraun, yet 15 *Ilybius* larvae were found. *Ilybius* larvae were also found in Tumduff and adults were first captured in 1999. *Hygrotus inaequalis* (Fabricius) (Coleoptera, Dytiscidae) was the most abundant adult beetle and Dytiscidae the most numerous beetle larvae in Tumduff. Hydrophilidae larvae were found in both wetlands suggesting that *Helophorus* was breeding. It is likely that many other beetle species were breeding, but that larvae were not captured or not identified to genus.

#### 4.3.2.7 Temporal variation

Figures 4.6 to 4.13 illustrate the seasonal trends in average catch per sample of 22 taxa that occurred in greater than 10% of samples in each wetland. The seasonal trend for *Theromyzon tessulatum* (Figure 4.6) was quite similar in both wetlands with highest abundance occurring in August. *Theromyzon* was not encountered in Tumduff until May 1997.

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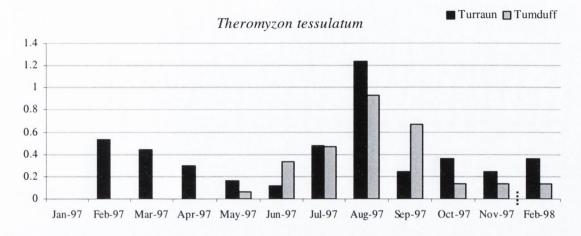


Figure 4.6 Seasonal trends in average catch per sample of *Theromyzon tessulatum* at Turraun and Tumduff

Figure 4.7 presents the trends in average abundance per sample for four species of gastropod mollusc. The sudden increase in *Potamopyrgus jenkinsi* abundance in June may reflect an addition of juvenile animals to the population. The species was rare at Tumduff. Abundance of *Lymnaea palustris* and *L. peregra* (Müller) was generally low in Turraun and Tumduff. *L. palustris* numbers were maximum in October 1997 in both wetlands, when abundance at Tumduff was exceptionally high. *L. peregra* abundance reached its maximum in February 1998 in Turraun and November 1997 in Tumduff. *L. stagnalis* was not present in Tumduff. It reached peak abundance in September at Turraun, slightly ahead of the Turraun peak for *L. peregra* and *L. palustris*. *L. stagnalis* numbers increased considerably over the sampling period and numbers in February 1998 were ten times higher than in February 1997.

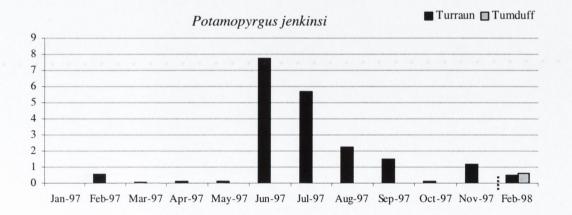
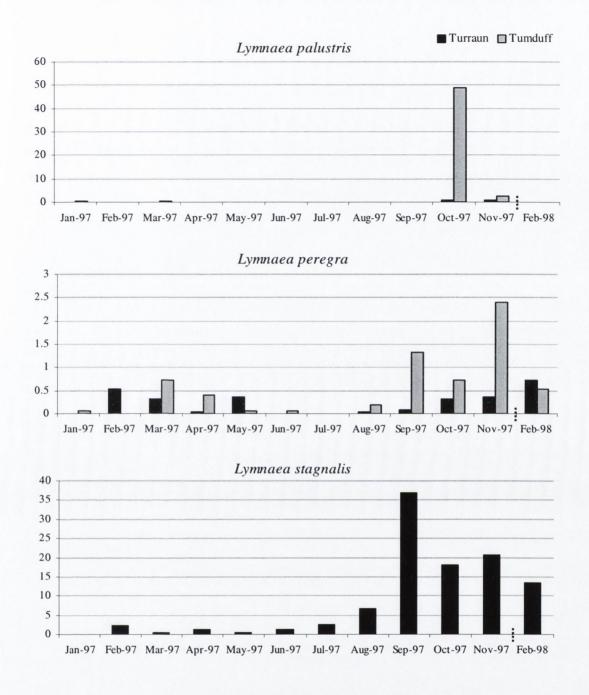


Figure 4.7 Seasonal trends in average catch per sample of Mollusca at Turraun and Tumduff





Temporal variations in average abundance of Hydracarina are illustrated in Figure 4.8. Numbers were greater in Tumduff than in Turraun. Seasonal variations demonstrate a bimodal distribution with peaks in April-May and July-August.

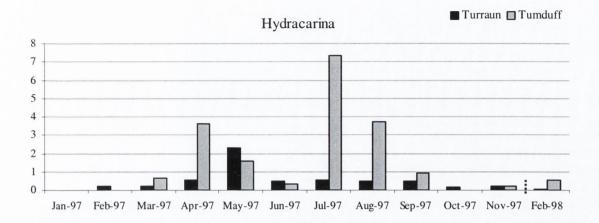


Figure 4.8 Seasonal trends in average catch per sample of Hydracarina at Turraun and Tumduff

Malacostracan Crustacea are illustrated in Figure 4.9. *Gammarus* was present throughout the study period at Turraun and abundance was highest in July 1997 and February 1998. Abundance was very low in October and November. *Asellus aquaticus* numbers at Turraun increased from February to May and again from June to February 1998. More *Asellus* were caught in February 1998 than in February 1997 at Turraun. October 1997 abundance was very low. *Asellus* numbers were maximum in November in Tumduff, but were generally too low to show any definite seasonal trend.

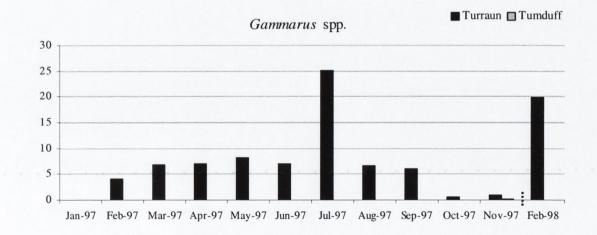
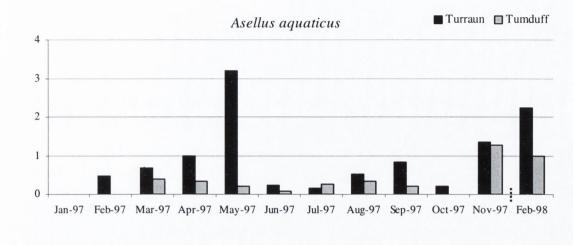


Figure 4.9 Seasonal trends in average catch per sample of Crustacea at Turraun and Tumduff



**Figure 4.9 continued** 

Figure 4.10 shows the seasonal trends in the two common ephemeropteran species. *Cloeon simile* Eaton abundance was low in both wetlands and the peak in abundance in November was notable. Seasonal trends were more evident for *Caenis luctuosa*. Numbers of nymphs decreased during the summer emergence period and began to increase again after July 1997. As with *Asellus*, abundance of *Caenis* was low in October in both wetlands.

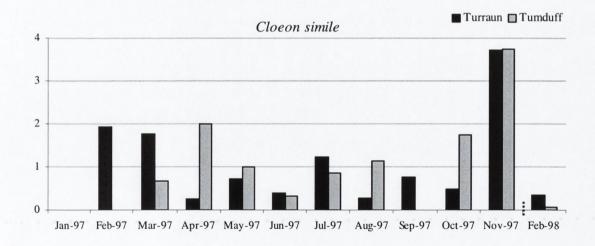
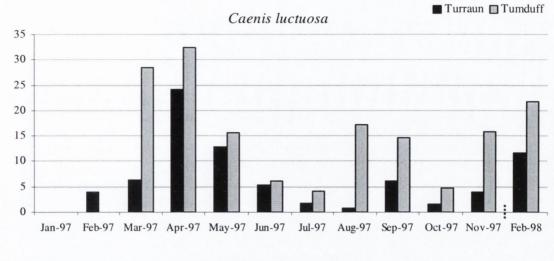


Figure 4.10 Seasonal trends in average catch per sample of Ephemeroptera at Turraun and Tumduff





Zygopteran nymphal abundance (Figure 4.11) showed a bimodal type distribution in both wetlands, with maximum numbers in March/April and again in August/September. The autumn peak at Tumduff was higher than the spring peak.

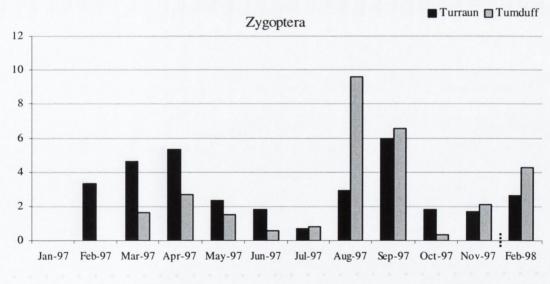
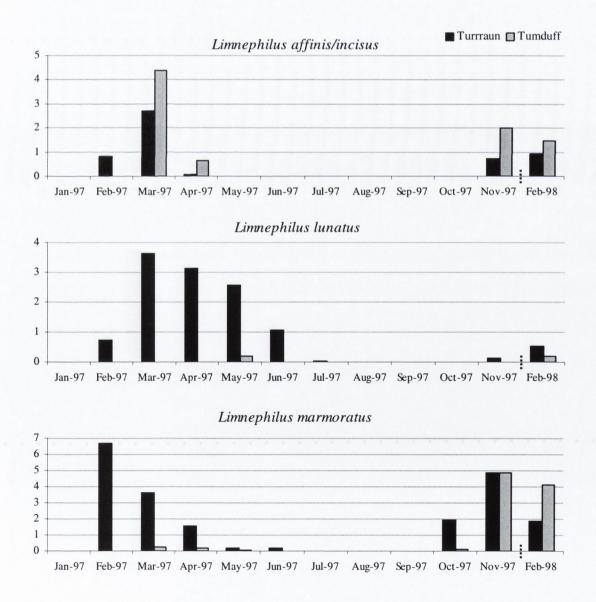


Figure 4.11 Seasonal trends in average catch per sample of Zygoptera at Turraun and Tumduff

Temporal changes in average abundance per sample of six trichopteran species is shown in Figure 4.12. All three *Limnephilus* species were most abundant in spring 1997 at Turraun.

*L. affinis/incisus* Curtis was most abundant in spring at Tumduff, *L. lunatus* Curtis was rare and *L. marmoratus* Curtis was most abundant in November 1997.

Three Leptoceridae species are shown in Figure 4.12 along with the seasonal trend in first to third instar leptocerids that could not be identified to species. *Athripsodes aterrimus* (Stephens) abundance was low in both wetlands, although it was more abundant in Tumduff. *Mystacides longicornis* was abundant in both wetlands, reaching maximum abundance in April at Tumduff and in June at Turraun. *Oecetis ochracea* (Curtis) abundance was highest in Turraun in September and in Tumduff in June. First to third instar Leptoceridae were most abundant during summer and early autumn months, when the abundance of identified leptocerid species was low (May, July, August and October).



### Figure 4.12 Seasonal trends in average catch per sample of selected Trichoptera at Turraun and Tumduff

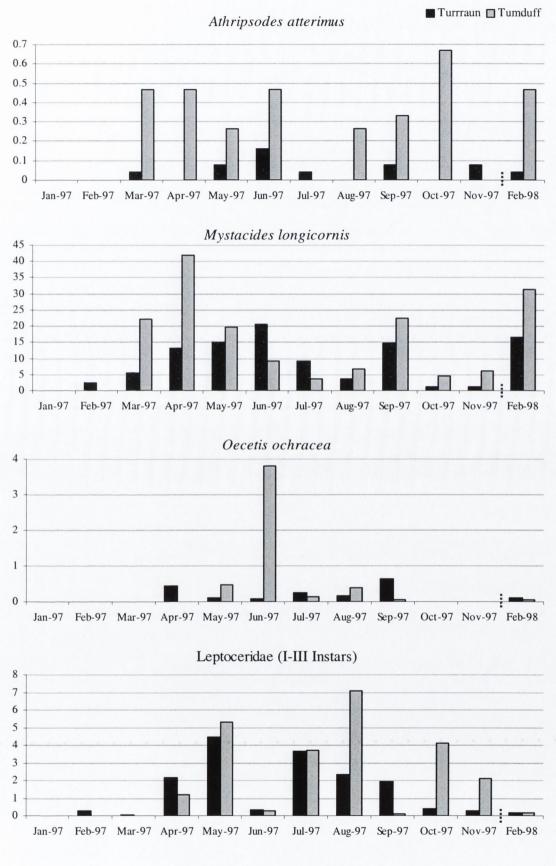
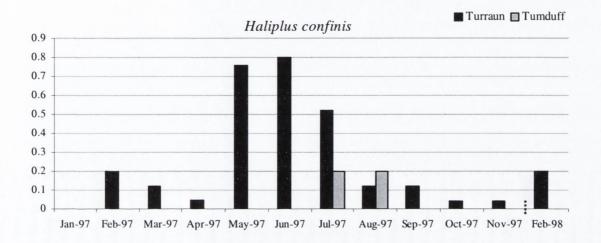
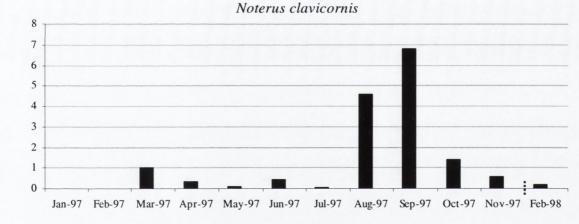
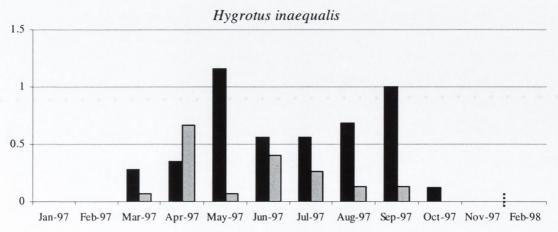


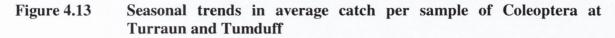


Figure 4.13 illustrates the seasonal trends of three adult coleopteran species. *Haliplus confinis* Stephens was far more abundant at Turraun, where numbers were highest in the summer months. *Noterus clavicornis* was absent from Tumduff. This species was very abundant in August and September at Turraun, when most species captured were tenerals. *Hygrotus inaequalis* was not found during the winter months at either wetland.









#### 4.3.3 Variations among sampling stations at Turraun and Tumduff

#### 4.3.3.1 Total catch and species abundance at different sampling stations

Of the eight sampling stations in the two wetlands, T4 had the largest number of taxa, while T3 had the greatest abundance. T1 was the most impoverished station in terms of taxon richness and abundance. The three Tumduff stations (B6, B7 and B8) were similar to each other and had fewer species than most Turraun stations. Table 4.6 shows the variation in species richness among sampling stations. It lists the number of taxa from various groups and the total number of taxa found at each sampling station. It also gives the average total catch per sample and the total catch at each sampling station over the sampling period, January 1997 to February 1998.

		number of taxa							
Phylum	Group	T1	T2	T3	T4	T5	B6	B7	B8
Cnidaria	Hydra spp				11.11.15	1			
Annelida	Oligochaeta	1	1	1	1	1	1	1	1
	Hirudinea	2	3	3	5	3	1	1	1
Mollusca		5	7	6	6	5	4	4	4
Chelicerata	Hydracarina	1	1	1	1	1	1	1	1
Crustacea		4	4	4	3	4	2	2	3
Insecta	Collembola		1	1	1				
	Ephemeroptera	2	2	2	2	2	2	2	3
	Anisoptera		1	1	1	1		1	3
	Zygoptera	1	2	2	2	2	2	2	2
	Corixidae	8	6	7	7	8	7	10	2 7
	Other Heteroptera	2	3	3	7	1	1	1	1
	Megaloptera			1	1	1			
	Trichoptera	7	8	7	7	7	8	8	7
	Diptera	3	5	5	8	5	5	4	4
	Coleoptera	4	14	15	23	17	12	8	6
Vertebrates		2	2	2	2	2	2	2	2
Total No. Taxa		42	60	61	77	61	48	47	45
Average Catch/Sample		34.49	65.54	241.88	204.16	94.7	86.71	85.13	84.0
Total Catch		1,897	3,277	12,094	11,229	4,735	4,769	4,682	4,62

 Table 4.6
 Total number of taxa caught in each sampling station at Turraun and Tumduff over the sampling period, January 1997 to February 1998.

T4 (marl with dense and diverse macrophytes) had the most taxa (77), with more leeches, other Heteroptera, Diptera and Coleoptera than any other sampling station. Stations T2, T3 and T5 had similar numbers of taxa, but T2 (granular peat and *Typha*) had relatively more mollusc and trichopteran species and T5 (peat with *Carex*) had more Corixidae. T1 (bare

compacted peat) had the lowest number of taxa of any sampling station. Taxon richness in Tumduff was low and similar at all three Tumduff sampling stations. However, B7 (glacial till) had the most Corixidae species (10) of any sampling station and the greatest number of anisopteran species was captured at B8 (shallow, sheltered station with peat and vegetation). B6 (fine peat) had more coleopteran species (12) than B7 and B8.

Average catch per sample and total catch was highest at T3 (very fine peat sediment, *Polygonum* and *Sparganium*). These were also high at T4. Catch was higher at T5 than T2 and T1 had the lowest average catch per sample and the lowest total catch of any of the eight sampling stations. The three Tumduff sampling stations were also similar in terms of average catch per sample and total catch.

Table 4.7 lists the average percentage abundance of all taxa captured at each of the eight sampling stations and illustrates the differences in species and proportional abundance of taxa among sampling stations. This table should be referred to throughout the descriptions of the individual sampling stations.

Comparing T1 (compacted peat substratum with no vegetation) to the other Turraun sampling stations, the abundance of Oligochaeta, Hirudinea, Mollusca, Anisoptera, Diptera and Coleoptera was low (Table 4.7). T1 was dominated by *Caenis luctuosa*, Corixidae, particularly *Sigara distincta* and *S. scotti* and *Mystacides longicornis*. While T1 appeared similar to the Tumduff sampling stations in terms of taxon richness and the abundance of *Caenis* and *Mystacides*, the habitats differed in the species found and the proportional abundance of mutual species.

When all samples were combined, the most prevalent and abundant species at T2 (gravel sized peat granules, *Typha* and some Angiosperms) were *Gammarus* spp. and chironomid larvae. T2 had the greatest percentage abundance of *Theromyzon tessulatum*, *Planorbis* spp., *Gammarus*, *Corixa panzeri* (Fieber), *Sigara dorsalis*, *Limnephilus lunatus*, *L. marmoratus*, *Haliplus confinis* and *H. obliquus* Stephens of any station. Oligochaeta, Hydracarina and *Asellus* were also relatively abundant at T2. *Sigara fossarum* had low percentage abundance, relative to the other Turraun stations.

Table 4.7Percentage abundance of macroinvertebrates at the eight sampling<br/>stations in Turraun and Tumduff between January 1997 and February<br/>1998. Data based on the average catch per sample of taxa at each sampling<br/>station.

	taxon	T1	T2	T3	T4	T5	B6	B7	B8
		%	%	%	%	%	%	%	%
Annelida	Oligochaete	0.21	6.57	9.21	4.75	1.20	1.51	1.17	1.40
Hirudinea	Piscicola geometra	0	0.06	0.03	0.04	0.11	0	0	0
	Theromyzon tessulatum	0.11	1.05	0.14	0.58	0.26	0.29	0.36	0.26
	Glossiphonia complanata	0.05	0.12	0.02	0	0.02	0	0	0
	Glossiphonia heteroclita	0	0	0	0.01	0	0	0	0
	Helobdella stagnalis	0	0	0	0.03	0	0	0	0
	Erpobdella octoculata	0	0	0	0.01	0	0	0	0
Mollusca	Potamopyrgus jenkinsi	0.37	0.68	1.77	1.43	1.87	0.10	0.06	0.02
	Lymnaea palustris	0	0.12	0.30	0.03	0.11	10.34	6.07	0.31
	Lymnaea peregra	0.11	0.03	0.35	0	0.41	0.78	0.34	0.98
	Lymnaea stagnalis	0.37	2.31	1.00	18.37	7.03	0	0	0
	Planorbis contortus	0.05	0.15	0.02	0.03	0	0	0	0
	Planorbis crista	0	0.34	0	0.06	0	0	0	0
	Pisidium spp.	0.84	2.75	9.90	7.81	1.87	0.02	0.06	0.37
Chelicerata	Hydracarina	0.37	0.74	0.29	0.56	0.24	2.03	1.82	2.23
Crustacea	Gammarus spp.	6.49	21.36	3.92	2.58	14.21	0	0	0.09
	Asellus aquaticus	0.58	1.11	0.31	0.76	2.02	0.34	0.21	0.72
Insecta									
Ephemeropter	ra Cloeon simile	0.16	0.93	0.30	1.37	1.18	1.72	1.30	0.66
	Caenis luctuosa	16.04	7.90	2.35	4.50	9.82	9.19	17.65	24.81
	Leptophlebia vespertina	0	0	0	0	0	0	0	0.02
Anisopte	ra Anisopteran nymph	0	0.06	0.02	0.04	0.04	0	0.13	0.17
Zygopte	ra Zygopteran nymph	0.16	1.60	0.87	4.89	1.44	3.31	3.12	3.10
Heteropte	ra Hydrometra nymph	0	0.03	0	0.01	0	0	0	0
	Hydrometra stagnorum	0.05	0	0.04	0.04	0	0	0	0
	Gerris argentatus	0	0.03	0	0.02	0	0	0	0
	Gerris lacustris	0	0	0	0.01	0	0	0	0
	Gerris odontogaster	0	0	0.01	0.03	0	0	0	0
	Gerris thoracicus	0	0	0	0.01	0	0	0	0
	Gerris nymph	0	0.03	0.02	0.30	0	0	0	0
	Nepa cinerea	0	0	0	0.02	0	0	0	0
	Notonecta glauca	0	0.03	0.06	0.04	0.02	0.02	0	0
	Notonecta nymph	0.05	0.15	0.03	0.04	0.02	0	0.02	0.02
	Callicorixa praeusta	0.05	0	0	0.01	0.02	0	0.04	0.09
	Corixa panzeri	0.11	1.05	0.31	0.21	0.15	0	0.02	0.02
	Hesperocorixa castanea	0	0	0	0	0	0	0.04	0.04
	Hesperocorixa linnaei	0	0	0	0	0.02	0	0.02	0
	Hesperocorixa ?moesta	0	0	0	0	0	0.02	0	0
	Arctocorisa germari	0.05	0	0	0	0	0	0.02	0
	Sigara distincta	13.19	6.48	10.05	7.23	7.14	2.29	2.71	1.42
	Sigara dorsalis	7.39	9.29	2.75	1.06	1.18	2.54	2.44	3.52
	Sigara falleni	0.11	0.06	0.12	0.23	0.02	0.02	0	0
	Sigara fossarum	8.07	3.21	29.48	11.17	11.34	1.57	2.63	1.01
	Sigara lateralis	0	0	0.01	0	0	0.02	0	0
	Sigara scotti	10.71	1.88	4.80	1.24	4.89	1.28	1.60	0.61
	Sigara semistriata	0	0	0	0	0	0.06	0.02	0.01
	Corixidae nymphs	2.06	1.67	4.31	0.97	2.17	4.13	5.45	2.60
	contrade nymphs	2.00	1.07	4.51	0.77	2.17	1.15	5.45	2.00

# Table 4.7 continued

taxon	T1	T2	Т3	T4	T5	B6	B7	B8
	%	%	%	%	%	%	%	%
Megaloptera Sialis larva	0	0	0.12	0.06	0.28	0	0	0
Trichoptera Agrypnia spp	0.10	0.06	0.03	0	0.02	0	0	0
Lasiocephala basalis	0	0	0	0	0	0	0.02	0
/Lepidostoma hirtum	0.50	0.77	0.00	0.02	1.07	0.44	0.01	1 10
Limnephilus affinis/incisus	0.58	0.77	0.29	0.03	1.07	0.46	0.81	1.49
Limnephilus lunatus	0.21	2.22	0.05	1.08	1.52	0.04	0.02	0.07
Limnephilus marmoratus	0.32	2.38	1.00	1.54	1.54	1.57	0.71	0.79
Limnephilus vittatus	0.52	0	0	0.01	0	0.04	0.13	0.12
Athripsodes aterrimus	0.16	0.09	0.02	0.04	0	0.04	0.06	0.68
Mystacides longicornis	22.43	4.94	2.66	11.78	6.11	19.49	17.99	16.33
Oecetis ochracea	0.32	0.12	0.09	0.14	0.13	0.46	1.11	0.04
Ylodes/Triaenodes	0.52	0.12	0.05	0.14	0.15	0.04	0	0.04
Ecnomus tenellus	0	0	0	0	0.02	0.04	0	0
Other Trichoptera	3.17	3.95	4.18	3.55	5.64	4.38	2.07	3.21
Diptera Tipulidae	0	0.37	0.05	0.12	0.15	0.04	0.06	0.02
Chaoboridae	0	0.57	0.05	0.11	0.15	0.04	0.00	0.02
Ceratopogonidae	0.16	0.80	0.63	0.65	0.32	0.10	0.13	0.59
Chironomidae	3.17	9.72	6.12	4.25	11.00	30.27	28.64	30.97
Dixidae	0	0.03	0.07	0.09	0.09	0	0	0
Tabanidae	0.11	0.03	0.42	1.06	0.64	0.04	0.11	0.20
Sciomyzidae	0	0	0	0.05	0	0	0	0.20
Stratiomyidae	0	0.06	0.13	0.01	0.04	0.02	0	0.02
Other larva	0	0.03	0.03	0.04	0.13	0.04	0.06	0
Dipteran pupa	0	0.12	0.11	0.04	0.02	0.54	0.13	0.39
Coleoptera Haliplus confinis	0.32	0.52	0.16	0.15	0.28	0.04	0.06	0.02
Haliplus fluviatilis	0	0.03	0	0	0	0.08	0	0
Haliplus lineatocollis	0	0	0	0.01	0	0	0	0
Haliplus obliquus	0	0.12	0.01	0.05	0.09	0	0	0
Haliplus rufficollis grp	0	0	0.02	0.03	0.02	0.06	0.02	0.04
Noterus clavicornis	0.21	0.06	0.28	3.05	0.64	0	0	0
Laccophilus minutus	0	0	0.01	0.04	0.02	0	0	0
Hygrotus inaequalis	0.11	0.37	0.17	0.62	0.26	0.20	0.17	0.17
Hydroporus gyllenhalii	0	0	0	0.01	0	0	0	0
Hydroporus pubescens	0	0	0	0	0.02	0	0	0
H. palustris	0	0	0.01	0.02	0	0	0	0
Graptodytes pictus	0	0	0	0.10	0.02	0.12	0	0
Porhydrus lineatus	0	0	0	0.03	0	0	0.02	0
Agabus nebulosus	0	0	0	0	0	0.02	0	0
Ilybius fuliginosus	0	0	0.01	0.01	0	0	0	0
Gyrinus marinus	0	0	0	0	0.02	0	0	0
Gyrinus substriatus	0	0.03	0	0	0	0	0	0
Helophorus spp.	0	0.28	0.11	0.20	0.64	0.06	0.15	0.07
Hydrobius fuscipes	0	0	0	0	0	0.02	0	0
Anacaena lutescens	0	0	0	0.02	0.02	0	0	0
Laccobius bipunctatus	0.10	0.03	0.02	0.06	0.09	0.02	0.04	0
Laccobius minutus	0	0.12	0.04	0.06	0.06	0	0.02	0
Chaetarthria seminulum	0	0.03	0	0	0	0	0	0
Ochthebius minimus	0	0.06	0.01	0.01	0.11	0.02	0	0
Hydraena ,	0	0	0	0.01	0	0	0	0
rufipes/britteni/riparia							AND DESCRIPTION	

Table	4.7	continued

 taxon	T1	T2	T3	T4	T5	B6	B7	B8
	%	%	%	%	%	%	%	%
 Elmis aenea	0	0	0	0	0.02	0	0	0
Donacia simplex	0	0.03	0	0	0	0	0	0
Megasternum obscurum	0	0	0	0.01	0.02	0	0	0
Fam. Curculionidae	0	0.12	0.02	0.10	0	0.02	0	0
Coccidula rufa	0	0	0.01	0.01	0	0	0	0
Haliplus larva	0.69	0.52	0.16	0.15	0	0.06	0.02	0.04
Noterus larva	0	0.03	0.01	0	0	0	0	0
Ilybius larva	0	0	0.08	0.02	0.06	0	0	0
Dytiscidae larva	0	0.06	0.06	0.11	0.04	0.02	0.02	0.13
Hydrophilidae larva	0.10	0.03	0.01	0.02	0	0	0.06	0.02
Laccobius larva	0	0	0	0	0.02	0	0	0
other larva	0	0	0	0	0	0	0	0.02

The most numerous species at T3 (very fine peat sediment with an abundance of algae and macrophytes) were Oligochaeta, *Pisidium* and *Sigara fossarum*, where they were found at greater percentage abundance than at any other station. *Potamopyrgus jenkinsi, Sigara distincta, S. scotti* and chironomid larvae were also relatively abundant. The abundance of *Lymnaea stagnalis, Caenis luctuosa, zygopteran nymphs, Mystacides longicornis* and other caddis species at T3 was relatively low.

The most abundant species at T4 (marl substratum with a diversity and abundance of macrophytes) was Lymnaea stagnalis at 18.37%. Pisidium sp., Sigara fossarum and Mystacides longicornis were also abundant. Most other taxa, e.g. Oligochaeta, Hirudinea, Potamopyrgus jenkinsi, Hydracarina, Limnephilus spp., Graptodytes pictus (Fabricius), were well represented. T4 had the greatest abundance of Lymnaea stagnalis, zygopteran nymphs, Gerris spp., Sigara falleni, Tabanidae, Noterus clavicornis and Hygrotus inaequalis of any station. The percentage abundance of Gammarus spp. and Caenis luctuosa along with Lymnaea palustris, L. peregra, Sigara dorsalis and S. scotti was relatively low at T4.

T5 (peat with dense stand of *Carex*) was similar to T2 in that both stations were dominated by *Gammarus* spp. and chironomid larvae. The abundance of *Lymnaea palustris*, *Pisidium* spp, *Asellus aquaticus*, and zygopteran nymphs at T5 was also similar to that at T2 and both stations had a relatively low abundance of *Mystacides longicornis*. T5 had the greatest abundance of *Piscicola geometra* (Linnaeus), *Potamopyrgus jenkinsi*, *Asellus*  *aquaticus, Sialis* larvae and *Helophorus* spp. of any sampling station. *Lymnaea stagnalis* was proportionally quite abundant at T5. There was a general absence of surface dwelling bugs from T5. As with all other Turraun stations, Corixidae formed a significant percentage of the population at T5, with *Sigara distincta, S. fossarum* and *S. scotti* abundant.

The absence of a number of taxa from the Tumduff stations is obvious in Table 4.7 and has also been dealt with in sections 4.3.2.1 and 4.3.2.2. The overall percentage abundance of most taxa was similar at all three Tumduff stations. *Lymnaea palustris*, however, comprised more than 10% of the population at B6 (glacial till) and 6% of that at B7 (peat with little vegetation) but only 0.31% at B8 (sheltered station with calcareous deposits and *Juncus* and *Glyceria*). *Caenis luctuosa* was an important constituent of the fauna at all three Tumduff stations, accounting for almost 10% of the population at B6, 18% at B7 and 25% at B8. *Mystacides longicornis* accounted for 15-20% and chironomid larvae almost 30% of the population at all three Tumduff stations. Hydracarina, Zygoptera and Corixidae were also important in Tumduff and *Hygrotus inaequalis* was the most abundant coleopteran species.

B6 had a greater percentage abundance of *Limnephilus marmoratus*, *Haliplus fluviatilis*, *H. rufficollis* group species and *Graptodytes pictus* than B7 or B8. *Oecetis ochracea* and *Helophorus* species were abundant at B7 relative to the other Tumduff stations. *Pisidium* sp. and *Limnephilus affinis/incisus* were more abundant at B8 than at the other two Tumduff stations.

### 4.3.3.2 Taxa distribution and habitat specificity

Almost all taxa showed a highly skewed frequency distribution, over time and among replicate samples, with low abundance in many samples and high numbers in only a few samples. In most cases sample variance was much greater than the mean. This suggests a clumped distribution. It appears that most taxa were aggregated within the littoral and also within each sampling station, with some replicates having a high abundance of a species and some having none. A clumped distribution suggests that the animals were aggregated in more favourable parts of the littoral habitat (Ludwig & Reynolds 1988).

The data were examined for habitat specificity, i.e. to say species or taxa which were found at one sampling station only. Only taxa that occurred more than once at any one sampling station were considered habitat specific in this study. *Helobdella stagnalis* (Linnaeus), *Nepa cinerea* Linnaeus and dipteran larvae of the family Sciomyzidae were specific to T4. *Porhydrus lineatus* was only found at T4 within Turraun and at B7 in Tumduff. At Tumduff, *Ylodes/Trianodes* caddis larvae, *Graptodytes pictus* and *Haliplus fluviatilis* were specific to B6, while the four *Gammarus* individuals were all found at B8.

After removal of those listed above, each taxon was examined statistically for differences between sampling stations. Those taxa found to be significantly more abundant in one sampling station were considered to have an association with the habitat at that station. As stated above, the data were highly positively skewed. Transformations were not applicable owing to the large number of zeros and consequently, standard parametric statistics could not be used. The Kruskal Wallace H test, a non-parametric alternative to one–way ANOVA was used. The taxa with significant between sampling station distribution are presented in Table 4.8.

Table 4.8Taxa demonstrating significant differences in distribution between<br/>sampling stations between January 1997 and February 1998. The<br/>Kruskal Wallace H test was used. N = 413 and the degrees of freedom<br/>= 7 in all cases. A.S. = Asymptotic Significance. The source of the<br/>difference (habitat association) as indicated by graphical evidence (see<br/>Figure 4.14) is also given.

taxon	$X^2$	A.S.	habitat association	
Oligochaeta	134.463	< 0.001	Т3	
Theromyzon tessulatum	51.954	< 0.001	T4	
Lymnaea stagnalis	241.504	< 0.001	T4	
Potamopyrgus jenkinsi	92.114	< 0.001	Т3	
Pisidium spp.	134.815	< 0.001	T3	
Hydracarina	44.116	< 0.001	Tumduff	
Gammarus spp.	210.193	< 0.001	T2 & T5	
Asellus aquaticus	37.892	< 0.001	T5	
Cloeon simile	44.391	< 0.001	T4	
Zygoptera	135.280	< 0.001	T4	
Gerris species	38.811	< 0.001	T4	
Sigara distincta	81.908	< 0.001	Т3	
Sigara fossarum	99.328	< 0.001	Т3	
Sigara scotti	83.657	< 0.001	Т3	
Limnephilus lunatus	83.539	< 0.001	T4	
Limnephilus marmoratus	34.305	< 0.001	T4	
Tabanidae	82.602	< 0.001	T4	
Noterus clavicornis	135.919	< 0.001	T4	

The differences between sampling stations were investigated using graphical means. Figure 4.14 illustrates the average catch per sample at each sampling station for all of the taxa listed in Table 4.8. The sampling stations listed under 'habitat association' in Table 4.8, are those where the taxon was found in greatest abundance.

Nine taxa demonstrated an association with T4 (marl), the most marked being *Lymnaea stagnalis*, *Gerris* species and *Noterus clavicornis*. Of the other six, *Theromyzon tessulatum* was also relatively abundant in T2, *Limnephilus lunatus* was abundant in T2 and T5 and Tabanidae larvae were abundant at T3 and T5 relative to the other sampling stations.

Six taxa were found most abundantly at T3 (fine peat, algae and macrophytes). Oligochaeta and *Pisidium* species were also relatively abundant at T4, while *Potamopyrgus jenkinsi*, *Sigara distincta* and *S. fossarum* were also relatively abundant at T4 and T5.

*Gammarus* species were significantly more abundant at Turraun than Tumduff. They were most abundant at T2 and T5, followed by T3. At Turraun they were least abundant at T1. Hydracarina were more abundant at B6, B7 and B8 than at all Turraun sampling stations. T4 had the highest abundance of mites within Turraun, while T1 and T5 had the lowest.

T5 and T4 had the greatest abundance of *Asellus aquaticus*. *Asellus* was least abundant at T1, B6 and B7. There were four taxa with low abundance at T1 relative to all other sampling stations. These were *Theromyzon tessulatum*, *Cloeon simile*, zygopteran nymphs and *Limnephilus marmoratus*.

Figure 4.15 presents graphs of average catch per sample of eight taxa with numbers too low to allow statistical testing. These taxa were chosen, as they appear to exhibit some degree of habitat association. *Graptodytes pictus* was most abundant at T4 in Turraun and at B6 in Tumduff. Other beetles (*Haliplus obliquus*, *Hygrotus inaequalis* and *Laccobius bipunctatus* (Fabricius)) were also most abundant at T4. *Helophorus* species were most abundant at T3. T5 and T2 also had relatively high numbers of some of these beetle species. *Hydrometra stagnorum* (Linnaeus) appeared to be associated with T4 and T5, while *Notonecta glauca* Linnaeus was abundant at T3 and also T4 and T2. *Planorbis* species were associated with T2 and T4. The effect of seasonal factors on the associations

between taxa and sampling stations could not be investigated owing to the absence/very low abundance of taxa in many months.

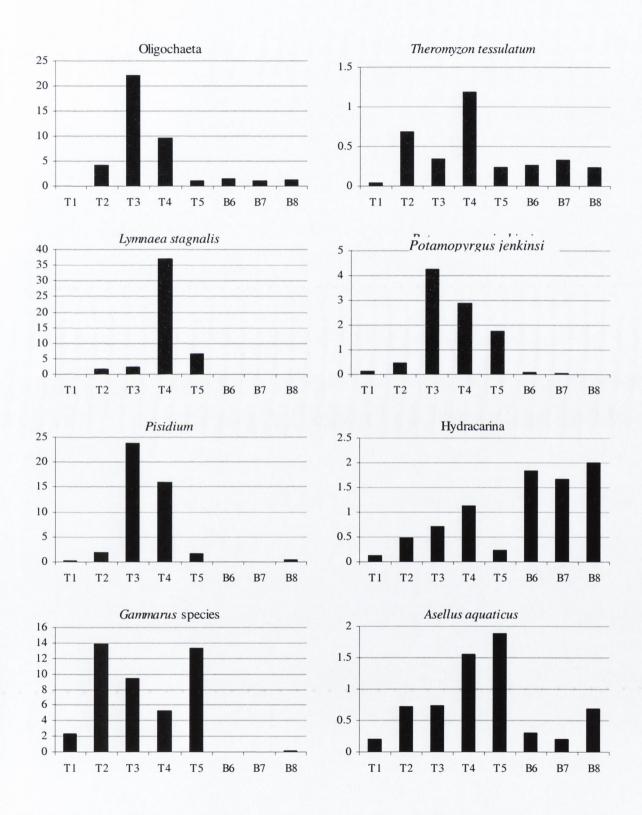
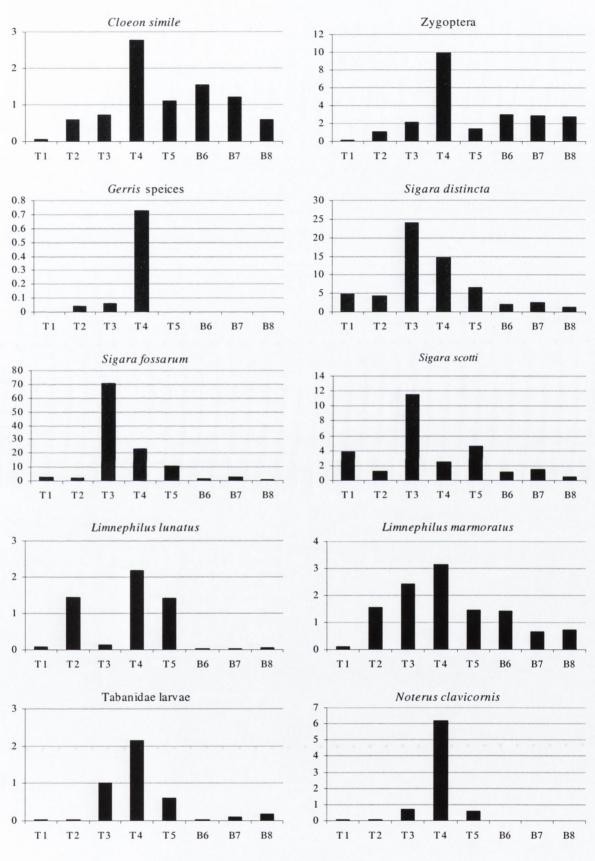
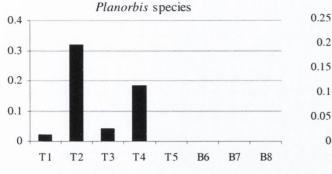
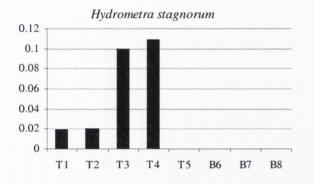


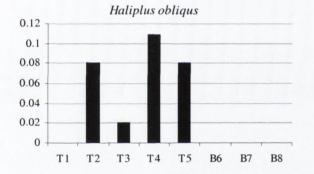
Figure 4.14Average catch per sample of taxa with significant between sampling<br/>station differences in distribution between January 1997 and<br/>February 1998. Kruskal Wallace H test was used. All eight Sampling<br/>Stations in Turraun and Tumduff are shown.

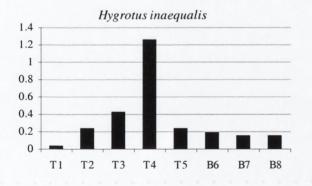


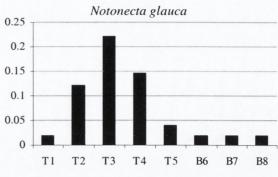


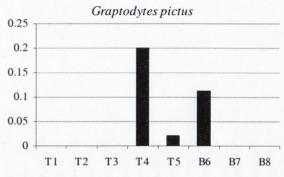


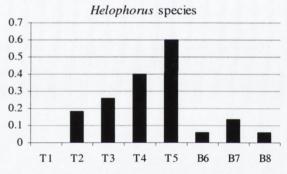












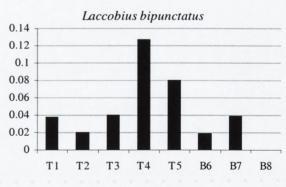


Figure 4.15Average catch per sample of taxa with apparent between sampling<br/>station differences in distribution between January 1997 and<br/>February 1998. Numbers were too low to allow statistical testing.

### 4.3.3.3 Diversity measures at the eight sampling stations

A number of diversity measures were calculated for each sampling station using the average catch per sample over the whole sampling period, January 1997 to February 1998 (Table 4.9). Averaged values for each wetland are also included. Taxon richness, or the total number of taxa captured at each location over the sampling period, is given by Hill's N0. Interpretation of these results must be approached with some caution, especially considering the high standard deviations.

Table 4.9 Diversity indices for Turraun, Tumduff and all eight sampling stations. Average values are given.  $\lambda$  is the Simpson's Index, H' is the Shannon Diversity Index, N0, N1 & N2 are Hill's diversity numbers. N0 is the total number of taxa used to calculate the diversity numbers, N1 is the exponential of H', N2 is the reciprocal of  $\lambda$ .

	λ	s.d.	H'	s.d.	N0	N1	N2
Turraun	0.23	(0.11)	1.94	(0.44)	90	7.58	5.41
Tumduff	0.34	(0.20)	1.54	(0.52)	59	5.22	3.77
T1	0.29	(0.13)	1.54	(0.40)	41	5.03	4.03
T2	0.23	(0.11)	1.91	(0.41)	58	7.30	5.37
T3	0.24	(0.12)	1.94	(0.42)	60	7.57	5.08
T4	0.18	(0.07)	2.21	(0.28)	76	9.43	6.37
T5	0.18	(0.08)	2.09	(0.35)	59	8.55	6.18
B6	0.37	(0.21)	1.43	(0.55)	48	4.78	3.52
B7	0.35	(0.21)	1.54	(0.53)	46	5.23	3.72
B8	0.31	(0.17)	1.65	(0.44)	42	5.66	4.08

ANOVAs calculated for Hill's N1 and N2 were highly significant ( $F_{(1,405)} = 26.8$  and 16.1 respectively,  $p \le 0.0001$ ). LSD post-hoc tests were used to indicate the source of the difference. T1, B6, B7 and B8 were shown to be significantly different from T2, T3, T4, and T5, but not from each other. In terms of N1, T4 was also significantly different from T2 and T3, bearing resemblance to T5 alone. In terms of N2, T4 was different to all sampling stations, except T2 and T5.

As stated in Section 4.3.3.1, T4 had the greatest number of taxa, while T1 had the lowest and Tumduff stations also had low taxon richness. The Simpson's index suggests that the three Tumduff sampling stations had a low diversity and were dominated by a small number of abundant taxa. Simpson's indices indicated that T4 and T5 had the highest diversity. Using the Shannon Diversity Index, T4 and T5 again appear to have the highest diversity. H', N0, N1 and N2 suggest that T4 contained the most diverse community. The standard deviations of  $\lambda$  and H' were lowest at T4. B6 appears the least diverse in all measures except N0.

#### 4.3.3.4 Multivariate analysis

The pattern of species distributions among sampling stations was first investigated over the entire sampling period. Average catch per sample was calculated for all taxa at each sampling station using data collected between January 1997 and February 1998. Figures 4.16 and 4.17 show the dendrograms constructed using TWINSPAN and hierarchical clustering respectively. The most different/least similar sampling stations in both dendrograms are the Tumduff stations with T1 and T2, T3, T4 and T5. Focusing on Figure 4.16, B7 and B8 are similar, while B6 and T1 are equally similar. T4 is the first sampling station separated from the remaining Turraun stations and T5 and T3 are the most similar Turraun stations.

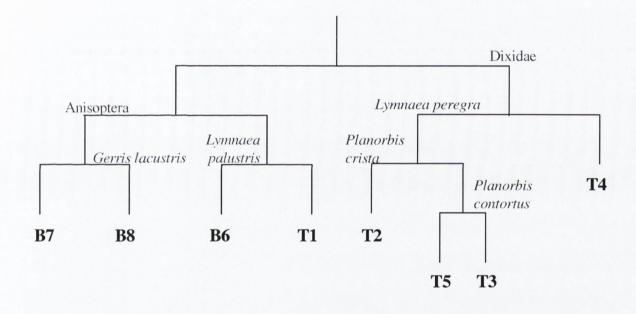


Figure 4.16 TWINSPAN dendrogram generated using average catch per sample at each sampling station, over entire sampling period, January 1997 to February 1998. T refers to Turraun and B to Tumduff.

Through Hierarchical Clustering, T2 and T5 appear very similar in Figure 4.17. T4 appears more similar to T2 and T5 than does T3. All Tumduff stations are similar. T1, however, is less similar to the Tumduff group than any of the remaining Turraun stations are to each other.

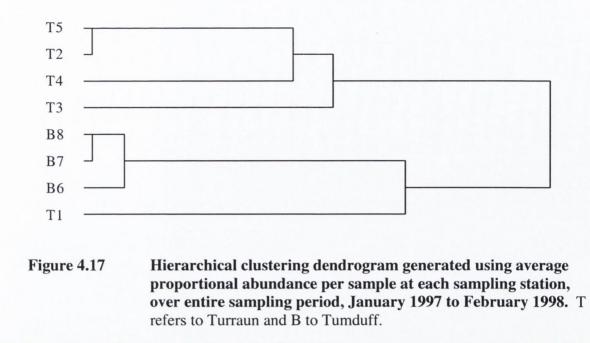


Figure 4.18 illustrates two dimensions of a three-dimensional DCA ordination of sampling stations. All three Tumduff stations cluster closely together. T1, T2 and T5 are adjacent to one another, with T1 placed closest to the Tumduff stations. T3 and T4 appear to be very different from each other and from all other sampling stations.

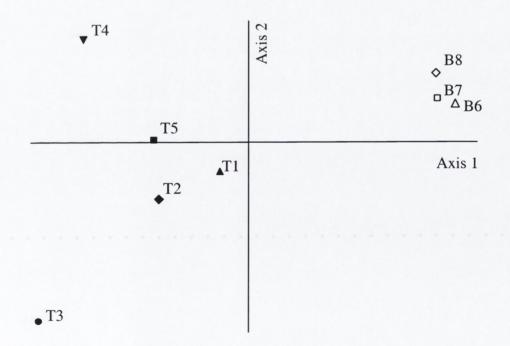


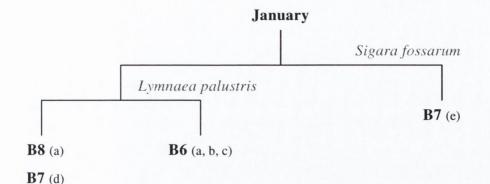
Figure 4.18DCA generated using average catch per sample at each sampling<br/>station, over entire sampling period, January 1997 to February 1998.<br/>T refers to Turraun and B to Tumduff.

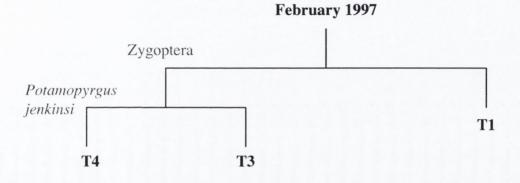
Using averaged data for each sampling station ignores variability between the replicate samples. Obviously samples from the same spot in different months will vary with seasonal trends, linked to life history events such as reproduction, emergence, death and/or diapause. In order to test whether replicate samples from each sampling station were similar and if sampling stations had distinct communities, dendrograms and ordination plots were constructed for each sampling date between January 1997 and February 1998. Figure 4.19 shows TWINSPAN dendrograms for each month. DCA ordinations for each month are given in Figure 4.20. These have been overlaid with the TWINSPAN groups. The five replicates taken from each station on each sampling date are labelled a, b, c, d and e.

Concentrating first on the Turraun sampling stations in Figure 4.19, T4 (marl substratum) appears to be the most distinctly different of all Turraun samples. All T4 replicates separate together in February 1997, April, May, July, September and November. Four of the five T4 replicates separate together in March and June, while in the remaining months all five T4 replicates are found together with replicate samples from T2, T3 and T5. A diverse range of species appears to account for the separation of T4 replicates from other samples. The presence and abundance of *Lymnaea stagnalis*, *Pisidium*, various Corixidae species and *Mystacides longicornis* was important in distinguishing T4 from other sampling stations.

T3 samples also appeared different to those from other habitats. All or most T3 replicates separated from other samples in February 1997, March, May, June, July, October and February 1998. All five T3 replicates separated with some T2 and T5 replicates in November. Oligochaeta, Chironomidae and Corixidae species appear to be important in separating T3 from other stations.

T1, T2 and T5 did not appear distinctly different from any other sampling station. All five T5 replicates, however, separated together in June. T5 separated along with some replicates from T1 in May, August and February 1998, with some replicates from T2 in May, July and August and with some replicates from T3 in July and August. T5 replicates were also found with T4 replicates in October. T1 and T2 replicate samples were found to separate out with replicates from all sampling stations, including those at Tumduff. All five T1 replicates separated out in February 1997 and September.





March

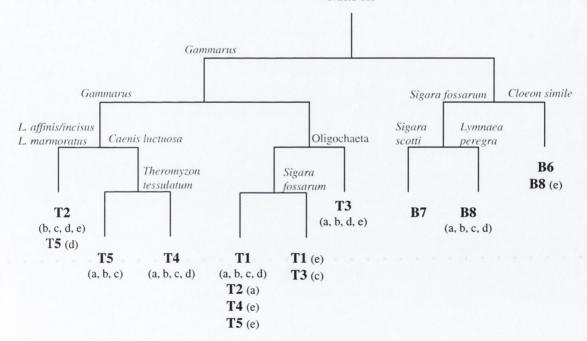
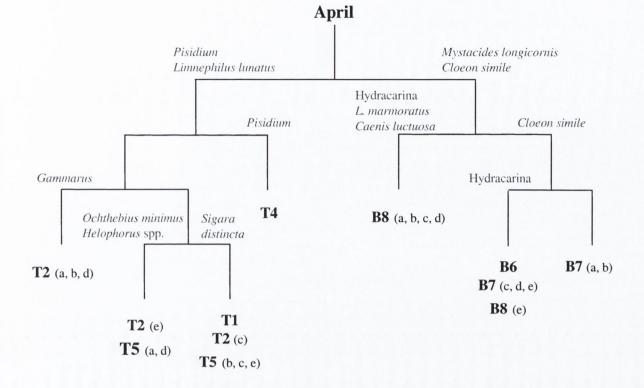
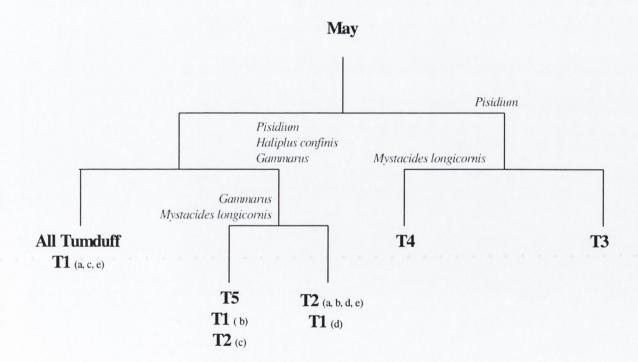
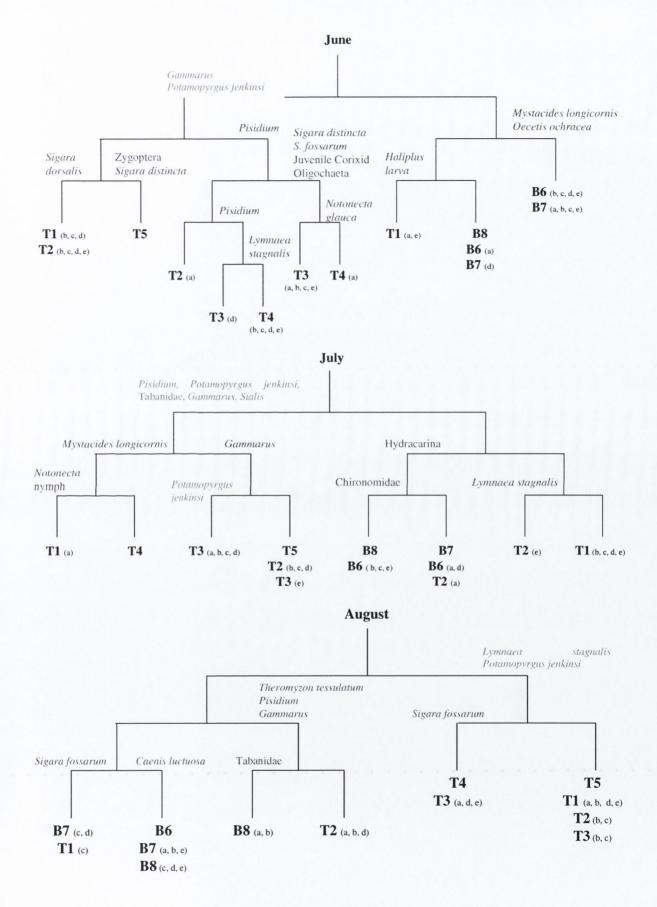


Figure 4.19 Monthly Dendrograms generated using TWINSPAN. Absolute abundance per replicate sample was used. T refers to Turraun and B to Tumduff. The five replicates at each sampling station are labelled a to e. When only the sampling station name is give, all five replicates are included.

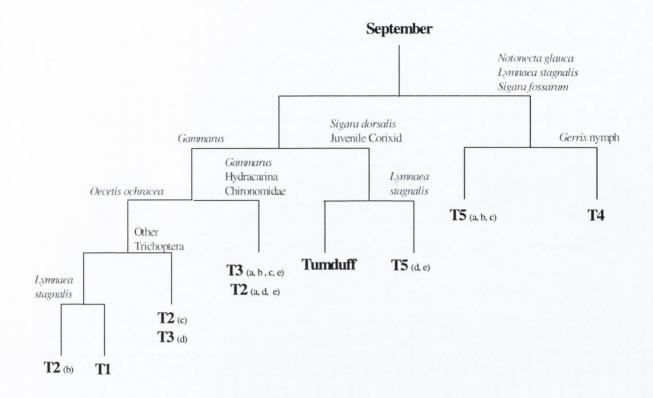




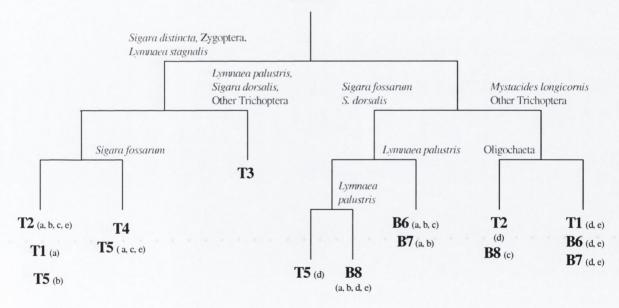
# **Figure 4.19 continued**



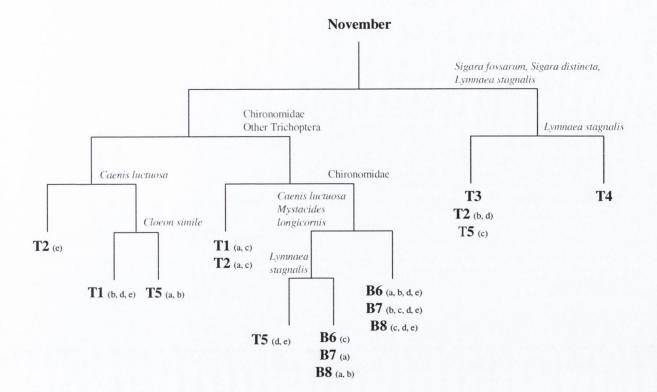
**Figure 4.19 continued** 



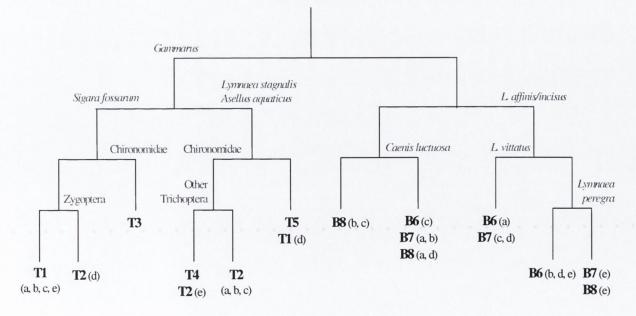
October



**Figure 4.19 continued** 



February 1998



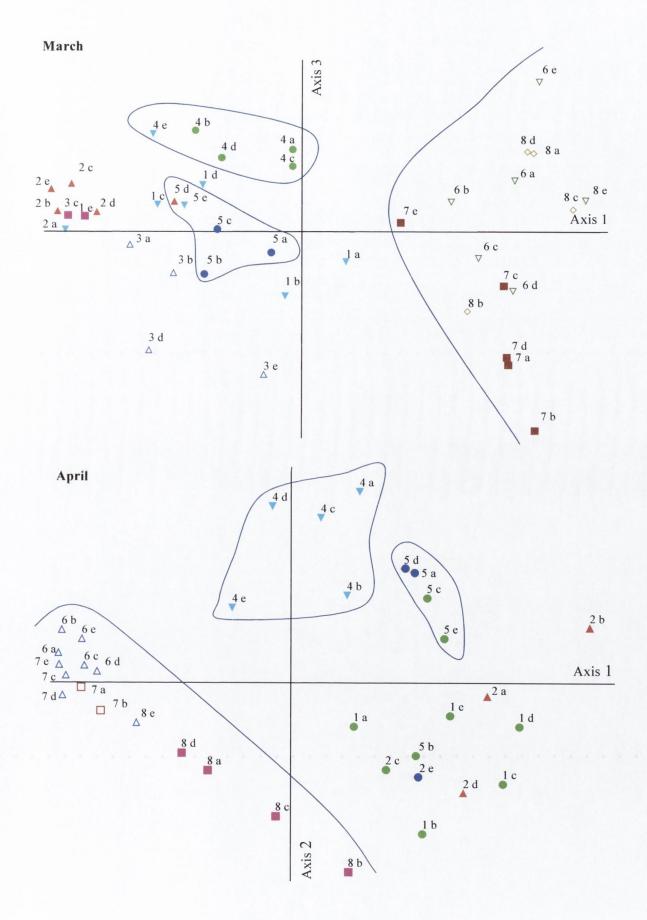
**Figure 4.19 continued** 

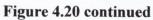
The Tumduff sampling stations do not appear to differ from one another, with only B7 in March separating from all other stations. All Tumduff replicate samples separate from Turraun samples in March, April, September and February 1998. Tumduff replicates are grouped with T1 replicates in May, June, August and October, with T2 replicates in July, August and October and with T5 replicates in October and November. All B6 replicates separate together, along with other Tumduff replicate samples, in March, April and August. All B7 replicates separate together in March and July and all B8 replicates separate in June and July.

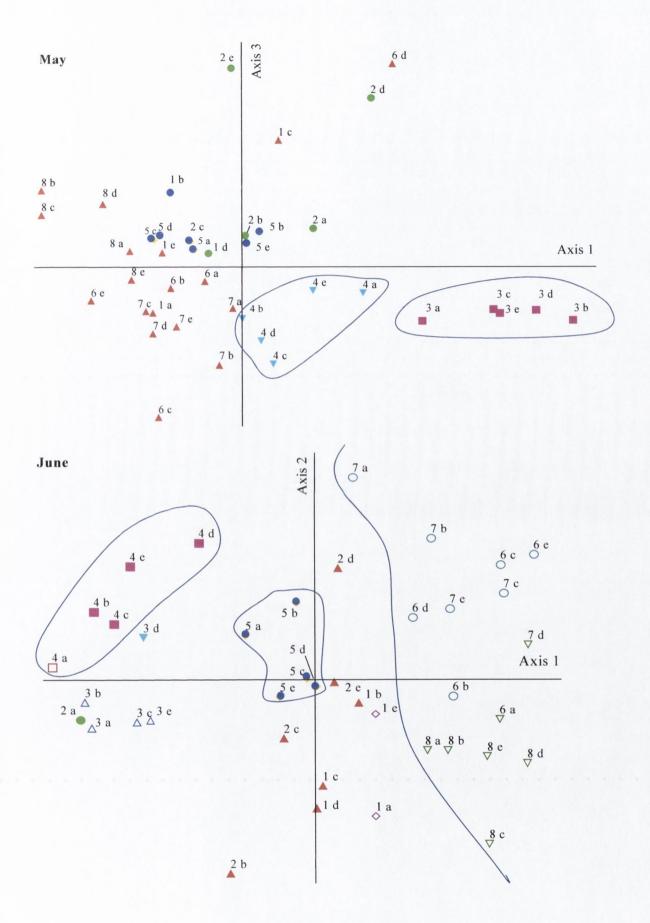
The low number or absence of *Lymnaea stagnalis*, *Potamopyrgus jenkinsi*, *Pisidium* and *Gammarus* species from Tumduff appears important in differentiating Tumduff samples from Turraun samples. An abundance of Hydracarina, *Mystacides longicornis* and Chironomidae was important in dividing Tumduff replicates from Turraun replicates in some months.



**Figure 4.20** DCA ordinations calculated on the basis of absolute abundance per replicate sample. Sampling Stations 1 to 5 are in Turraun and 6 to 8 in Tumduff. Replicate samples are labelled a to e.









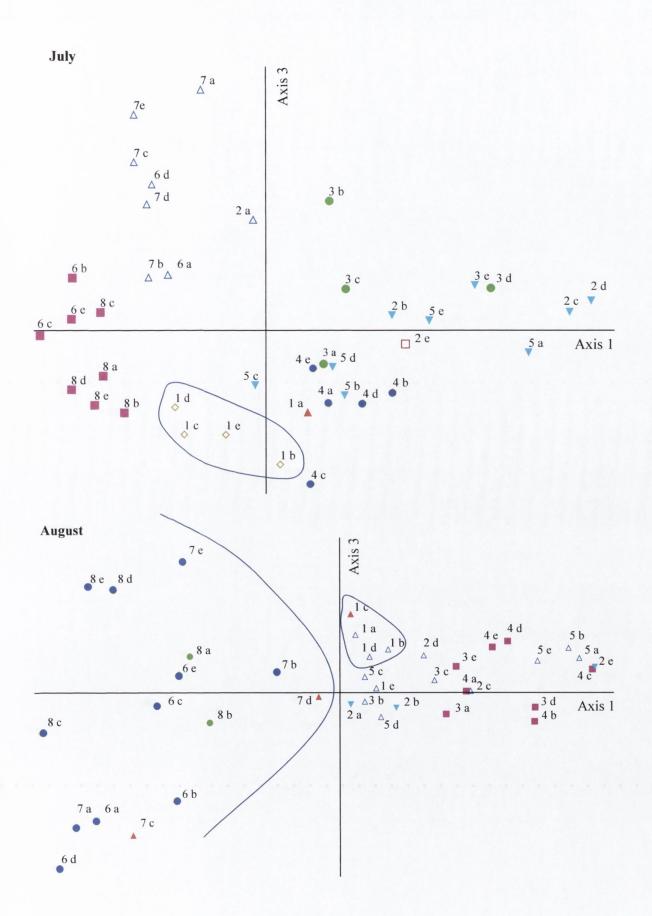


Figure 4.20 continued

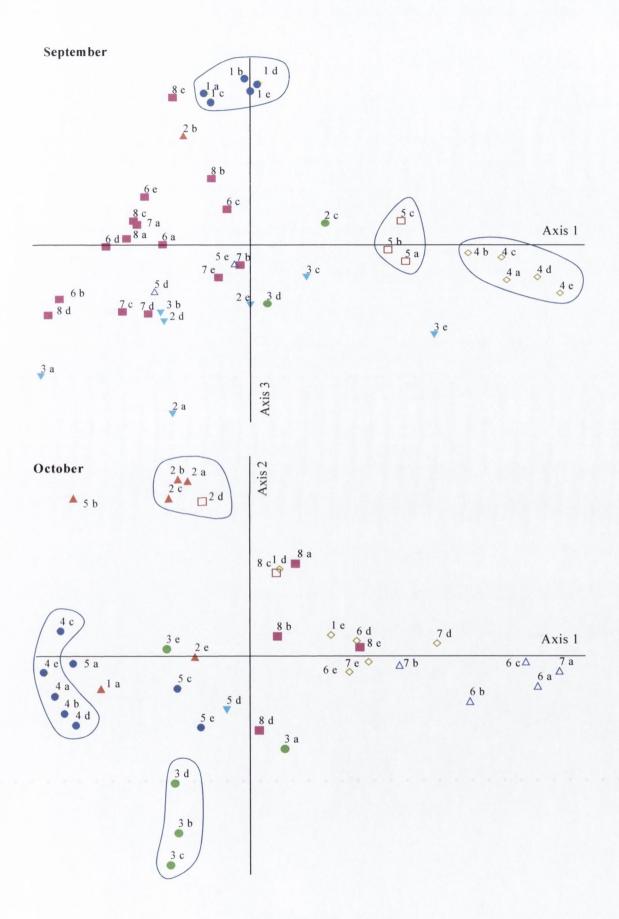


Figure 4.20 continued

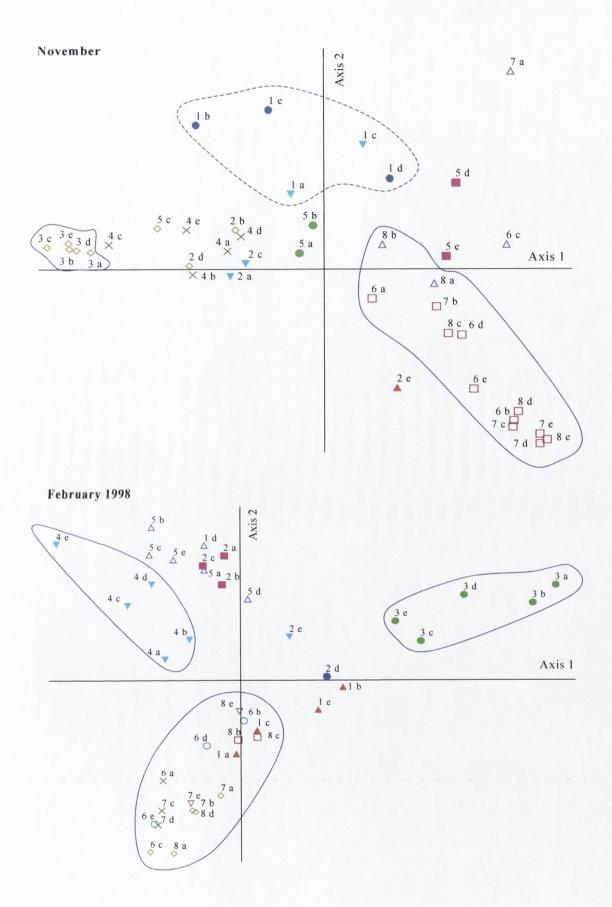


Figure 4.20 continued

The DCA plot (Figure 4.20) for February 1997, reflects the TWINSPAN groupings for Turraun very clearly, with T4 and T1 being most dissimilar. T4 replicates were found to cluster closely in the ordination in March and June, and along with T3 replicates in November, T2 (a, b, c, d) in October and T5 (a, c, d, e) in April. In many cases, however, the clear TWINSPAN groups were obscured in the ordination, e.g. T4 in July, August and November, T3 groups in March, July, August and October. In many months all Turraun replicate samples were intermixed on the ordination, particularly samples from T1, T2 and T5.

The DCA plots clearly separate Tumduff replicate samples from Turraun replicates in March, April, June, July and August. Tumduff samples are also moderately distant from Turraun in all other months, although, there is some intermingling with Turraun replicates, particularly from T1. The clusters of Tumduff replicates often obscure the TWINSPAN groups, particularly in March, August, October, November and February 1998. The TWINSPAN groups for Tumduff are shown best in June and July.

## 4.3.3.5 Feeding guilds

In an attempt to explain the findings the functional trait feeding was explored for differences among sampling stations. The taxa were divided into five feeding guilds - filter feeders, deposit feeders, scrapers, shredders and carnivores after Moss (1998). Filter feeders were considered to be animals that filter suspended detritus from the water column. Deposit feeders were those that fed on detritus on or in the sediment. Scrapers were those feeding on Aufwuchs (periphyton). Shredders were animals feeding on fragments of plant material and the associated biofilm. Carnivores were those feeding on other animals in any way.

Feeding guilds were assigned according to ecological notes in the keys named in section 4.2.2.4, with additional information from Coyler and Hammond (1968), Cummins and Klug (1979), Moss (1998) and Fitter and Manuel (1986). Richoux (1994) was used to define feeding strategies of coleopteran adults and larvae. A list of taxa used and the feeding guilds to which they were assigned is given in Appendix 4.3.3.7. 36 taxa were defined as predators, 13 as scrapers, four each as deposit feeders and shredders and two as suspension feeders.

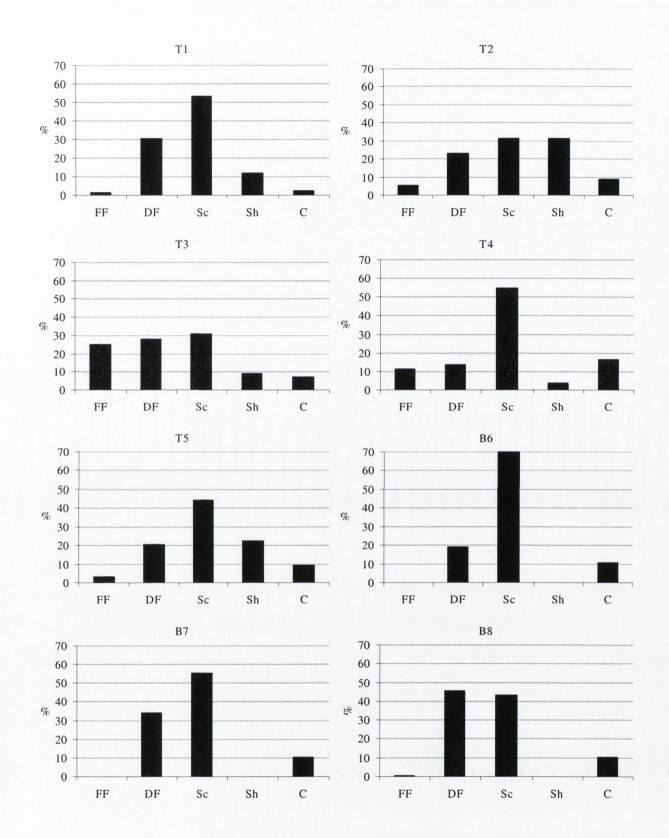


Figure 4.21Average percentage abundance of five feeding guilds at the eight<br/>sampling stations. FF – filter feeders, DF – deposit feeders, Sc –<br/>scrapers, Sh – shredders, C – carnivores.

As Chironomidae were not identified to species, they were not included in the analysis. Chironomid larvae may be carnivorous (e.g. Tanypodinae), parasitic (e.g. some Chironominae), scrapers (e.g. Orthocladiinae), filter feeders (e.g. *Rheotanytarsus*, *Glyptotendipes*) or deposit feeders (e.g. *Chironomus*) (Bryce & Hobart 1972). Corixidae were also omitted. Corixidae were believed to be phytophilous by many authors (Southwood & Leston 1959), although Reynolds (1975) showed that species of *Sigara* have a diverse diet including periphyton, phytoplankton and zooplankton, oligochaetes, insect larvae and crustaceans.

Figure 4.21 shows the average percentage abundance per sample of the five macroinvertebrate feeding guilds at each sampling station. Scrapers were the most important guild in both wetlands, forming greater than 30% of the population at all sampling stations. They dominated at T1, T4, T5, B6 and B7. Detritus appeared to be a significant source of food at T3, where filter and deposit feeders were almost as abundant as scrapers. Filter feeders were also moderately abundant at T4. However, these were almost absent from Tumduff and of low proportional importance at T1, T2 and T5. Deposit feeders were abundant at B7 and B8, and at T1 in Turraun. The lowest percentage abundance of deposit feeders was found at T4. Shredders were of much lower percentage abundance at the remaining Turraun stations and almost absent from Tumduff. The greatest percentage abundance of carnivores was at T4 and the lowest was at T1, followed by T3.

The most even distribution of guilds was found at T2 and T3, while all guilds except shredders were well represented at T4. T5 had a good spread of feeding guilds, but the abundance of filter feeders was low. Filter feeders and carnivores were scarce at T1, and filter feeders and shredders were nearly absent from the Tumduff stations.

## 4.4 Discussion

The discussion will follow a sequence through four main topics. Firstly the preliminary surveys of the six cutaway wetlands will be discussed. Next, differences between the macroinvertebrate communities of Turraun and Tumduff will be examined. In the third section, the differences between the eight sampling stations will be considered. Fourthly, the life history and ecology of some species captured in Turraun and Tumduff will be discussed.

### 4.4.1 Preliminary surveys of six artificial wetlands on raised bog

Of the six wetlands sampled in the preliminary survey, the oldest (Turraun) and the youngest (Tumduff) had the most and least taxa respectively. Differences in the macroinvertebrate fauna between all six wetlands were probably linked to the age, morphology and substrata of the waterbodies. pH may also have been a factor. Gastropod molluscs were absent from Boora Lake, Tumduff, Lullybeg Lake and Barnaran Pond. These latter two wetlands, from which *Gammarus* was also absent, were acidic (Kaens 1996). The remaining wetlands were alkaline and influenced by groundwater to various extents.

Macrophyte and periphyton growth was prolific at Blackwater Lake and it was suspected that supplementary feeding of waterfowl may have led to enrichment. The abundance of *Asellus aquaticus* and chironomid larvae in the wetland suggested some organic enrichment may have occurred. Boora Lake was created as the first experimental fishery; macrophytes and associated invertebrates were introduced and the presence of fish may explain the absence of some taxa from the sample (notably Gastropoda, Trichoptera, Diptera and Coleoptera).

# 4.4.2 Comparing the two study sites, Turraun and Tumduff

In the following discussion, Turraun and Tumduff are first compared in terms of overall species richness and diversity. Possible reasons for the differences between wetlands in terms of overall abundance are next explored. The subsequent paragraphs are devoted to seasonal variations in terms of overall numbers, diversity and species abundance. Finally

the multivariate statistics are considered. Diversity indices were calculated during this study in order to supplement information gained from species richness, abundance data and multivariate statistics. The limitations of diversity indices are recognised and include difficulty of interpretation, ambiguity and lack of sensitivity. There appears to be a general lack of agreement amongst ecologists as to the usefulness of these indices, and their popularity tends to vary over time and amongst disciplines.

Species richness, abundance and diversity were all greater at Turraun than at Tumduff. 108 taxa were found in Turraun and 71 in Tumduff, between October 1996 and August 1999. Between January 1997 and February 1998, a total of 90 taxa were found in Turraun and 59 in Tumduff. Even removing the rare taxa found between January 1997 and February 1998, species richness remained greater at Turraun. 47 of all taxa found at Turraun were absent from Tumduff, while only ten Tumduff taxa were absent from The total catch and average catch per sample between January 1997 and Turraun. February 1998 was considerably larger in Turraun than Tumduff. Monthly average catch per sample was also generally greater at Turraun. All average diversity measures (H',  $\lambda$ , Hill's numbers) indicated that diversity was higher at Turraun than at Tumduff. The community was simpler in Tumduff than in Turraun, being dominated by a few taxa. This can be seen in the percentage abundance values, with Diptera, Trichoptera, Ephemeroptera and Corixidae completely dominating the Tumduff fauna, and also in the Hill's numbers, with significantly more taxa abundant at Turraun than at Tumduff. Percentage abundance was generally more evenly distributed amongst the taxa at Turraun. Corixidae, however, were very abundant and dominant in some months.

A number of factors may have contributed to the differences in macroinvertebrate communities between wetlands. These can be divided into four main headings, age, water chemistry, habitats (particularly macrophytes) and morphology. The number of species in alkaline, artificial ponds has been found to increase with age (Barnes 1983, Williams 1993). Age may explain the greater taxon richness in Turraun, which is four years older than Tumduff and has, therefore, had a longer period for colonisation. It is possible that Turraun acted as a significant source of macroinvertebrate colonists for Tumduff, partly explaining similarities in their species composition. Pond area has also been linked to rates of macroinvertebrate colonisation and species richness (Popham 1943, Friday 1987,

Williams 1993), and the far greater surface area at Turraun may have attracted more species to that wetland than to Tumduff.

Friday (1987) stated that pH was the most important variable for macroinvertebrate and also macrophyte species richness, the number of taxa generally increasing with pH. Calcium is also considered important to macroinvertebrates (Macan 1977, Elliott & Mann 1979, Friday 1987, Lodge et al. 1987). pH is above neutral and calcium abundant in Turraun and Tumduff, suggesting that these factors are not limiting and do not explain differences in macroinvertebrates between wetlands. Savage (1996, 2000) found that species richness was negatively correlated with conductivity in a chemically unstable lake subject to high salt concentrations. Savage (1982, 1994) has also shown that corixid species are restricted to different and relatively narrow conductivity ranges. Conductivity in the study sites falls within the range for non-saline waterbodies and is unlikely to have limited macroinvertebrates. The significantly higher conductivity at Tumduff, however, may account for some differences in species composition between wetlands. Waterbody productivity can affect invertebrate abundance (Death 1995, Harrison & Hildrew 1998). Total phosphorus and chlorophyll a concentrations suggest that primary productivity was higher at Turraun than at Tumduff (see Chapter 3). High primary productivity at Turraun probably generated high secondary productivity and may also have influenced species richness.

Many authors have considered habitat important to macroinvertebrate species richness and/or abundance (e.g. Macan 1973, Barnes 1983, Friday 1987, Lodge *et al.* 1987). Macan (1973) indicated that the more variable the conditions in a water body, the more species can inhabit it, owing to the Darwinian principle that species evolve to fill particular niches and that there is one species per niche. One main habitat factor, macrophyte vegetation, is here considered important to macroinvertebrates. Sediment, exposure, depth and slope are also briefly discussed.

Macrophytes can affect macroinvertebrate species richness/diversity (Palmer 1981, Friday 1987, Lodge *et al.* 1987, Hanson 1990, Savage 2000), abundance (Macan 1973, Voigts 1976, Cyr & Downing 1988, Hanson 1990, Savage 1996, 2000) and macroinvertebrate distribution (Barnes 1983, Lodge 1985, Carpenter & Lodge 1986, Cyr & Downing 1988, Painter 1999). Species specific macroinvertebrate-macrophyte relationships appear to exist

(Lodge *et al.* 1987, Cyr & Downing 1988). The means by which macrophytes can influence macroinvertebrates are manifold, but can be divided into five broad, overlapping topics. These are morphology/structure, food, refuge, life history and locomotion/ attachment.

Macrophyte structure varies with species, and can directly and indirectly influence invertebrate species richness and abundance. The morphology of the plant governs the diversity and form of microhabitats (Palmer 1981). The structure of macrophytes also determines the surface area available for periphyton growth (Cyr & Downing 1988) and can influence physical features of the environment, such as light, temperature, water flow and substratum (Carpenter & Lodge 1986). Different plants will create more or less shade and different vertical temperature gradients. Plants can also alter water flow, prevent sediment erosion (Carpenter & Lodge 1986) and act as a sieve to accumulate phytoplankton, detritus and fine sediment (Cyr & Downing 1988, Suren & Winterbourn 1992).

Littoral vegetation is a recognised source of food for macroinvertebrates (Carpenter & Lodge 1986, Savage 1996). Plants can be grazed upon directly (Carpenter & Lodge 1986) and Jacobsen & Sand-Jensen (1992) found that the herbivory loss varied widely among plant species. Macrophytes also provide a substrate for the important macroinvertebrate food source, epiphyton (Barnes 1983, Cyr & Downing 1988). Epiphyton communities can be specific to certain plants, owing to exudates or microclimates (Carpenter & Lodge 1986), and this leads to selective grazing (Lodge 1985). Death and decomposition of macrophytes generates detritus and coarse particulate organic matter, the quality of which may vary between species (Barnes 1983). Some macroinvertebrate predators ambush their prey from the concealment of macrophyte stands.

Macrophytes can also act as a refuge from fish and invertebrate predators (Macan 1965b, Barnes 1983, Carpenter & Lodge 1986, Lodge *et al.* 1987, Cyr & Downing 1988, Savage 1989, 1996, Hanson 1990). The effectiveness of a plant as a refuge depends on structure. Some caddis species harvest plant material to construct a protective case. A number of macroinvertebrates are dependent on different macrophyte species during their life history. Some insects oviposit on or in plants (Macan 1973, Scudder 1976, Barnes 1983, Savage

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1989). Macrophytes are essential for the emergence of some species (Barnes 1983), while plants may also be important for aerial adult stages.

Macrophytes act as sites of attachment for sedentary species (Barnes 1983). Plant structure or surface texture combined with macroinvertebrate requirements may result in specific macrophyte-macroinvertebrate associations (Lodge 1985). Larger heavier crawling invertebrates may require larger plants (Cyr & Downing 1988). Macrophytes may also affect macroinvertebrate species richness, abundance or distribution through the presence of defensive chemicals (Cyr & Downing 1988), the presence of attractant chemicals (Lodge 1985), the removal of toxic ammonia, oxygenation of water and sediments, and provision of access to the air-water interface for respiration (Carpenter & Lodge 1986). Macrophytes may indirectly influence the fauna through accumulation of organic material and alteration of the sediment.

Macrophyte species richness and density was far greater at Turraun than at Tumduff, and contributed significantly to differences in macroinvertebrate taxon richness, diversity and abundance between wetlands (indicated by Tables 4.3, 4.4 and 4.6, and Figures 4.1, 4.2 and 4.3). The structural diversity of macrophytes in Turraun was very high with submerged and floating forms, as well as a range of emergent species.

Local changes in substratum may be a major factor for invertebrates (Friday 1987). Sediment character, particularly nutrient content and texture, can also affect vegetation distribution (Friday 1987, Weisner 1991), and hence, macroinvertebrates. Turraun had a greater diversity of sediment, with marl and a variety of textures of peat (see Section 2.4, Chapter 2), as opposed to Tumduff, which was covered with fine textured peat. This contributed to the greater diversity and abundance of macroinvertebrates found at Turraun (Tables 4.6 and 4.7).

Exposure to waves can reduce macroinvertebrate abundance (Lodge *et al.* 1987, Harrison & Hildrew 1998) and affect species richness (Voigts 1976). Exposure also partly determines the distribution of emergent macrophytes (Weisner 1991). Morphological features, terrestrial vegetation and, as noted above, macrophytes control exposure. Inlets, bays and macrophyte beds created sheltered areas in Turraun, while other areas were exposed and influenced by waves. Islands, birch scrub and macrophytes reduced the water

fetch and hence, wave erosion at Turraun. Most of the shoreline at Tumduff was exposed and erosion was evident. Thus, the exposed, uniform littoral zone in Tumduff contributed to low macroinvertebrate taxon richness and abundance.

Water depth directly influences macroinvertebrates (Friday 1987), with some insects confined to shallow water owing to their need to respire at the air/water interface (Brinkhurst 1974). The greater abundance of shallow water at Turraun may have facilitated high macroinvertebrate diversity and abundance. Slope has been shown to directly influence macroinvertebrate species composition, with more gentle slopes supporting higher diversity in ditches in Wicken Fen (Painter 1999). Slope can also affect vegetation colonisation. The slope of the shoreline at Turraun was gentle with some steep banks. The slope at Tumduff was consistently steep, leading to lack of consolidation in the sediment and preventing plants from establishing.

Biotic interactions, such as predation and competition can be important in structuring macroinvertebrate communities (Friday 1987, Lodge *et al.* 1987, Death 1995, Harrison & Hildrew 1998). Differences in biotic interactions between wetlands probably also contributed to differences in macroinvertebrate communities.

As already stated, primary productivity appeared to be greater at Turraun than Tumduff. Food selectivity may be important in determining the distribution and abundance of macroinvertebrates (Lodge *et al.* 1987, Suren & Winterbourn 1992). The availability of macroinvertebrate food in the form of detritus and plant matter, particularly planktonic and epiphytic algae, also appeared to be much greater in Turraun than Tumduff. These facts are borne out by the greater relative importance of filter feeders and shredders in Turraun, along with the high abundance of scrapers. The available food was of a more diverse nature at Turraun than Tumduff, as suggested by the more even distribution of feeding guilds in the former wetland. The greater abundance of carnivorous invertebrates at Turraun may have been encouraged by the abundance of phytophilous and detritivorous animals.

Trends in average total catch per month can be partly explained by the abundance of individual taxa. This pattern was more obvious in Tumduff where a few abundant taxa dominated the fauna. The trend in average catch per sample from January to August at

Tumduff almost perfectly reflected seasonal changes in *Caenis luctuosa*. Average catch during the rest of the year tended to follow the chironomid seasonal pattern, low in summer and high from August to November. Corixids also contributed to the high average catches in September and November. At Turraun, the high average catch in March appeared to reflect the abundance of *Sigara dorsalis* and *S. scotti* in that month. Oligochaetes, *Pisidium, Potamopyrgus jenkinsi* and corixid nymphs were largely responsible for the high average catch in June and July. *Lymnaea stagnalis* was very abundant in September and combined with corixid numbers, resulted in an increased average abundance per sample in that month. Corixidae, particularly *Sigara distincta* and *S. scotti* contributed to the November peak in average abundance. The average catch per sample appeared to increase between February 1997 and February 1998 at Turraun, possibly as a result of continued colonisation. Corixid data for 1998 and 1999 (Chapter 5) indicate that monthly abundance may have decreased after February 1998.

Seasonal trends in diversity (Hill's N1) also reflect species' life cycles and temporal abundance. Diversity was low between September and November in Turraun owing to the abundance of *Lymnaea stagnalis*, *Sigara distincta* and *S. fossarum*, rather than the number of taxa recorded. The high diversity in March and June appears to have been owing to the co-dominance and high abundance of a number of taxa, including Oligochaeta, *Pisidium* sp., *Gammarus* spp., *Caenis luctuosa*, various corixid species and nymphs, various Trichoptera larvae and Chironomidae larvae. The number of taxa captured in these months (53) was also relatively high. High diversity in spring may be related to the naturally high abundance of a variety of insect larvae and fully aquatic invertebrates. As larvae have generally reached the latter instars at this time, it is also easier to identify them to species, adding greater definition to the diversity measures. Hill's N1 did not fluctuate much at Tumduff over the sampling period and the highest value, found in August, was probably owing to a combination of taxon richness (34) and co-dominance by a greater number of taxa than in other months. High diversity in August could indicate that this was a period of colonisation and establishment for new species.

In general, most taxa showed similar temporal changes in abundance in both wetlands. Where differences did exist, it was most often because of low abundance at Tumduff obscuring clear seasonal trends. This was the case with Oligochaeta, *Potamopyrgus jenkinsi*, *Pisidium* sp., *Gammarus*, *Limnephilus lunatus* and *Haliplus confinis*. In the case

of *Theromyzon tessulatum* and *Limnephilus marmoratus*, average catch per sample was considerably lower in Tumduff than Turraun in early 1997. These species could have been absent from Tumduff at the beginning of the survey and may have only successfully colonised or established themselves in that wetland during summer 1997.

Although there was a good deal of overlap between wetlands in terms of species composition, each had a distinct macroinvertebrate community. The NMDS plot using average abundance per month clearly clustered most Turraun and most Tumduff months together, while separating the wetlands from each other. The wetlands were also separated from each other in the DCA plot, however, some samples were equally different to other monthly samples as to second wetland samples. Multivariate analysis of the various sampling stations also separated samples for the two wetlands.

#### 4.4.3 Variations between sampling stations at Turraun and Tumduff

Following some general comments, this section discusses each of the sampling stations separately. It may be useful to refer to Sections 2.3 and 2.4, Chapter 2, where full descriptions of the sampling stations are given. The sampling stations are dealt with in numerical order (T1, T2, T3, T4, T5, B6, B7 and B8). The most notable features of each, in terms of species richness, species abundance, diversity, dominant species and feeding guilds, are mentioned. Explanations are sought for the macroinvertebrate assemblages found. Discussion centres on exposure, sediment, vegetation and food. Similarities and differences with other sampling stations, as evident from percentage abundance of species and multivariate statistics, are investigated. After each sampling station has been discussed in this fashion, multivariate statistics are considered and results are summarised.

The eight sampling stations varied in terms of macroinvertebrate abundance, species richness and diversity. A number of abundant taxa were more or less ubiquitous, but differed in average catch per sample and percentage abundance among sampling stations. Of the less abundant species, a few were more numerous at certain stations, while others were habitat specific. In spite of these clear differences, there was a good deal of overlap between replicate samples from different sampling stations. Multivariate statistics suggested that some sampling stations contained quite distinct macroinvertebrate assemblages, while others bore resemblance to all other sampling stations.

T1, the sampling station on compacted peat and lacking vegetation, had the most impoverished macroinvertebrate fauna of any habitat examined. It had the lowest abundance, in terms of average catch per sample and total catch, and the fewest taxa of any sampling station. Diversity measures were lower here than elsewhere in Turraun and similar to those of Tumduff. The station was dominated by abundant, ubiquitous taxa, such as *Caenis luctuosa*, Corixidae and *Mystacides longicornis*.

There may be a number of reasons why T1 had low species richness and abundance. First it was one of the most exposed stations at Turraun, affected by wave action and easterly winds in particular. Neither was there any terrestrial vegetation to shelter the habitat from westerly winds. Second the peat sediment at T1 was compacted and this may have limited or precluded burrowing animals, such as oligochaete worms and dipteran larvae. Sediment compaction would also have made it difficult for macrophytes to colonise the station. This absence of macrophyte vegetation compounds the problem of exposure and leads to an absence of macroinvertebrate anchoring substrate and food. Sit and wait predators, such as Odonata and Hirudinea, that use vegetation to hide from their prey, and active predators, such as beetles that hunt amongst plants, were not abundant at T1. Species that cling to and graze upon plants, such as Mollusca, Cloeon simile and Limnephilus marmoratus had lower abundance at T1 than elsewhere. This total absence of macrophytes may be responsible for the more impoverished fauna at T1 than at Tumduff. The habitat at T1 may be comparable to the rocky shores of natural lakes, where only attached organisms survive. Macan & Maudsley (1968) found the fauna of the stony littoral of Windermere was composed of many species that survived there only as a result of reinforcement from other habitats.

The species present at T1 were predominantly scrapers (>50%) and deposit feeders. Aufwuchs or phytoplankton fallen from suspension may have been the food of scrapers, as the presence of calcium carbonate deposits on the peat indicates that photosynthetic activity did occur at T1. *Mystacides longicornis*, one of the most important species at the station, is a scraper and used the abundant dead snail shells along with peat to build its case. The abundance of deposit feeders, particularly *Caenis luctuosa*, suggests that detritus was washed up from other areas of the wetland or generated through the colonisation and break down of *in situ* peat particles. Corixidae were also abundant at T1, as elsewhere in 1997. These are very mobile creatures and may not have been permanently resident at T1.

Both dendrograms generated on averaged data (Figures 4.16 and 4.17) indicated that the T1 macroinvertebrate assemblage was more similar to that of Tumduff stations than to other Turraun stations. Like T1, the Tumduff sampling stations were exposed to strong wind and waves and had low percentage cover of vegetation and an abundance of bare sediment. These factors may explain similarities in the macroinvertebrate fauna. From the cluster dendrogram, however, it is clear that the three Tumduff stations were far more similar to each other than to T1. This was also obvious looking at the species present and the percentage abundance. In the monthly dendrograms, most T1 replicates clustered with those from other Turraun stations. T1 replicates were found to separate with replicates from all other sampling stations. This is probably linked to the fact that T1 was an impoverished station with only ubiquitous taxa present. Any replicate from another station with low taxon richness and abundance was most likely to resemble a sample from T1.

Macroinvertebrate abundance was relatively low at T2, the sampling station with gravellike peat and *Typha*. Abundance was higher than at T1, but lower than at all Tumduff sampling stations. Species richness was high, however, being similar to T3, the station with fine peat and diverse vegetation, and T5, the station with *Carex*. Diversity was similar to T3 and higher than Tumduff and T1. The most abundant taxa included oligochaete worms, *Gammarus* spp. and chironomid larvae and universally numerous taxa such as *Caenis luctuosa* and Corixidae. The feeding guilds were quite evenly distributed there.

A number of factors may have encouraged a large number of species, while not supporting abundance. The high number of species may simply be an effect of the age, size and habitat development at Turraun, which are all greater than Tumduff. T2, being adjacent to T1, was exposed to wind and waves, but was sheltered to some extent by the *Typha* stand. The substratum was gravel-like pellets of compacted peat, which encouraged taxa such as *Gammarus* that bury under loose substrate. At the same time, gravel substrata are not very stable, moving easily under the influence of waves and as a result, are not readily colonised and have a small permanent community (Moss 1998). The gravel-like peat would have been unsuited to burrowing deposit feeders.

*Typha* dominated the habitat, particularly in winter, however, the diversity of flowering plants was high during the spring and summer. *Typha* provided structure and food, in the

form of periphyton, coarse fragments of leaf litter and detritus. The upright structure of the emergent vegetation may have been important for species such as *Theromyzon tessulatum*, which appeared to express an association with T2, and *Gammarus*. *Gammarus* and chironomid larvae were abundant, the former probably shredding fragments of *Typha* leaves and the latter found regularly in the aerenchyma of the plant. Deposit feeders, such as *Asellus aquaticus* and Oligochaeta worms, were also abundant at T2, crawling around the leaf litter and feeding on detritus found there. Voigts (1976) also found that *Asellus* and *Planorbis* spp. were abundant in emergent stands with floating dead vegetation.

Scrapers were not as abundant at T2 as elsewhere, although they were diverse, and it is possible that *Typha* did not support as abundant a periphyton community as other macrophytes found in the wetland. Periphyton may have been seasonally abundant because of the presence of flowering plants. The diversity of periphyton may also have increased with this vegetation and the scrapers present may have had a preference for communities associated with different plant species. This may explain the different suite of scrapers found at T2, with high mollusc diversity and an abundance of species such as *Limnephilus lunatus*, *L. marmoratus*, *Haliplus confinis* and *H obliquus*. Lodge (1985) found snails to be associated with epiphyton assemblages specific to various plants, with *Planorbis vortex* (Linnaeus) found on *Glyceria* and *Lymnaea peregra* on *Elodea canadensis*. *Glyceria fluitans* was found at T2 (as well as T5 and B8) and this may explain the presence of *Planorbis* spp. Similar to the scrapers, the suite of carnivores found at T2 was slightly different to that found at other Turraun stations, with Hydracarina, leeches, Odonata, Tipulidae and Ceratopogonidae important. It is likely that the difference in the primary consumers led to a difference in the secondary ones.

The greatest abundance of macroinvertebrates was found at T3, which had more than twice the average catch of any station with the exception of T4. Taxon richness was also high, with T3 having the same number of taxa as T5 and just one more taxon than T2. T3 appeared quite similar to T2 in terms of diversity measures and was less diverse than either T4 or T5. Six taxa, largely detritivores, expressed some degree of association with T3, however, most were also relatively abundant at other sampling stations. Multivariate statistics suggested that the assemblage at T3 was quite distinct from those at other Turraun stations. Although this sampling station was on the western shore of the wetland, it was far more sheltered than either T1 or T2. Protection was provided by the northern wetland embankment, the western railway line and a stand of birch trees. Reduced wind and wave action may have created a more stable habitat at T3, allowing the development of an abundant and reasonably diverse macroinvertebrate assemblage. The peat sediment at T3 was fine and soft, much of it having resettled from suspension in this former drain site. These conditions would have favoured burrowing deposit feeders and indeed Oligochaeta were very abundant.

T3 was a highly productive station as evidenced by the abundance of macrophytes and periphyton, in the form of epiphyton and epipelic organisms on the peat. The area of this sampling station was fertilised and seeded before flooding (Brendan Kavanagh personal communication) and this probably contributed to the high primary productivity. High primary productivity would have in turn generated high secondary productivity at this station. Shelter, soft sediment and nutrients from local fertilisation may also have indirectly affected macroinvertebrates through the high plant diversity.

Invertebrates feeding on detritus dominated T3, which had the greatest combined percentage of filter feeders and deposit feeders. The detritus would have originated from the abundant periphyton and also autochthonous and allochthonous leaf litter. Taxa like *Pisidium* sp. and Oligochaeta were very important, while *Caenis luctuosa* was not abundant. The soft peat may have been an unsuitable anchoring medium for the mayfly or it may have been out-competed by the other species. Scrapers were also abundant at T3, though less so than at most other sampling stations and some ubiquitous species were relatively low in abundance (*Lymnaea stagnalis, Mystacides longicornis*). Corixidae were very abundant at T3 and must have found a plentiful supply of food at this station.

Carnivore abundance was low at T3 relative to most other stations. This is surprising considering the large number of other macroinvertebrates present. It is possible that the organisms abundant at T3 did not make suitable prey, and for example, few predators could extract the animal from the tightly shut valves of *Pisidium*. Preferred prey items may have been less abundant at T3 than elsewhere, e.g. the abundance of Trichoptera was relatively low. It is also possible that the habitat, with soft substratum, abundant algae and detritus filled water column, was inappropriate for many predators. The most important

predators at T3 were odonate nymphs and predacious Diptera and Coleoptera. The greatest abundance of *Notonecta glauca* was also found at T3. The percentage abundance of other invertebrate predators, such as *Theromyzon tessulatum* and Hydracarina was relatively low.

Multivariate statistics suggested that there was a relatively distinct macroinvertebrate assemblage at T3. Hierarchical clustering indicated that T3 was quite distinct from T2, T4 and T5, as well as Tumduff and T1. The monthly dendrograms showed that T3 replicates were different from those of other sampling stations in seven months, but overlapped with other Turraun stations in the remaining months. Oligochaeta, Corixidae and Chironomidae were important in separating T3 from other sampling stations. T3 was most distinctly different in March and winter 1997/8, and this may be linked to the abundance of Corixidae in these months.

T4, the sampling station over marl, was one of the most productive stations, with average and total abundance second only to that of T3. It had the highest taxon richness, having the greatest number of leeches, Heteroptera (apart from corixids), Diptera and beetle species. All diversity measures ( $\lambda$ , H', N0, N1 & N2) indicated that T4 was the most diverse sampling station. Multivariate statistics also identified T4 as having the most distinct assemblage associated with it.

T4 lay in the north-western corner of the marl floored bay, where it was sheltered on two sides by embankments and scrub. Dense stands of *Typha*, *Phragmites* and *Scirpus* to the east and south of the sampling station also ensured that T4 was protected from strong wind and waves. Shelter, including that provided by macrophytes within the habitat, is important to the surface dwelling Heteroptera: these were most abundant and diverse at T4. The marl sediment may have been important in a number of ways. It is a fine substratum capable of supporting a complex community of macroinvertebrates, including animals that can burrow. The marl also sustained dense and diverse macrophyte stands. In this respect the fine texture and chemical composition may have been important. Macrophyte diversity and abundance may also have been encouraged by shelter and possibly slope and depth.

The richness and diversity of macroinvertebrates was probably most influenced by the macrophytes at T4. The plant community was diverse, consisting of emergent, floating leaved and submerged forms and this diversity of structure supported a range of small-

scale niches and hence, animals. *Myriophyllum* sp. was the most abundant plant at T4 and this genus has been shown to support a high abundance of macroinvertebrates in other studies (Cyr & Downing 1988). The importance of macrophytes is evidenced by the dominance of animals, which crawl along plants feeding on the attached biofilm. It is possible that the diverse plants found here may have encouraged more epiphytic growth than those at T2, T3 or T5. The abundant scrapers included molluscs, such as *Lymnaea stagnalis* and *Potamopyrgus jenkinsi*, and cased caddis larvae, such as *Mystacides longicornis* and *Limnephilus* spp.

The macrophytes along with allochthonous inputs from surrounding trees and bank side vegetation ensured a good supply of detritus, and taxa such as *Pisidium* sp. and Oligochaeta were reasonably abundant. Deposit feeders, however, had a relatively low percentage abundance at T4. This may be owing to the enormous abundance of scrapers overshadowing the actual importance of other groups. It is also possible that the marl sediment did not supply as much detritus as stations with peat sediment. Filter feeders and deposit feeders were not as abundant at T4 as at T3, suggesting that detritus was in lower abundance at T4. The rich and abundant primary consumer fauna provided a variety of food for secondary consumers and T4 had the greatest abundance and diversity of predators (e.g. Zygoptera, *Gerris* spp., Tabanidae, *Noterus clavicornis, Hygrotus inaequalis* etc.).

T4 had four predatory taxa that appeared to be specialised to the habitat. These were *Helobdella stagnalis*, *Nepa cinerea*, Sciomyzidae and *Porhydrus lineatus* and the presence of these predators at T4 is probably also the result of the abundance and variety of other macroinvertebrates. A large number of taxa, e.g. *Theromyzon tessulatum*, *Lymnaea stagnalis*, *Noterus clavicornis*, also seemed to be associated with this station. Unsurprisingly, many of these were scrapers and predators. Other taxa had their greatest abundance at T4, e.g. *Hydrometra stagnorum*, *Haliplus obliquus*, *Hygrotus inaequalis* and *Laccobius bipunctatus*.

T4 had the most distinct macroinvertebrate assemblage in the TWINSPAN of averaged data and bore most resemblance to assemblages at the other vegetated Turraun stations. Monthly TWINSPAN results also suggested that T4 had the most distinct assemblage of any sampling station, with replicates clustering in most months. T4 did overlap to a very

small extent with T2, T3 and T5. The importance of *Lymnaea stagnalis* and *Mystacides longicornis* at T4 can be seen in their influence in separating that station from others.

Abundance was moderately low at T5, the sampling station over peat with *Carex*, and similar to the Tumduff stations. More animals were captured at T5 than at T1 and T2, but considerably fewer than at T3 and T4. Taxon richness was similar to T2 and T3. Diversity was high at T5, and  $\lambda$  and N2 values resembled those found at T4. T5 had similarities to T2 in terms of species present and their percentage abundance and to T4 with respect to species present. Multivariate statistics also suggested T5 was similar to T2, T4 or possibly T3. T5 supported a relatively high percentage of shredders and scrapers and a variety of carnivores, including *Piscicola geometra*, *Sialis* larvae and beetle species.

T5 was at the south-eastern edge of the marl bay and very exposed to westerly winds. Lack of shelter may have contributed to the macroinvertebrate abundance being lower at T5 than at T3 or T4. The peat sediment was almost a combination of stations T1, T2 and T3, consisting of compacted peat, peat granules and fine peat. The variable sediment may have contributed to the diversity at T5. *Carex rostrata*, the dominant macrophyte, has a densely tufted, upright, emergent structure. The density of the plant at T5 may have allowed only smaller creatures to live within the stand and led to reduced abundance. It may also have been an overall lack of food that prevented large numbers from existing at T5. Periphyton was not observed to proliferate on *Carex* plants and the toughened cuticle may not have supported a dense a biofilm. Filter and deposit feeders were not as important at T5 as elsewhere, suggesting that detritus was not plentiful.

Similarities in the macroinvertebrate populations of T2 and T5 can be seen in terms of the percentage abundance of species such as *Caenis luctuosa*, Zygoptera, other Heteroptera, *Sigara falleni*, *Limnephilus affinis/incisus*, *Mystacides longicornis* and chironomids. This may be owing to the fact that T5 closely resembled T2 in terms of exposure, peat and vegetation structure. The most striking similarity between T2 and T5 was in *Gammarus* abundance and may have been caused by a preference for physical shelter among granular sediments, upright plant structure and/or leaf litter. It is possible that emergent plants supply more coarse fragments of organic matter suitable for shredders than other macrophytes. Leaf litter may also have been responsible for the abundance of *Asellus aquaticus* at T5.

*Lymnaea stagnalis* was common at T5, though not as abundant as at T4 and the diversity of beetle species at T5 was second only to that of T4. The percentage abundance of *Cloeon simile, Sigara dorsalis, S. fossarum, Limnephilus lunatus, L. marmoratus,* Tipulidae and Dixidae was similar at the two stations. It is possible that the densely packed vegetation and exposed shoreline at T5 may not have been an ideal habitat for many of the invertebrate species found and prevented them from reaching large numbers. It is also possible that some species were not resident at T5 but had drifted in or were washed up by waves from T4 and other areas. Some species may not have survived at T5 but for the proximity of the productive and diverse marl habitat.

The hierarchical cluster dendrogram indicated that T5 was very similar to T2, while the TWINSPAN dendrogram for averaged data suggested T5 and T3 were the most similar pair of sampling stations. The latter was not supported by other observations and must have been a result of averaging the data or the calculations involved in TWINSPAN. T5 replicates were not distinctly different to those from other sampling stations and separated from each other in most monthly dendrograms. T5 replicates were associated with T2 and T4 on an equal number of occasions. In November T5 replicates were intermixed with replicates from most other stations, including Tumduff and T1. It appears that T5 had a macroinvertebrate assemblage intermediate between that at T2 and T4, but did not have a cohesive, distinct community. It seems possible that T5 had a dynamic assemblage, constantly changing and perhaps very influenced by exposure and wind direction.

The three Tumduff stations, B6, B7 and B8, were very similar to each other in terms of average and total catches, taxon richness and diversity. Replicates from all three stations intermixed in most months and it appears that the same macroinvertebrate assemblage was found at each. This is unsurprising considering the uniformity of the shoreline. All areas were exposed to strong winds and waves, had sharply sloping bottoms and the water was deeper than at any of the Turraun stations. The three stations had a high percentage of bare sediment and low cover and diversity of macrophytes. All of these factors would have hindered the development of a diverse and abundant macroinvertebrate assemblage. Any differences between the stations, e.g. boulder clay at B7, did not appear to significantly affect the macroinvertebrate assemblage.

The few differences observed between Tumduff sampling stations may have been coincidental and few conclusions can be drawn from them. Scrapers were extremely abundant at B6, suggesting that periphyton was more abundant there than at B7 or B8. Abundant periphyton at B6 may have been responsible for the higher diversity and abundance of beetles, either directly as food or indirectly through the abundance of suitable macroinvertebrate prey. Deposit feeders and scrapers were the most important guilds at B7 and B8, suggesting that the main foods at these stations were detritus and periphyton. Shredders were rare in Tumduff, probably reflecting the lack of vegetation to provide CPOM. The near absence of filter feeders indicates the lack of development of phytoplankton. More anisopteran species were found at B8, possibly because this station was slightly more sheltered than elsewhere or because nymphs from other locations escaped capture. Diversity appeared to be lowest at B6, possibly as a result of the fact that four taxa (*Lymnaea peregra, Caenis luctuosa, Mystacides longicornis* and Chironomidae) comprised more than 70% of the fauna at this station.

In summary, macroinvertebrate abundance was greatest at sampling stations with fine sediments, i.e. T3 and T4. Exposure may also have affected abundance, with the most exposed stations, T1, T2 and Tumduff having the lowest numbers. Macroinvertebrate taxon richness on the other hand, appeared to be influenced by macrophyte diversity and cover. Taxon richness was greatest at T4, the sampling station with the greatest cover and structural diversity of plants, and lowest at T1, the station from which plants were absent. Taxon richness was also low at Tumduff, where vegetation was scarce, but was reasonably high at the remaining vegetated Turraun stations.

Considering again the multivariate results, it appears that the abundant taxa were responsible for separating T3 and T4 in the monthly TWINSPAN dendrograms. The low numbers or absence of *Potamopyrgus jenkinsi*, *Pisidium* sp., *Gammarus* spp. and *Lymnaea stagnalis* from Tumduff, along with the abundance of Hydracarina, *Mystacides longicornis* and Chironomidae larvae, were important in distinguishing Tumduff from Turraun communities. There appeared to be less differentiation in October and November, with replicates for most sampling stations intermixed and the two wetlands not clearly separated. This may have resulted from the dramatic flooding between September and October (see Section 2.2.3.3, Chapter 2), which probably caused considerable disturbance of the macroinvertebrate communities. During this time Turraun surface water level rose

by over 10 cm and Tumduff by perhaps even more. It is also possible that plant die back or the effects of strong winds may have impoverished the littoral fauna in these months.

Examining the DCA plots generated by DECORANA, no environmental variable provides an obvious explanation for the distribution of data on the various sampling dates. The spread of data may be linked to vegetation cover and diversity on the horizontal axis of the average plot in February 1997 and May 1997. February 1997 was probably the most readily interpretable plot, with the five replicates from each of the three stations clustering, and fineness of sediment, vegetation cover and diversity and food availability increasing left to right and exposure decreasing. It is also possible that the spread in many of the plots was controlled by community data, such as diversity, taxon richness etc. or that the controlling factors were not observed in the field, many of which may have varied on a small scale.

In most monthly DCA plots the spread of Tumduff replicates was very large, suggesting that the Tumduff replicate samples were very different to each other. All other results suggest that the variability at Turraun is far greater than that at Tumduff, however, and the computational method used by DECORANA may have emphasised samples with low total abundance or low taxon richness. Many of the Tumduff replicates were very impoverished in terms of taxa and abundance. It is also possible that there was a lot of variability within the sampling stations at Tumduff, which consisted of a combination of single *Juncus* plants or small stands of *Glyceria* mixed with large patches of bare sediment. The fact that Tumduff replicates do not generally cluster in the DCA plots supports the theory that the three sampling stations were very similar to each other and essentially part of a single macroinvertebrate community.

Although T1 was somewhat similar to B6, B7 and B8, it appears from the results that all sampling stations within Turraun or Tumduff were more similar to each other than to those in the second wetland. Sampling stations T4 and T3 appeared to have the most distinct macroinvertebrate assemblages. T4 was dominated by scrapers and had high diversity in all groups, especially beetles, while T3 was dominated by detritivores and contained a very high abundance of organisms but low diversity and abundance of carnivores. T1 was dominated by common taxa and had similarities to all other sampling stations, including those of Tumduff. T2 contained an abundance of shredders, and leaf litter and detritus

were important. T5 was a diverse sampling station with an assemblage intermediate between that of T2 and T4.

Taken together, the results indicate that the littoral of a wetland can be considered a continuum and that the macroinvertebrate community found within one wetland littoral zone will be significantly different to that of another wetland. The reasons for this are complex and manifold. However, within the littoral, macroinvertebrates will vary in abundance, taxon richness and diversity with the changes in sediment and especially plants (see also Section 4.4.2). The assemblages associated with different littoral habitats are sometimes distinct and could be considered communities. It is probable that small-scale macroinvertebrate assemblages and specific niche requirements were not identified, owing to the sampling unit being too large to encompass single macroinvertebrate niches.

### 4.4.4 Comments on the temporal variation and ecology of macroinvertebrate species captured

108 taxa were discovered in Turraun and 71 in Tumduff, and in total 90 different species were identified for Turraun and 55 for Tumduff. In this section temporal variations and elements of the ecology of some of these species and taxa will be discussed. Macroinvertebrates will be considered in taxonomic order, as given in the species list, Appendix 4.3.2.1. The ecology of corixid species recorded will be examined in Chapter 5. Coleoptera will be discussed in detail.

Although oligochaete worms were not identified to Family, it is possible that were Naididae. Members of this family are recognised as rapid colonists of new ponds owing to their asexual reproduction (Barnes 1983).

All leech species found during the macroinvertebrate survey are common in the British Isles. Six species were found in Turraun, while only one was present in Tumduff. Elliott & Mann (1979) stated that availability of food organisms and suitable substratum (macrophytes or stones) are the most important factors governing leech distribution. *Theromyzon tessulatum* is a parasite of waterfowl (Macan 1965a, Elliott & Mann 1979) and the availability of birds at both wetlands obviously contributed to the abundance of this species. *Glossiphonia heteroclita* and *G. complanata* (Linnaeus) feed on Gastropoda and

also on oligochaetes and insect larvae (Elliott & Mann 1979, Young & Ironmonger 1980, Bradley 1983). *Helobdella stagnalis* sucks the body fluids of chironomid larvae, mayfly nymphs, oligochaetes, *Asellus aquaticus* and molluscs, and *Erpobdella octoculata* is carnivorous on chironomid and trichopteran larvae, oligochaetes and small *Asellus aquaticus* (Young & Ironmonger 1980, Bradley 1983). As the prey organisms of these four leech species were more abundant in Turraun than Tumduff food may be responsible for the greater leech species richness in the former wetland. The abundance of macrophytes at Turraun along with the variable sediment, may also have been responsible for the higher abundance and diversity of leeches at that wetland.

The occurrence of *Piscicola geometra* was interesting, as this species is a common ectoparasite on fish. On most occasions it was captured while free swimming, only one individual found attached to a stickleback. It may have been introduced to the wetland with a population of brown trout, released to Turraun in the early 1990s (Brendan Kavanagh personal communication).

Little is known about the life cycle of *Theromyzon tessulatum*, but eggs are usually laid in June/July and young remain attached to the parent for three or four months (Elliott & Mann 1979). *Theromyzon* appeared to follow this pattern in Turraun and Tumduff, producing a high abundance of young in July, August and September.

The molluscan fauna of Turraun and Tumduff consisted of species that are common and abundant in the British Isles (Macan 1977, Byrne *et al.* 1989). Barnes (1983) found *Lymnaea peregra* was abundant in one pond, but absent from a similar, adjacent pond, and stated that patch distributions of gastropods are owing to chance events and reproductive methods. The dominant snail in Turraun was *Lymnaea stagnalis*, however, this species was absent from Tumduff, where *L. peregra* was abundant. This difference in species composition was probably determined by the species present in drains and streams that were opened into the ponds and by chance colonisation.

Macrophytes are important in determining mollusc species richness and abundance (Macan 1977, Lodge 1985, Carpenter & Lodge 1986, Lodge *et al.* 1987). As the chemical environments of the two wetlands were similar, macrophyte abundance and diversity, along with the age of the wetlands, was probably responsible for the greater gastropod

diversity and abundance at Turraun. Macrophytes and food also appear to have been largely responsible for the distribution of snails within the wetlands. Gastropods were most abundant at T4, the station that contained the greatest percentage of scrapers and where periphyton appeared to be most developed. *Pisidium* is associated with mud (Macan 1965a) and was most abundant at T3, where detritus appeared to be most available.

*Potamopyrgus jenkinsi* bred from around June to September in Denmark (Dahl & Winther 1993), but breeding appeared to begin slightly earlier in Turraun with abundance increasing dramatically in May. *L. palustris* has been shown to be univoltine in Irish turloughs, with oviposition beginning in May and juveniles found in June/July to late August (Byrne *et al.* 1989). No clear seasonal trends in *Lymnaea palustris* were evident in the cutaway ponds, although, the species was extremely abundant at B6 in October. Hanson (1990) suggested that macroinvertebrates temporarily colonise flooded terrestrial vegetation during high rainfall. October rainfall led to a dramatic increase in the surface water level at Tumduff and *L. palustris* may have selectively invaded the newly flooded vegetation. It is also possible that strong waves dislodged individuals and washed them ashore at B6. This suggests that the species was abundant elsewhere within the littoral and may have been overlooked on other sampling occasions.

L. peregra populations in turloughs oviposited from May to early July, and juveniles appeared from May to August (Byrne *et al.* 1989). The lifecycles of *L. peregra* and *L. stagnalis* resembled those found in the turloughs, although recruitment may have extended later into the year. *L. peregra* numbers increased from July onwards, reaching a maximum in Tumduff in October. New recruits to the *L. stagnalis* population first appeared in June and numbers rapidly increased to a September maximum. Abundance remained high over the winter, indicating that these snails survived well in Turraun. The fact that *L. stagnalis* abundance peaked before that of *L. peregra* may indicate some difference in lifecycle between wetlands.

A number of Hydracarina species was present in both wetlands and larvae were found as ectoparasites on corixids and beetles. It is interesting that mites were more abundant in Tumduff than Turraun. Mites appeared to be a top invertebrate predator in Tumduff and their success may have been facilitated by rapid colonisation and the fact that they swim or crawl in open water and have little need for vegetation. Mites are clearly capable of surviving in macrophytes too, as in Turraun they were most abundant amongst the dense vegetation at T4.

Adult Hydracarina are found during summer and the life cycles of parasitic forms have been well documented (Davids & Schoots 1975, Davids *et al.* 1978). These species overwinter as larvae attached to invertebrate hosts such as Heteroptera and Coleoptera. The larvae drop off their hosts in April and develop rapidly into free-living nymphs and then adults (Davids & Schoots 1975, Davids *et al.* 1978). The adults reproduce in early summer and the eggs develop rapidly into larvae, which find parasitic hosts (Davids *et al.* 1978). Adult Hydracarina develop again in late summer and this second generation reproduces in early autumn. Adult mites are short lived, surviving about three to four weeks in the field (Davids *et al.* 1978). Two summer generations of adult mites can be clearly seen at Tumduff, with peaks in April and July.

*Gammarus duebeni* and *G. lacustris* were found together in Turraun. *G. duebeni* is the dominant *Gammarus* species in Ireland (Gledhill *et al.* 1976, Giller *et al.* 1998) and *G. lacustris* is a common lake species (Gledhill *et al.* 1976, Sutcliffe 1993a). *Gammarus* was very abundant in Turraun, but only four *Gammarus* individuals were found at Tumduff, despite the presence of the genus in adjacent waterbodies such as Boora Lake (see Section 4.3.1). The Tumduff specimens were found in July, August and November 1997, so the species must have been surviving in low numbers in the wetland. It is most likely that this low abundance was owing to the absence of food and suitable habitat. At Turraun, *Gammarus* was associated with emergent vegetation, leaf litter and coarse peat sediment, conditions that were essentially absent from Tumduff.

The seasonal trend in *Gammarus* abundance represented a combination of both *G. duebeni* and *G. lacustris*. These species have similar reproductive strategies with a distinct spring-summer season (Sutcliffe 1993a), however, *Gammarus* can adapt its life cycle to local environmental conditions and may change its reproduction strategy in response to the presence of a second *Gammarus* species (Sutcliffe 1993a and b). Reproduction in *G. duebeni* appears to occur throughout much of the year. In a freshwater stream in the Isle of Man, there was a decline in *G. duebeni* production from October to January and in July and August (Hynes 1954). In Brittany, *G. duebeni* was found to reproduce between September and March (Pinkster *et al.* 1970). Macan (1965b, 1973) noted that *Gammarus pulex* 

(Linnaeus) breeds from January to October. As the crustacean life cycle contains more than one generation a year with a number of overlapping cohorts, it is difficult to elucidate life histories without length or weight data. Hynes (1954) found that *G. duebeni* abundance was high from April to August, with peak values in June. Similarly, in Turraun the highest abundance of *Gammarus* was found in July and the species probably bred between January and October.

*Caenis luctuosa* and *Cloeon simile* are typical still water species (Harris 1977), common and abundant in Ireland (Giller *et al.* 1998). *Caenis* nymphs are less particular about their habitat than most mayfly species (Macan 1965a, Harris 1977) and this lack of habitat specialisation probably explains the ubiquitous distribution of the nymphs in Turraun and Tumduff. *C. luctuosa* was most abundant in open unvegetated areas, such as Tumduff and T1. It appears to be a pioneer coloniser of these wetlands, capable of exploiting any available food, but may be out competed by other species in more complex, plant dominated habitats. On the other hand *C. simile* is often associated with macrophytes (Macan 1965a, 1970, Harris 1977) and appeared to be associated with the dense, diverse vegetation at T4.

*C. luctuosa* and *C. simile* over winter as nymphs (Harris 1977). *Cloeon simile* duns emerge from March to November, depending on location, but are most abundant from April to early June, mid August to October (Macan 1965a, Macan 1970, Harris 1977). Macan (1973) also observed that *C. simile* had a long winter generation, emerging in May, and a short summer generation, emerging in August/September in Hodson's Tarn. *C. simile* appeared to emerge from Turraun from April to June and from Tumduff in May and June. A second generation may have emerged in August, September and possibly even October. *Caenis* adults usually flies in June, July and August (Harris 1977) and *Caenis luctuosa* appeared to emerge from both wetlands in May, June and July. The abundance of *C. luctuosa* decreased at Turraun over time, possibly owing to succession and competition from other species.

The odonate fauna, as indicated by nymphs, was limited in Tumduff and particularly so in Turraun. The suite of species found was typical of lowland, neutral to alkaline habitats (Colm Roynane personal communication). *Aeshna grandis*, in particular would be expected from Turraun-type sites with reasonable shelter and dense vegetation, and it has

been found in Charleville Lake, Tullamore as well as other midlands sites (O'Connor & Murphy 1988). *Libellula quadrimaculata* Linnaeus is a widespread species (Ní Lamhna 1978) and has been recorded from pools on Mongan bog (Reynolds 1984), a raised bog in west County Offaly. The absence of other species typical of lowland, alkaline, vegetated waterbodies may be a result of the relative newness of the wetlands.

Many adult Odonata have been observed on the Lough Boora Parklands. Trodd (1995) recorded adult Aeshna juncea, Libellula quadrimaculata and Orthetrum cancellatum (Linnaeus) from Turraun. Bond mentions Ischnura elegans (Vander Linden), Sympetrum striolatum (Charpentier) and Aeshna juncea (Linnaeus) in his lepidopteran study (Heery & Finney 1999). Quirke recorded Sympetrum striolatum, Libellula quadrimaculata, Ischnura elegans and Enallagma cyathigerum (Charpentier) at Finnamores (N210 205) and Libellula quadrimaculata, Ischnura elegans and Enallagma Finney 1999).

*Hydrometra stagnorum* is the only *Hydrometra* species in Ireland. It is widespread and common to all types of lowland water body, and was found most commonly in emergent and grazed marginal vegetation, at the sheltered edges of water bodies in Northern Ireland (Macan 1965c, Nelson 1995). Results from this study support these conclusions, with *H. stagnorum* found amongst the sheltered vegetation of T4 and T3, however, one individual was found at the un-vegetated sampling station, T1.

Gerris has a more truly aquatic existence than Hydrometra and can dwell on open water (Macan 1965c). Three specimens of Gerris argentatus Schummel, one of G. thoracicus and four of G. odontogaster (Zetterstedt) were recovered from Turraun. Reynolds (1984) found these three on Mongan raised bog and claimed the first midlands records for the species. G. argentatus is a restricted species (Southwood & Leston 1959), found in mesotrophic to eutrophic lakes or large ponds in Northern Ireland (Nelson 1995). There are few other published records of this species in Ireland. G. thoracicus is thought to have a chiefly coastal distribution (Reynolds 1984, Nelson 1995). Nelson (1995) also recorded G. thoracicus in bog, quarry and heathland pools, as well as marginal fen on lakes. G. odontogaster was recorded on small lakes and pool systems on cutover bogs and fens in N.I. (Nelson 1995). G. lacustris, which is widespread in Ireland, has been recorded from Mongan and Clara bogs (Reynolds 1984), high altitude peat pools in Co. Kerry

(Southwood and Leston 1959) and many lowland lakes and bog pools in Northern Ireland (Nelson 1995). *G. lacustris* is commonly found on lakes with *G. argentatus* and on pools with *G. odontogaster* in N.I. (Nelson 1995). It seems that available colonisation sources, productivity, peat sediment, abundance of vegetation and size of the water body encouraged a diversity of pond skater species at Turraun.

*Nepa cinerea* is found on most lowland water bodies, and is associated with vegetation (Southwood and Leston 1959). It appears to prefer mesotrophic and slightly eutrophic conditions, as at Turraun, but is also found on acid pools on cutover (Nelson 1995). It is seldom found in large numbers (Macan 1965c). *Notonecta glauca* is a ubiquitous species and was the most commonly recorded heteropteran species in N.I. (Nelson 1995). It can be abundant at individual sites and was observed to be very numerous at Fin Lough on 2<sup>nd</sup> July 1999. *N. glauca* is also known to be a strong flier (Nelson 1995). This, along with the abundance of the species in the region, meant its early colonisation of artificial cutaway ponds was to be expected.

A total of 49 species of Heteroptera from eight families have been recorded in Ireland, as opposed to 61 in Great Britain (Nelson 1995). The number of heteropteran species (including Corixidae) recorded in Turraun (21) and Tumduff (17), totalling 22 was very large for Irish water bodies. Reynolds (1984) recorded just five species from Mongan Bog and four from Clara Bog. 21 species have been found in the entire Killarney district (O'Connor *et al.* 1986). Nelson (1995) recorded a total of 40 species in his detailed survey of Northern Ireland and 15 species from the richest site, a cutover bog-pool-complex. He found that many of the most diverse and notable sites were artificial, and many were in bog or fen.

All species of Trichoptera found were common and widespread. *Mystacides longicornis*, a common species of new waterbodies (Harris 1977), was ubiquitous in the wetlands. It probably owes its success in the cutaway ponds to early colonisation and perhaps also the suitability of the habitat. *M. longicornis* made its cases out of a combination of peat particles and shell fragments, which were abundant everywhere. The species was least abundant at T5 and T2, suggesting food abundance or quality, and/or biotic interactions did not favour *M. longicornis* in emergent vegetation. *Limnephilus lunatus* and *L. marmoratus* were most abundant at T2 and may have out-competed *M. longicornis* at this station.

*Limnephilus* spp. are generally restricted to areas with vegetation as they harvest leaf fragments for case construction.

K.G.M. Bond recorded some adult Trichoptera during his study of Lepidoptera at the Lough Boora Parklands (Heery & Finney 1999), including five species from Turraun and three from Tumduff Mór. He found adult *Agrypnia varia*, *Phryganea grandis* Linnaeus, *Limnephilus lunatus*, *L. marmoratus* and *Oecetis ochracea*, confirming the presence of four species recorded as larvae.

The main emergence period in *Mystacides longicornis* seems to have occurred in July and August. Emergence may have been slightly later in Turraun than in Tumduff, with peak abundance in Tumduff in spring and Turraun in summer. Abundance increased in September in both wetlands with the addition of new larvae from the summer reproductive period. The decrease in abundance of *M. longicornis* in October and November probably represented a period of die-off owing to winter conditions. The unusually high abundance of *Oecetis ochracea* in June in Tumduff was probably artificial and owing to species aggregations. *Limnephilus affinis/incisus* appeared to emerge in April and *L. lunatus* emerged from April to July. Populations of *L. marmoratus* and *L. affinis/incisus* did not appear to have stabilised, with the former increasing in Tumduff and the latter decreasing in both wetlands. It is possible that the early decline (February onwards) in *L. marmoratus* numbers was linked to predation or some factor other than emergence as adults of this species are found in June and July (Macan 1965a).

There are around 200 aquatic beetle species in Ireland (Foster *et al.* 1992) and more than 350 species in Great Britain (Foster & Bilton 1998). Bilton (1988) recorded 131 species of aquatic and wetland beetles in central Ireland and the Burren. 38 species were captured in Turraun and 16 in Tumduff. Most of the species captured were common and widespread and beetle diversity can be considered moderately high. Coleopteran abundance was also much greater at Turraun than Tumduff. Species richness of aquatic Coleoptera tends to be high at high spatial variability and intermediate temporal variability (Richoux 1994). The larger range of habitats present and the greater age of Turraun were probably responsible for its relatively high beetle species richness.

Two interesting records were made at Turraun. *Gyrinus caspius* Ménétriés is associated with fen type conditions and is typically a coastal species (Friday 1988), so it is somewhat unusual to find it in central Ireland. Bilton (1988) also found *G. caspius* in the midlands, at Loch Ennell, Co. Westmeath and states it is found inland in Scotland. *Haliplus variegatus* Sturm is considered a fen pool species (Friday 1988) and has only been recorded in two locations in Ireland since 1980, Lough Neagh and this specimen in Turraun (Garth Foster personal communication). It is considered rare in the UK, where it is also found on cutover bogs (Foster & Bilton 1998). *Haliplus variegatus* is possibly under-recorded in Ireland, but is definitely on the decline in England (Garth Foster personal communication).

Gyrinidae are common on bog pools where *G. substriatus* and *G. minutus* are the most frequently encountered species (Foster & Bilton 1998). *Gyrinus marinus* can also be found in peaty waters (Friday 1988), as well as in floating vegetation in Ireland (Bilton 1988). Turraun and Tumduff provided suitable habitats for *Gyrinus* species, with peaty water, an ample supply of dipteran larvae, on which the predatory larvae feed and emergent vegetation for pupation (Foster & Bilton 1998). Other recorded beetle species, with peatland associations include *Chaetarthria seminulum* and *Anacaena lutescens* (Stephens). *Chaetarthria seminulum* is found in the moss and mud of fens and bogs (Friday 1988) and is widespread in central Ireland (Bilton 1988). *Anacaena lutescens* is an acid water species (Friday 1988) and occurs in patterned mires (Foster & Bilton 1998). *Hydroporus* species, including the three found in Turraun, frequently occur in natural bog pools and peaty waters (Friday 1988, Foster & Bilton 1998). *Hydroporus gyllenhalii* is an acid water species (Friday 1988) and common in Irish acid freshwaters (Bilton 1988).

Some of the *Haliplus* species encountered are associated with pools and ponds, including those on fen and bog (Friday 1988). *H. rufficollis* Degeer was frequently found in densely vegetated fens in Ireland (Bilton 1988) and *H. fulvus* (Fabricius), *H. lineatocollis* and *H. rufficollis* occur occasionally in deep pools on intact bog in the UK (Foster & Bilton 1998). *H. obliquus* is local in central Ireland and often associated with *Chara* in clear water (Bilton 1988). All haliplids feed on plants (Richoux 1994) and their distribution within the wetlands was probably closely linked to the distribution of periphyton.

*H. fluviatilis* and *H. lineatocollis* are considered river species (Friday 1988, Bilton 1988). *Limnebius truncatellus* and *Elmis aenea* are also characteristic of rivers (Friday 1998). *Limnebius truncatellus* has also been recorded in pools on intact bogs (Foster & Bilton 1998) and *Elmis aenea* has been found on stony, exposed lake shores in Ireland (Bilton 1988).

A number of the beetle species found have associations with macrophytes. *Noterus clavicornis* is often associated with weed-rafts (Friday 1988) and it was associated with and was very abundant at sampling station T4, where vegetation was most diverse and dense. *Donacia simplex* is widespread in Ireland and generally found crawling and feeding on macrophytes (Bilton 1988, Richoux 1994). *Porhydrus lineatus* is found amongst vegetation in clear water in Ireland (Bilton 1988). *Graptodytes pictus* is associated with macrophytes and *Laccophilus minutus* (Linnaeus) with decaying vegetation and both are widespread in central Ireland (Bilton 1988). *Hygrotus inaequalis* is found in ponds or bays of lakes (Friday 1998), is associated with rotting vegetation and is very common in Ireland (Bilton 1988). *Porhydrus lineatus* and *Hygrotus and Hygrotus inaequalis* at T4 suggests this station contained an abundance of dead as well as live plant matter. *Laccobius bipunctatus*, a common mud dwelling species (Bilton 1988, Friday 1988) was also most abundant at T4.

Many of the remaining species (e.g. *Oulimnius tuberculatus* (Müller) and *Ochthebius minimus*) are common or ubiquitous and were probably available locally for colonisation and capable of adapting to different habitats. *Ilybius fuliginosus* is common in Ireland. Foster *et al.* (1992) associated this species with open substrata, whereas Bilton (1988) stated it was most abundant in grassy waters. In Turraun, *Ilybius fuliginosus* was found amongst the vegetation at T3 and T4. *Agabus nebulosus* is found in ponds, especially recently created ones with bare substrata (Barnes 1983, Friday 1988, Foster *et al.* 1992) and has been associated with silt and turloughs in Ireland (Bilton 1988, Foster *et al.* 1992).

*Helophorus brevipalpis* is one of the commonest British beetles (Bilton 1988, Garth Foster personal communication) and readily colonises almost every piece of water owing to its flying ability (Bilton 1988). *Helophorus* spp. were most abundant at T3, and may have preferred the fine, gently sloping sediment to crawl upon or have fed upon the epipelic organisms. The carnivorous *Helophorus* larvae may have fed upon the abundant macroinvertebrate fauna at T3. It is perhaps unusual that *Hydrobius fuscipes*, one of the

most commonly encountered and ubiquitous coleopteran species in the British Isles (Bilton 1988, Garth Foster personal communication) was recorded once in Tumduff but not in Turraun.

Although only two *Dytiscus* individuals were captured during the course of the study, a number were observed in Turraun. On the 9<sup>th</sup> January 1999, two great diving beetles were observed swimming slowly under a sheet of ice in the vegetation at T4. These are strong fliers and would easily have colonised the wetland. *D. semisulcatus* Müller is abundant in Ireland and western Britain, where it is associated with vegetation, however, it is on the verge of extinction in Eastern Europe (Bilton 1988). It is thought to feed mainly on cased caddis larvae (Foster & Bilton 1998), of which there was an abundance at Turraun. *Dytiscus marginalis* Linnaeus feeds mainly on tadpoles (Foster & Bilton 1998), and whilst a number of frogs were encountered and one tadpole captured, no frogspawn was observed in either wetland. Dytiscidae adults and larvae, all of which are predators (Richoux 1994), were most abundant at T4 where suitable prey was most abundant and were also encountered at the very productive station, T3.

Few beetles were numerous enough to allow seasonal variations to be plotted. *Haliplus confinis* and *Hygrotus inaequalis* were most abundant from late spring to autumn suggesting that these species overwinter as eggs, larvae or pupae, develop into adults in spring and reproduce over the summer months. *Noterus clavicornis* was most abundant in Turraun in September and October, indicating that this species may overwinter as an adult and reproduce in spring/early summer, with the egg, larva and pupal stages developing rapidly to produce an abundance of teneral adults in early autumn.

The coleopteran fauna of Turraun and Tumduff contained species characteristic of a range of habitats. Some were riverine species, others were typical of base-poor conditions, some species found have a preference for mud and others a preference for vegetation. A number of species were described by Friday (1988) as common on bogs or fen, although the fauna at Turraun and Tumduff did not contain the characteristic rare or relict species of natural fens (Bilton 1988, Foster *et al.* 1992). This range of beetle species reflects the variety of habitats present at Turraun and the unusual condition of base-rich wetlands with peat as the predominant substrate.

The species composition of beetles at Turraun perhaps most closely resembled the group identified by Foster *et al.* (1992) as representative of cutover bogs and of rafts of acid fen vegetation with some base-rich influence. Their group included a combination of fen species, e.g. *Dytiscus marginalis* and *Chaetarthria seminulum*, and typically acidophilic species, such as *Hydroporus gyllenhalii*, as well as species considered indicative of eutrophic conditions, such as *Noterus clavicornis* and *Laccophilus minutus* (Foster *et al.* 1992). As with Heteroptera (Nelson 1995), Foster *et al.* (1992) found the highest number of beetle species (47) in the cutover pools at Montiagh's Moss. 47 species were also found in the peat cuttings at Derryleckagh Bog (Foster *et al.* 1992). Natural fens and cutover bogs are considered 'inherently more species rich', in terms of beetles than natural pools on bogs (Foster & Bilton 1998) and indeed, the fauna of the cutaway wetlands bore little resemblance to that of intact bogs. Foster *et al.* (1992), however, did suggest that complexes of cutover bog pools provided conditions akin to those found in transition mires, a type noted for its invertebrate richness and diversity.

The fauna of the cutaway wetlands also resembled that of turloughs, but without the rarer turlough species (Bilton 1988, Foster *et al.* 1992). The beetles encountered in Turraun and Tumduff that are regular members of the turlough fauna included *Haliplus obliquus*, *Agabus nebulosus, Laccobius minutus, Laccophilus minutus, Porhydrus lineatus, Helophorus minutus* Fabricius, *Ochthebius minimus* and *Anacaena lutescens* (Foster *et al.* 1992). Turlough communities have also been found in some marl lakes and quarry ponds and are associated with 'fluctuating margins of base-rich water' as found in Turraun and Tumduff (Foster *et al.* 1992).

Many beetles are predators and it has been argued that the number of predatory invertebrate species at a site is an important indication of environmental quality (Foster *et al.* 1992). If this is the case, the quality of the environment at both wetlands is reasonably good, especially considering the relatively short period that has been available for colonisation. The beetle fauna of the cutaway wetlands was quite rich and contained an interesting combination of species from different habitats. No rare species have yet been recorded, with the exception of *Haliplus variegatus*, which is probably under-recorded rather than rare.

Foster *et al.* (1992) included type of substratum, exposure/vegetation abundance and water permanence amongst the most important environmental variables controlling water beetle assemblages in Ireland. In order to maximise the diversity of beetles and hence, the conservation value of future cutaway wetlands, it is important to create permanently flooded water bodies with both exposed and densely vegetated regions and with heterogeneous substrate where possible.

The macroinvertebrate species encountered at Turraun and Tumduff included species typical of many different habitats and a number that have been previously recorded on exploited peatland (Bilton 1988, Nelson 1995, Foster & Bilton 1998). As these wetlands essentially represent a 'new' habitat, no characteristic or typical species have yet been identified. It is also difficult to compare the macroinvertebrate fauna of the cutaway wetlands to that of intact raised bog owing to the lack of research on bogland fauna. Reynolds (1984) found two main groups of species in the midlands raised bogs, one with no clear preference for habitat type, exploiting every available wetland, e.g. Libellula quadrimaculata and Gerris lacustris and another more typical of acid, upland conditions. The fauna was somewhat similar at Turraun and Tumduff, however, the base-rich water and available nutrients allowed species more typical of lowland alkaline wetlands and fens to colonise. Species that are often negatively associated, e.g. Hesperocorixa castanea (Thomson) and H. sahlbergi (Fieber) (Macan 1954) existed in sympatry in these cutaway wetland. Reynolds (1985a) also found both species in the Clara Bog soak and considered this to highlight "the unusual nature of this water-body". The cutaway wetlands may allow many species to return to a region in which they once survived and others to colonise new territory.

As the wetlands are artificial, the species present may largely depend upon the species capable of colonising from different surrounding waterbodies. The young age of each wetland means that the fauna is undergoing succession and changing over time. It is probable that these wetlands will continue to change, in terms of vegetation cover, sediments and depth, and consequently, the macroinvertebrate fauna may not reach a stable equilibrium for a considerable time yet.

#### Conclusions

The first aim of the macroinvertebrate survey of Turraun and Tumduff was to find out what species were present. It is obvious from the results that these wetlands were quite diverse and contained an interesting mix of species. The assemblages resembled those of soak lakes on intact raised bog (Reynolds 1984), but were more diverse and abundant. They were also similar to the assemblages found in other artificial ponds on cutover and cutaway and in natural fens and marginal fens on lakes (Nelson 1995, Tully *et al.* 1991). Many of the beetle species encountered are associated with turloughs in Ireland (Bilton 1988). It is clear that the macroinvertebrate populations were quite dynamic, but the size of these artificial wetlands and the number of habitat niches present suggested that many species will survive. Many species are already well established and breeding within the wetlands. The mixture of species typical of many different habitats, from acid lakes and intact peatland to lowland, alkaline, productive lakes makes artificial wetlands on cutaway a very interesting subject for aquatic macroinvertebrate studies.

In investigating a number of sampling stations within each wetland, an attempt was made to associate macroinvertebrate assemblages with sediment and particularly vegetation. High secondary productivity was associated with high primary productivity and the greatest abundance of macroinvertebrates was found at T3, a station with abundant algae, detritus and plants and T4, the station with the greatest abundance and diversity of macrophytes. Diversity of macroinvertebrates was also greatest at T4 and appeared to be strongly related to shelter and to macrophyte diversity. Macroinvertebrate abundance was low at stations dominated by emergent plants and their leaf litter, however, diversity was reasonably high. Different species were abundant at these emergent stations. The suite of species also appears to have been strongly influenced by the granular nature of the peat in these habitats. Low diversity and abundance of macroinvertebrates was associated with high percentage bare sediment and low plant diversity and cover, at stations such as T1, B6, B7 and B8. Areas of bare sediment appeared to be important to some abundant species, such as Caenis luctuosa and Mystacides longicornis, and the continued survival of such species may be determined by the availability of bare peat. Diversity of habitats appears to be the key to macroinvertebrate diversity and abundance.

None of the eight sampling stations had macroinvertebrate assemblages completely distinct from all others and replicate samples from all stations were seen to intermix in TWINSPAN dendrograms. Sampling stations T3 and T4 appeared to have the most distinct macroinvertebrate assemblages and were moderately different to all other stations. Considering the scale examined, the degree of overlap between sampling stations was quite small. One would expect samples from different waterbodies over a wide geographical spread to separate from one another, however, within a single lake or pond the littoral zone represents a macroinvertebrate continuum. Two ponds with similar morphology, water chemistry, sediment, vegetation and geographical location will have similar macroinvertebrate assemblages.

Most ecosystems can be considered spatial continua, with the environmental factors that control the distribution of organisms changing gradually, and clear communities are often difficult to identify. The organisms may also be tolerant of a wide range of conditions. This problem is more obvious in animal than plant communities and is compounded by the mobility of most macroinvertebrates. The habitat in which a species is captured may not necessarily be where it feeds or rests, and may not be important in determining its survival. This problem should be eliminated by taking a large number of samples, which increases the probability of finding a species within its preferred habitat. Another problem in identifying macroinvertebrate 'communities' is the fact that the sampling unit is three-dimensional and that vertical usage of the water column, e.g. sediment versus submerged leaves, can not be identified.

The size of the sampling unit is crucial for one to identify distinct communities (Schouten 1990). It is possible that the sampling unit chosen for this study encompassed a number of small-scale niches and hence, more than one small-scale macroinvertebrate community. These may have been more distinct than the assemblages identified and more specific to the habitat identified as the sampling station. It is unlikely, however, that more mobile animals, particularly predators, would be confined to specific small scale niches. These probably used a large area of littoral containing a number of habitats and larger sampling units would have been essential to record their presence. The use of specific small-scale niche sampling in conjunction with habitat sampling may be useful in order to refine the identification of macroinvertebrates associated with different macrophytes and sediment.

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Identifying macroinvertebrate communities bears resemblance to the phytosociologist's search for plant communities. Identification of the 'stand' is difficult and requires experience; the size of the sampling unit is crucial and arguments can be made for using more than one size. The third dimension of the sampling unit must be taken into account if the abiotic and biotic factors governing distribution are to be discovered. To include all elements of a plant community, sampling must be conducted in spring/summer. To include all elements of a macroinvertebrate community, sampling must be conducted all year round. Macroinvertebrate communities should be defined as all species living in and utilising a particular habitat, where the habitat can be considered a cohesive unit consisting of a certain morphology, sediment, macrophyte community and food availability. It is essential that a macroinvertebrate community is a temporal as well as spatial unit, as a species can alter conditions to favour a second, irrespective of whether they coexist concurrently. Macroinvertebrate communities vary in terms of the type of species present, species richness, diversity and abundance, and can be distinguished from the communities found in other locations.

Few definite conclusions can be made on the variables that determine macroinvertebrate diversity and abundance within the cutaway wetlands, although, many strong hypothesis have emerged. The most important factors in determining the diversity and abundance of macroinvertebrates within the littoral of these cutaway wetlands appeared to be exposure, sediment and macrophytes. Exposure and sediment were important in determining macroinvertebrate abundance, and also influenced the diversity of structure and the abundance of plants. Macrophytes appeared to be closely related to macroinvertebrate species richness.

These cutaway waterbodies are very important to the Irish midlands. They increase the range and diversity of macroinvertebrates in the region and contain very interesting, diverse and dynamic populations. The conservation value of these habitats is high and constantly increasing.

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**Section C** 

# ECOLOGICAL INVESTIGATIONS OF CORIXIDAE AT TURRAUN & TUMDUFF

#### Foreword

Corixidae were amongst the most species rich and abundant macroinvertebrates in the study sites. Corixids were the most abundant taxa found during the general macroinvertebrate survey of Turraun with 11,482 individuals taken between February 1997 and February 1998 (see Chapter 4). This represented 34% of the total macroinvertebrate population. Corixidae were also abundant at Tumduff, with 1,700 individuals captured between January 1997 and February 1998, representing 12% of the macroinvertebrate total.

This high abundance prompted an extension of the macroinvertebrate survey, during which only Corixidae were collected from the eight sampling stations. Chapter 5 presents the results of the full corixid survey, consisting of sixteen sampling occasions between January 1997 and April 1999. Species composition, abundance and comprehensive temporal variation data are given. Corixid ecology and spatial distribution are also discussed.

Chapters 6, 7 and 8 investigate why corixids, and in particular *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti*, reached such high abundance in the cutaway wetlands. Three ecological hypotheses were developed to explain the success of Corixidae in Turraun and Tumduff. It was considered that predation and parasite pressure might be low, allowing corixids to increase in abundance and to inhabit all parts of the wetlands. It was also hypothesised that food availability facilitated the survival of large numbers of corixids. Finally it was thought that the habitat types found at the study sites were strongly selected for or preferred by the four main species.

In Chapter 6, variations in overall and seasonal corixid sex ratio at Turraun and Tumduff are examined, in order to elucidate reasons for the dramatic seasonal changes in corixid abundance. Corixid length distribution is also analysed in Chapter 6 and sexual dimorphism considered. Length data are compared to the literature to see if the conditions encountered in Turraun and Tumduff support large or small corixids. Variations in length between wetlands and among sampling stations are used to give further insight into the ecology of the four dominant species. Finally in Chapter 6, parasitism by larval mites is explored in an attempt to explain the overall abundance of corixids in the wetlands, seasonal changes in corixid abundance and/or variations in corixid numbers between wetlands and among sampling stations.

Chapter 7 is devoted to laboratory based feeding trials investigating the diet of the four most abundant corixid species in the study sites, *S. dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti*. The possible influences of corixid feeding on species composition, abundance and distribution are considered.

In Chapter 8, habitat selectivity of the four dominant corixid species is studied in the laboratory and the field to determine if these species are associated with the specific habitats found in Turraun and Tumduff. These data are also used to interpret the distribution of corixids amongst sampling stations.

Chapter 5

## THE CORIXID POPULATIONS OF TURRAUN & TUMDUFF

#### 5.1 Introduction

Corixidae (Hemiptera, Heteroptera) (See Plate 11) are fully aquatic animals, with aquatic eggs, nymphs and adults. They cannot survive for long in terrestrial conditions (Popham 1964), but are adept at flying (Savage 1989). Corixids have a world-wide distribution and utilise virtually all aquatic habitats (Scudder 1976), having been found in hot springs, icebound pools and estuaries (Southwood & Leston 1959). Corixids are common in freshwater, where they are more often found in lentic than in lotic waters (Savage 1989). 12 genera of corixids can exist in coastal and inland saline environments, although *Trichocorixa* is the only genus found in truly marine environments (Scudder 1976).



Plate 11 Male corixids (Sigara scotti).

Corixids are amongst the first invertebrates to colonise a new water body (Macan 1973, Barnes 1983, Williams 1993). Colonisation and migration in corixids has been the focus of much study (e.g. Popham 1943, 1964, Brown 1951, Fernando 1959, Macan 1962, Williams 1993). Emigration requires a minimum air temperature to be reached and occurs during anticyclonic weather (Fernando 1959, Popham 1964, Savage 1989). Overcrowding, habitat changes, and possibly lack of food also initiate emigration (Brown 1951, Popham 1964). Migration rates vary among species owing to flight polymorphism and Young (1965a and b) investigated wing and wing muscle polymorphism in British corixids. Most corixid species are thought capable of surviving in the air for 2-3.5 hours (Scudder 1976) and may be able to travel 50-90 km per day (Popham 1964, Scudder 1976). Corixids that rise a few hundred feet can be carried much greater distances by upper atmosphere winds (Popham 1964). Corixids are attracted to reflective surfaces from the air (Popham 1964, Scudder 1976) and readily immigrate to new water bodies.

A considerable volume of corixid biogeographical work has been conducted, which provides valuable pointers to corixid distribution and colonisation limits. Macan (1938) studied the distribution of corixids in the Lake District and Macan (1954) described the habitats of British corixids. Savage has given much attention to the ecology of corixids in England (e.g. Savage 1971b, 1982, 1989, 1994, 1996, Savage & Pratt 1976). In Ireland, corixids have been studied in Clare Island (Halbert 1912), Roundstone blanket bogcomplex (Crisp & Heal 1958), the Aran Islands (Reynolds 1985b), Killarney (O'Connor *et al.* 1986), Counties Clare, Cork and Kerry (Kirby 1991) and the Corrib catchment (Tully *et al.* 1991). Nelson (1995) conducted a comprehensive survey of the Heteroptera of Northern Ireland.

The predominance of Corixidae in Turraun and Tumduff was noted during routine macroinvertebrate sampling (January 1997 to February 1998). Because of their relative importance and seasonal fluctuations, the survey of corixids was extended for five further sampling dates into 1999. This chapter presents the corixid data collected over sixteen sampling occasions between January 1997 and April 1999. Particular attention is given to temporal changes in corixid abundance. In order to compare the corixid species composition in the cutaway wetlands with that of other lentic waters in the region, two natural lakes in County Offaly (Fin Lough and Pallas Lake) were sampled for corixids.

#### 5.2 Material and Methods

#### 5.2.1 Corixidae of Turraun and Tumduff

Corixidae samples were taken from Turraun and Tumduff on the dates indicated in Table 5.1. Corixidae collected between January 1997 and February 1998 were taken as part of the general macroinvertebrate survey described in Chapter 4. The last five dates (September 1998 to April 1999) represented an extension of the original sampling regime, during which time only Corixidae were removed. Five replicate samples, each consisting of five standard sweeps (as detailed in Section 4.2.2.2, Chapter 4) were taken from all eight sampling stations on all sampling dates.

Table 5.1Dates on which corixid samples were taken from the<br/>eight sampling stations at Turraun and Tumduff.Turraun, B = Tumduff.

date	pond	date	pond	
13 <sup>th</sup> Jan 1997	В	20 <sup>th</sup> Oct 1997	ТВ	
7 <sup>th</sup> Feb 1997	Т	29 <sup>th</sup> Nov 1997	ТВ	
18 <sup>th</sup> Mar 1997	ТВ	18 <sup>th</sup> Feb 1998	ТВ	
18 <sup>th</sup> Apr 1997	ТВ	6 <sup>th</sup> Sep 1998	ТВ	
19 <sup>th</sup> May 1997	ТВ	21 <sup>st</sup> Oct 1998	ТВ	
18 <sup>th</sup> Jun 1997	ТВ	2 <sup>nd</sup> Dec 1998	ТВ	
21 <sup>st</sup> Jul 1997	ТВ	17 <sup>th</sup> Feb 1999	ТВ	
18 <sup>th</sup> Aug 1997	ТВ	12 <sup>th</sup> Apr 1999	ТВ	
22 <sup>nd</sup> Sep 1997	ТВ			

The animals were sorted, stored and identified as detailed in Section 4.2.2.3, Chapter 4. Any additional macroinvertebrates caught on the last five sampling dates were returned to the study ponds or released into a pond at the rear of the Zoology Department, Trinity College Dublin.

#### 5.2.2 Corixidae of nearby natural lakes

While Offaly has a number of water bodies, such as the Grand Canal, ponds and drains on cutover peatland and farmland, there are few natural lakes. Two small natural lakes lying relatively close to the Lough Boora Parklands, Fin Lough and Pallas Lake, were sampled on 2<sup>nd</sup> July 1999. Fin Lough (N 037 294), lies in west Co. Offaly on the fringes of Blackwater Bog, and near Mongan Bog and Clonmacnoise. It is approximately 15 km

north west of Turraun and 18 km north west of Tumduff. Pallas Lake (N 271 193) lies west of Tullamore, Co. Offaly and approximately 10.5 km south east of Turraun and 9 km east of Tumduff. Both lakes are shallow with marl sediments. Organic matter is deposited within the abundant macrophyte beds.

The littorals of both lakes were sampled qualitatively with a sweep net. Two samples were taken from Fin Lough, one from amongst dense reed beds and one from open water over *Chara*. A single qualitative sample was taken from Pallas Lake, in open water over *Chara* and amongst reeds. The samples were returned to the laboratory and stored at 8 °C overnight, before being sorted and preserved in 70% alcohol. Corixidae were separated and identified.

#### 5.2.3 Data processing and statistical analysis

Data were sorted, subtotals calculated and graphs plotted on Microsoft Excel 97<sup>®</sup>. Statistical tests were performed using Data Desk 6.0<sup>®</sup> and SPSS 8.0 for Windows<sup>®</sup>.

#### 5.3 Results

The data of the earlier routine survey (January 1997 to February 1998) and of the supplementary survey (September 1998 to April 1999) are here considered together. Corixid data from January 1997 to February 1998 were also mentioned in Chapter 4 in terms of species composition, abundance and distribution. Some of the data are reviewed here, for completeness. Temporal variations in abundance are presented, followed by the results of the investigation of Fin Lough and Pallas Lake.

#### 5.3.1 Corixid species composition and abundance at Turraun and Tumduff

13 confirmed species of Corixidae were captured in Turraun and 12 species in Tumduff, over the entire sampling period from October 1996 to August 1999. Table 5.2 lists the species found in the study sites and their average abundance per sample over 16 sampling occasions between January 1997 and February 1998.

species	Turraun	s.d.	Tumduff	s.d.
Callicorixa praeusta	0.026	±0.175	0.063	±0.259
Corixa panzeri	0.270	±0.175	0.013	±0.111
Corixa punctata/iberica	0.003	±0.051	0	
Hesperocorixa castanea	0.010	±0.125	0.017	±0.182
Hesperocorixa linnaei	0.003	±0.051	0.004	±0.065
Hesperocorixa sahlbergi	0.003	±0.051	0	
Arctocorisa germari	0.003	±0.051	0.004	±0.065
Sigara dorsalis	2.525	±7.881	2.500	±3.981
Sigara distincta	8.668	±23.418	1.546	±3.427
Sigara falleni	0.119	±0.517	0.008	±0.091
Sigara fossarum	17.213	±66.033	1.346	±2.977
Sigara lateralis	0.003	±0.051	0.004	±0.065
Sigara scotti	3.675	±9.083	0.792	±1.985
Sigara semistriata	0		0.021	±0.143
total corixids	34.808	±96.566	8.917	±11.306

Table 5.2Average catch per sample of corixid species at Turraun and<br/>Tumduff between January 1997 and April 1999.Standard<br/>Deviation (s.d.) is also given.

Four species were clearly more abundant than all others: Sigara dorsalis, S. distincta, S. fossarum and S. scotti. S. fossarum was the most abundant of all corixids at Turraun, having the highest average catch and was also the most abundant macroinvertebrate in that wetland between January 1997 and February 1998. S. distincta, followed by S. scotti and S. dorsalis were the next most abundant corixid species in Turraun. S. dorsalis was the

most abundant corixid at Tumduff, followed by *S. distincta*, *S. fossarum* and *S. scotti*. These four species were also present on all sampling occasions and were assumed to be breeding in both wetlands.

Sigara falleni and Corixa panzeri were reasonably abundant at Turraun and found on ten of the 16 sampling occasions. All other species were less abundant and occurred less frequently. Between January 1997 and April 1999, only one individual of *Hesperocorixa linnaei*, Arctocorisa germari and Sigara lateralis was found in each wetland, while one female Corixa punctata (Illiger)/ *iberica* Jansson and one Hesperocorixa sahlbergi was found in Turraun. Callicorixa praeusta (Fieber) was rare (occurred in less than 5% of samples) in both wetlands, while C. panzeri, Hesperocorixa castanea, S. falleni and S. semistriata (Fieber) were rare in Tumduff.

One female suspected to be *H. moesta* was found in Turraun in April 1997 and a second in April 1999. A similar female was found at Tumduff in October 1997. Dr Brian Nelson of the Ulster Museum has examined these specimens and also believes them to be *H. moesta*, though without males this cannot be confirmed.

Corixids were more abundant at Turraun than at Tumduff (Table 5.2). All common species, including *S. dorsalis*, had greater average abundance at Turraun, although, *C. praeusta* was more abundant at Tumduff than Turraun.

#### 5.3.2 Distribution of corixids at Turraun and Tumduff

Corixids were found at all sampling stations. Average abundance per sample was greatest at T3 (see Table 5.3). Average abundance at T4 was less than half that at T3, while abundance at T5 was almost half that at T4. The average abundance at all other sampling stations (T1, T2, B6, B7 and B8) was similar at c. 10 corixids per sample.

*S. dorsalis, S. distincta, S. fossarum* and *S. scotti* were the most abundant species at all stations (Tables 5.3 and 5.4). *S. dorsalis* had high average abundance per sample (Table 5.3) at T3 and T4, while its greatest relative abundance (Table 5.4) was found at T1, T2 and all Tumduff stations. *S. distincta* also reached its highest average abundance at T3 and T4. The percentage abundance of *S. distincta* was greatest at T1, followed by T2, T4 and

T5. The average and percentage abundance of *S. fossarum* was greatest at T3, where it reached the highest abundance of any corixid species at any sampling station. This species also had high average abundance at T4, while its percentage abundance was high at T4 and T5. Again, the highest average abundance of *S. scotti* was found at T3. The average abundance of *S. scotti* was similar at T1, T4 and T5 and low at T2 and all Tumduff stations. The percentage abundance of this species was greatest at T1 followed by T5.

T1 T2 T3 T4 **T**5 **B6 B**7 **B**8 species 0.01 0.01 0.05 0.03 Callicorixa praeusta 0.03 0.03 0.05 0.11 Corixa panzeri 0.03 0.45 0.49 0.30 0.09 0 0.03 0.01 Corixa punctata/iberica 0 0 0 0.01 0 0 0 0 Hesperocorixa castanea 0 0 0 0.05 0 0.03 0.03 0 0 0 0 0.01 0.01 Hesperocorixa linnaei 0 0 0 0 0 0 0 0.01 0 0 Hesperocorixa ?moesta 0 0 0 0 0.01 Hesperocorixa sahlbergi 0 0 0 0 0.01 0 0 0.01 0 Arctocorisa germari 0 0 0 1.75 4.04 1.56 0.76 2.21 2.09 3.20 Sigara dorsalis 4.63 3.56 19.05 11.91 5.52 1.94 Sigara distincta 3.43 1.63 1.08 Sigara falleni 0.03 0.03 0.20 0.33 0.01 0.01 0.01 0 Sigara fossarum 2.15 1.75 50.69 22.26 9.88 1.28 1.99 0.78 Sigara lateralis 0.00 0.01 0.01 0 0 0 0 0 0.92 0.96 2.80 3.41 0.84 0.58 Sigara scotti 2.71 8.65 0.04 0.01 Sigara semistriata 0 0 0 0 0 0.01 Nymph 0.56 0.72 7.28 1.58 1.45 2.86 3.40 1.53 Total 10.67 11.48 91.07 40.82 21.20 8.91 10.52 7.31

 Table 5.3
 Average abundance per sample of corixids at the eight sampling stations between January 1997 and February 1999.

## Table 5.4Percentage abundance of corixids at the eight sampling stations between<br/>January 1997 and April 1999. Values expressed as a percentage of the<br/>corixid total.

species	T1	T2	Т3	T4	T5	B6	B7	B8
Callicorixa praeusta	0.12	0.12	0.06	0.06	0.13	0.28	0.48	1.54
Corixa panzeri	0.23	3.95	0.54	0.73	0.44	0.00	0.24	0.17
Corixa punctata/iberica	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00
Hesperocorixa castanea	0.00	0.00	0.00	0.12	0.00	0.00	0.24	0.34
Hesperocorixa linnaei	0.00	0.00	0.00	0.00	0.06	0.00	0.12	0.00
Hesperocorixa ?moesta	0.00	0.00	0.00	0.03	0.00	0.14	0.00	0.00
Hesperocorixa sahlbergi	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00
Arctocorisa germari	0.12	0.00	0.00	0.00	0.00	0.00	0.12	0.00
Sigara dorsalis	16.39	35.19	5.08	3.83	3.58	24.82	19.83	43.76
Sigara distincta	32.08	31.01	20.92	29.18	26.04	18.23	18.41	14.70
Sigara falleni	0.23	0.23	0.22	0.80	0.06	0.14	0.12	0.00
Sigara fossarum	20.14	15.21	55.67	54.53	46.60	14.31	18.88	10.60
Sigara lateralis	0.00	0.00	0.01	0.00	0.00	0.14	0.00	0.00
Sigara scotti	25.41	8.01	9.50	6.86	16.10	9.40	9.14	7.86
Sigara semistriata	0.00	0.00	0.00	0.00	0.00	0.42	0.12	0.17
Nymph	5.27	6.27	7.99	3.86	6.86	32.12	32.30	20.85
Total catch	854	861	6,830	3,266	1,590	713	842	585

To recap in terms of sampling stations: T1 was dominated by *S. distincta. S. dorsalis* and *S. distincta* were abundant at T2. *S. fossarum* was dominant at T3, where all species had high average abundance. *S. distincta* was the second most abundant species at T3. *S. distincta* and *S. fossarum* also dominated T4 and T5. The average abundance of *S. dorsalis* was notably low at these two stations. *S. dorsalis* had the greatest average and percentage abundance of any species at all three Tumduff sampling stations. Corixid nymphs were also abundant at Tumduff. *S. distincta* and *S. fossarum* percentage abundance was generally lower at Tumduff sampling stations than at Turraun stations.

### 5.3.3 Temporal variations in corixid abundance

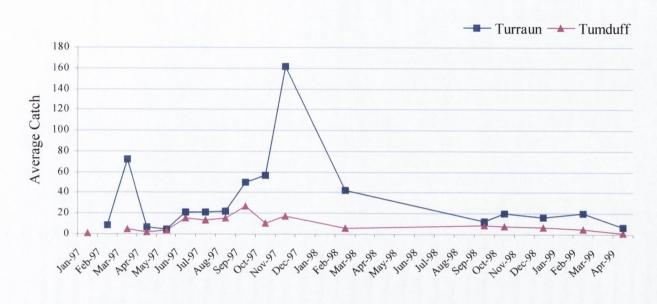
A total of 13,868 individual corixids (including nymphs) was captured in 385 samples at Turraun between February 1997 and April 1999. Of these, 11,482 were taken in 260 samples between February 1997 and February 1998, as part of the main macroinvertebrate survey, in which corixids represented 34% of the total macroinvertebrate population. Corixid abundance was lower at Tumduff and 2,147 individuals were taken in 240 samples between January 1997 and April 1999. 1,700 of these were captured in 165 samples between January 1997 and February 1998 (12% of total macroinvertebrate population).

Large fluctuations in corixid abundance were observed in both wetlands over time. Figure 5.1 illustrates the changes in total corixid abundance between January 1997 and April 1999. These data, along with the average catch per sample of *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* on each sampling date are given in Tables 5.5 and 5.6.

Corixidae were abundant in March 1997 at Turraun, but decreased dramatically in April and May (Figure 5.1). Average catch per sample gradually increased from June 1997, reaching a maximum value for the entire sampling period in November 1997. The abundance in 1998 and 1999 did not reach 1997 levels, with average catch per sample in February 1999 half that of February 1998. Abundance found in April 1999 was almost as low as that found in April 1997 (Table 5.5).

Corixidae were far less abundant at Tumduff than at Turraun throughout the sampling period (Figure 5.1, Tables 5.5 and 5.6). September 1997 had the highest average abundance of corixids at Tumduff and the temporal pattern was somewhat similar to that at

Turraun. Corixidae abundance increased throughout 1997 and fell off in 1998 and 1999 (Figure 5.1). September and October 1998 were lower than the same months in 1997, although February 1999 average abundance was almost the same as February 1998.



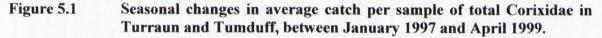


Table 5.5	Average catch per sample of total Corixidae and four abundant species at
	Turraun, February 1997 to April 1999. Standard deviation (s.d.) is given.

	Corixidae		S. distincta		S. dorsalis		S. fossarum		S. scotti	
month	average	s.d.	average	s.d.	average	s.d.	average	s.d.	average	s.d.
Feb '97	8.4	6.34	0.9	1.41	5.5	4.82	0.2	0.41	1.3	1.75
Mar '97	72.5	62.20	18.4	17.67	21.2	22.08	10.7	18.25	18.6	21.27
Apr '97	6.3	6.23	3.6	4.55	1.0	1.26	0.5	0.69	0.9	1.82
May '97	5.2	4.28	1.9	2.76	1.4	1.12	0.5	0.77	0.7	1.68
Jun '97	21.2	19.01	3.1	2.76	2.1	2.73	4.8	5.32	4.8	6.31
Jul '97	21.4	35.09	1.9	1.64	0.5	0.92	4.6	9.31	1.2	2.15
Aug '97	22.6	24.16	2.1	3.50	0.4	0.77	6.2	8.63	1.3	1.99
Sep '97	49.9	84.69	13.4	26.48	1.2	2.12	30.9	50.74	3.0	5.60
Oct '97	51.9	97.44	16.4	24.00	2.2	4.33	29.3	62.51	3.8	8.05
Nov '97	162.0	309.00	39.9	71.79	3.8	6.28	110.3	218.58	7.8	15.64
Feb '98	42.5	66.06	11.6	13.76	0.9	1.05	24.6	48.54	5.5	10.96
Sep '98	12.4	13.84	3.1	3.89	0.1	0.28	6.0	7.30	0.9	1.83
Oct '98	20.5	38.68	4.1	7.49	0.2	0.52	14.1	30.59	1.8	3.01
Dec '98	16.7	24.55	3.1	3.36	0.3	0.61	10.8	19.02	2.3	3.74
Feb '99	20.2	23.81	8.7	11.56	0.5	1.19	9.6	12.47	1.4	1.73
Apr '99	7.1	10.02	2.5	3.08	0.1	0.28	2.1	3.48	2.0	3.47

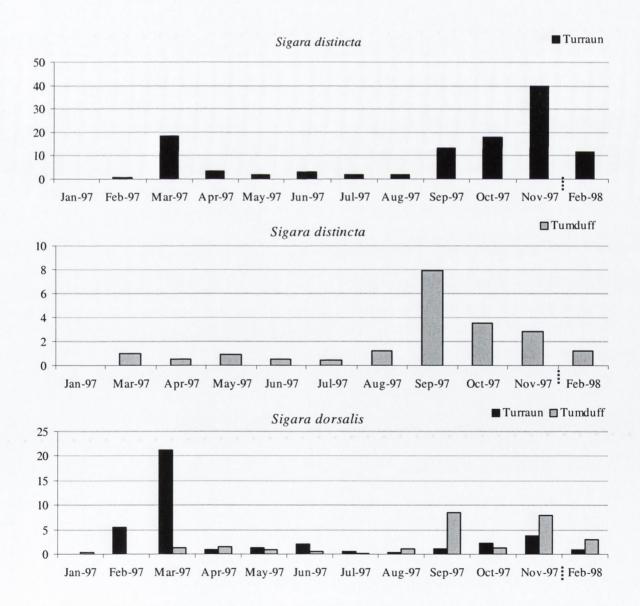
	Corix	idae	S. distincta		S. dorsalis		S. fossarum		S. scotti	
month	average	s.d.	average	s.d.	average	s.d.	average	s.d.	average	s.d.
Jan '97	0.2	0.41	0	0	0.1	0.35	0.7	0.26	0	0
Mar '97	4.5	5.30	1.0	1.81	1.4	1.92	0.9	0.96	0.6	1.12
Apr '97	2.3	3.15	0.5	1.06	1.5	1.85	0.1	0.35	0.2	0.77
May '97	3.4	2.64	0.9	1.33	1.0	1.00	0.3	0.46	0.4	1.12
Jun '97	15.1	6.20	0.5	0.83	0.6	0.83	0.3	0.59	0.5	1.25
Jul '97	13.0	9.11	0.5	0.64	0.1	0.35	0.6	0.91	0.1	0.35
Aug '97	15.5	16.11	1.3	2.40	1.1	1.44	1.3	2.74	0.5	0.83
Sep '97	27.1	23.56	7.9	8.75	8.5	6.92	7.0	7.49	2.1	4.09
Oct '97	9.6	9.46	3.3	5.30	1.2	1.01	2.3	3.09	2.7	2.89
Nov '97	17.3	11.54	2.9	3.54	7.9	7.96	2.7	3.02	3.7	3.63
Feb '98	5.3	3.69	1.3	1.67	3.0	2.20	0.8	1.01	0.1	0.26
Sep '98	9.1	7.37	1.1	1.53	3.7	2.69	0.7	1.40	0.2	0.56
Oct '98	7.5	5.55	1.1	1.55	5.2	3.78	0.5	1.13	0.3	0.59
Dec '98	6.5	5.40	1.7	1.54	2.5	1.81	1.9	3.17	0.2	0.41
Feb '99	5.0	4.86	0.7	0.82	1.5	2.53	1.8	2.11	0.9	1.87
Apr '99	1.3	2.49	0.1	0.26	0.6	1.12	0.3	0.80	0.1	0.35

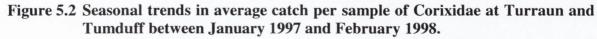
Table 5.6	Average catch per sample of total Corixidae and four abundant species at
	Tumduff, January 1997 to April 1999. Standard deviation (s.d.) is given.

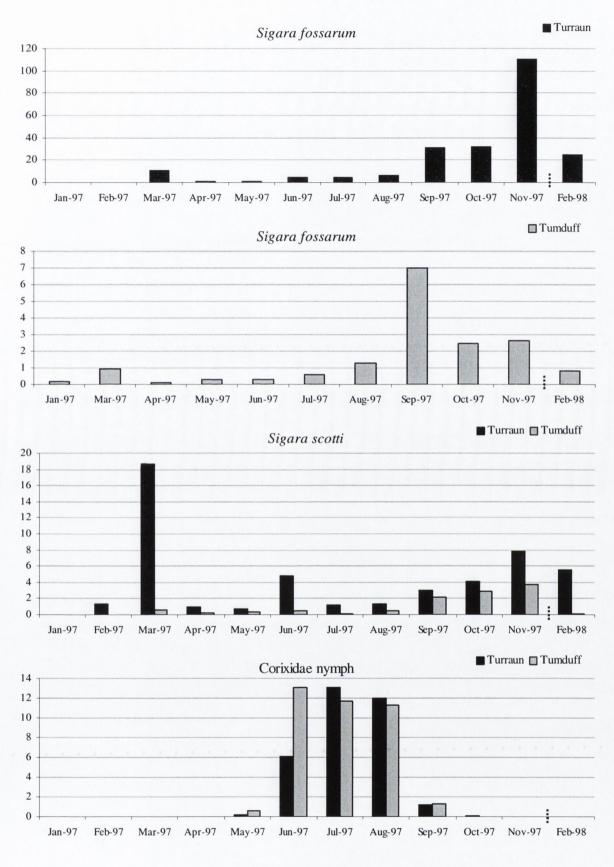
As the data set is most complete for 1997, and for ease of interpretation, changes in the average abundance of *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* between January 1997 and February 1998 at Turraun and Tumduff are depicted in Figure 5.2. These data are also given in Tables 5.5 and 5.6. All species show low summer numbers and an increase in abundance in the autumn and winter months. Corixid nymphs are present from May to October and most abundant from June to August. Figure 5.3 illustrates the changes in relative abundance of the various corixid species and corixid nymphs at Turraun and Tumduff between January 1997 and April 1999.

Sigara dorsalis was most abundant in early 1997 at Turraun (Figure 5.2, Table 5.5). Average abundance recovered somewhat in late 1997, but was very low in 1998 and 1999. This pattern of decrease in abundance of *S. dorsalis* over the sampling period is also evident in Figure 5.3, which expresses the monthly abundance of each species as a percentage of the total corixid catch. *S. dorsalis* had a far greater relative importance at Tumduff than at Turraun. This decreased during summer 1997 when corixid nymphs were very abundant (Figures 5.2 and 5.3), but did not appear to change over the course of the sampling period. Absolute abundance of the species was greatest in September and November 1997, but it appeared to be generally higher in 1998 than in 1997.

S. distincta followed the general Corixidae pattern and appeared to increase in abundance from winter 1996/7 to winter 1997/8 and decrease then to winter 1998/9 (Tables 5.5 and 5.6, and Figure 5.2). S. distincta was most abundant in November 1997 at Turraun. The species had a greater average abundance in February 1998 than in February 1999 and much greater than February 1997. In terms of percentage abundance, the relative importance of S. distincta in Turraun increased after February 1997 and except for low summer values when corixid nymphs were abundant, changed little over the sampling period (Figure 5.3). Tumduff was similar to Turraun, in that average abundance of S. distincta per sample was greatest in winter 1997/8 and numbers appeared to drop in 1998 and 1999. Percentage abundance also suggests that the species may have decreased in relative importance in 1998/9.







**Figure 5.2 continued** 

The pattern in average abundance of *S. fossarum* at Turraun was very similar to that of *S. distincta*, increasing in winter 1997/8 but decreasing in winter 1998/9. At the same time percentage abundance increased from February 1997 to September 1997 and subsequently remained more or less constant until April 1999 when it decreased. Temporal changes in *S. fossarum* at Tumduff were also similar to changes in *S. distincta*, however, it was more

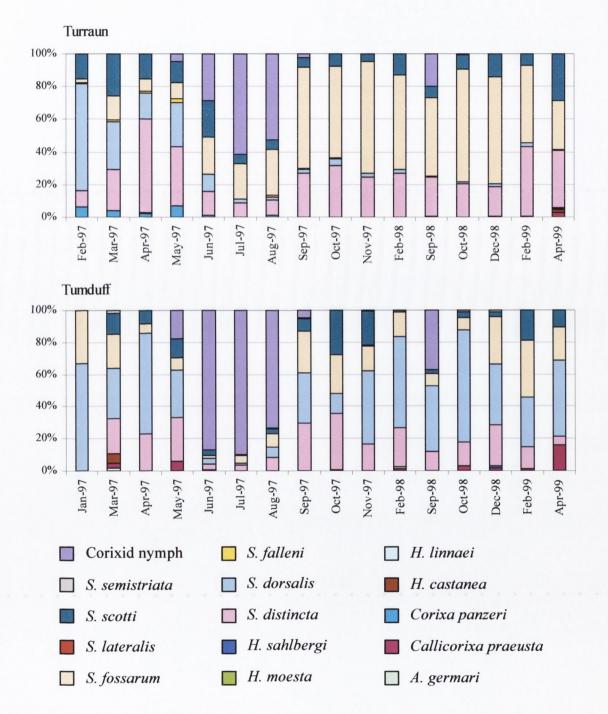


Figure 5.3 Temporal changes in species composition of corixid faunas between January 1997 and April 1999. All 14 species and corixid nymphs are expressed as a percentage of the total corixid catch at Turraun or Tumduff on each sampling date.

abundant in February 1999 than February 1998 or January 1997. The relative abundance of *S. fossarum* fluctuated greatly at Tumduff and it was most important in January 1997, September 1997 and February 1999.

At Turraun, *S. scotti* had a similar temporal trend in average abundance to *S. dorsalis*. The greatest abundance was found in March 1997 after which numbers dropped. The 1998/9 abundance of *S. scotti* was not as low as that of *S. dorsalis* and percentage abundance fluctuated but did not show a general decrease over the sampling period. *S. scotti* was not very abundant at Tumduff but showed a temporal pattern similar to the other three species, increasing up to winter 1997/8 and decreasing again in 1998 and 1999. Again percentage abundance did not show an overall increase or decrease over the sampling period.

Referring again to Figure 5.3, a number of other species changed in terms of relative abundance over time. Two species appeared to decrease in abundance after 1997; *Corixa panzeri* did not occur regularly after September 1997 at Turraun and *S. falleni* decreased after November 1997 at Turraun. *Callicorixa praeusta* appeared to increase in 1998 and 1999, particularly in Tumduff.

Figures 5.4 to 5.7 are graphs of the seasonal changes in average abundance of *Sigara distincta*, *S. dorsalis*, *S. fossarum* and *S. scotti* at the eight sampling stations, between January 1997 and February 1998. Some interesting differences in pattern emerge among sampling stations.

All four species were abundant at T3 and T4, where the seasonal patterns generally reflected those for Turraun (Figure 5.2 above). At T3, however, the abundance of the four species was low in September and *S. scotti* (Figure 5.7) was almost as abundant in November as in March 1997. *S. scotti* was also abundant in October at T3 but almost absent from the other Turraun stations in that month. *S. distincta* (Figure 5.5) abundance was relatively low in March at T3, whereas at the four other Turraun stations it was relatively high. At T4 all four species were abundant in September, however, abundance dropped in October, particularly for *S. fossarum* (Figure 5.6).

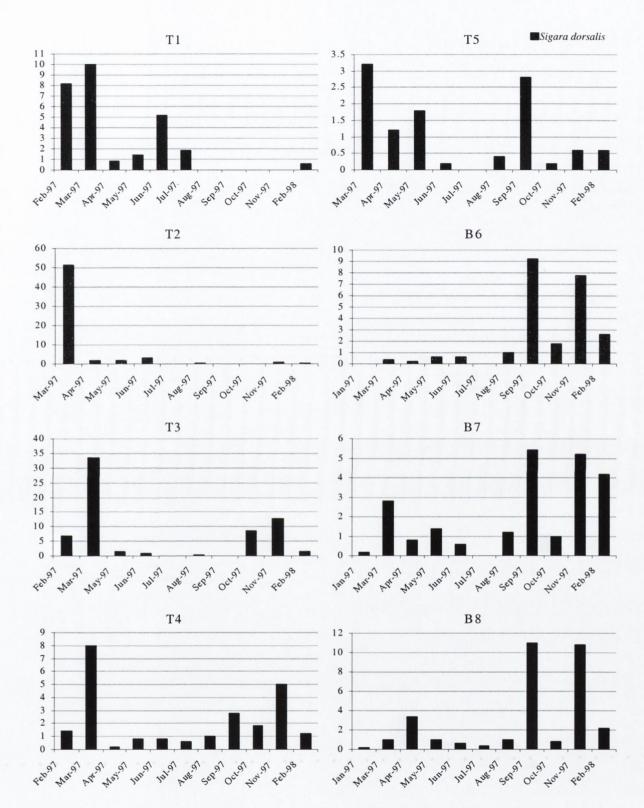


Figure 5.4 Seasonal variation in *Sigara dorsalis* at the eight sampling stations between January 1997 and February 1998. Average catch per sample in each month was used to produce the graphs. Only months in which sampling took place are illustrated.

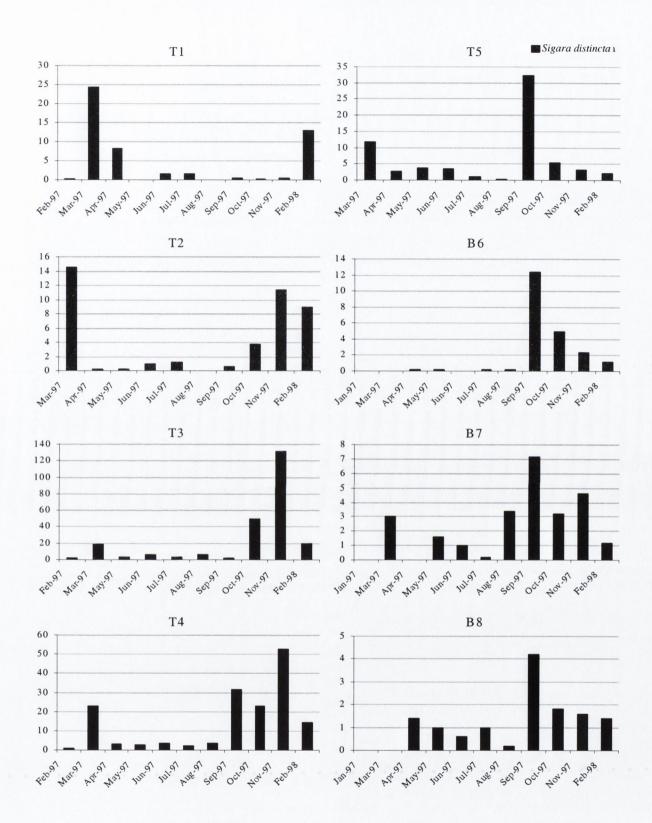


Figure 5.5 Seasonal variation in *Sigara distincta* at the eight sampling stations between January 1997 and February 1998. Average catch per sample in each month was used to produce the graphs. Only months in which sampling took place are illustrated.

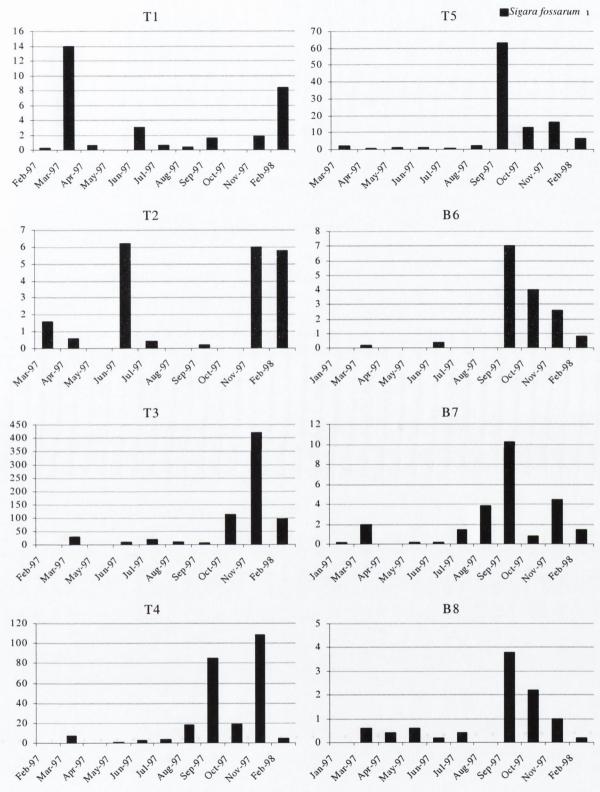


Figure 5.6Seasonal variation in Sigara fossarum at the eight sampling stations<br/>between January 1997 and February 1998. Average catch per sample<br/>in each month was used to produce the graphs. Only months in which<br/>sampling took place are illustrated.

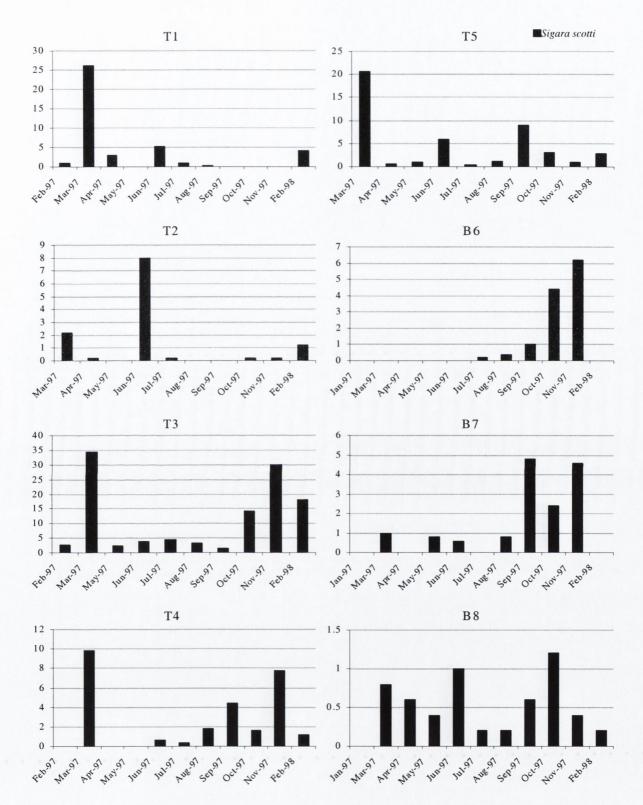


Figure 5.7 Seasonal variation in *Sigara scotti* at the eight sampling stations between January 1997 and February 1998. Average catch per sample in each month was used to produce the graphs. Only months in which sampling took place are illustrated.

The seasonal patterns for each species at T1 did not reflect wetland patterns, although *S*. *distincta* (Figure 5.5) and *S. scotti* (Figure 5.7) were abundant and *S. dorsalis* (Figure 5.4) was relatively abundant. All four species were most abundant in March and *S. distincta* and *S. fossarum* were also relatively abundant in February 1998. Corixid numbers were low in September, October and November at T1 when they were abundant at most other sampling stations. *S. dorsalis*, *S. fossarum* and *S. scotti* were relatively abundant in June when numbers were very low at other sampling stations.

Sigara dorsalis was very abundant at T2 in March 1997, as was S. distincta. The other three Sigara species had very low abundance at T2, particularly S. fossarum. S. distincta was the only species at T2 to follow a pattern similar to the general Turraun pattern, however, it differed in the very high March abundance. After the March high, S. dorsalis was almost absent in winter 1997/8. S. fossarum and S. scotti were most abundant in June and neither species demonstrated a clear seasonal pattern.

S. distincta, S. fossarum and S. dorsalis were relatively abundant in September 1997 at T5, and their seasonal patterns resembled those at Tumduff (Figure 5.2). S. scotti and S. dorsalis were most abundant in March, although the abundance of S. dorsalis was generally low. The overall wetland pattern in seasonal abundance of the different corixid species at Turraun is thus, an amalgam of sampling station specific patterns. Following from this, the pattern in total corixid abundance is a combination of separate species specific and sampling station specific patterns.

S. distincta had a similar seasonal pattern at all three Tumduff sampling stations, with maximum abundance in September. S. distincta was most abundant at B6. S. dorsalis also showed a similar trend at the three stations, maximum abundance again occurring in September. Abundance was low in October. S. fossarum numbers were also low in October at B7 and in August at B6 and B8. The general pattern at the three stations was a dramatic increase in numbers in September followed by a gradual decline to February 1998. S. scotti numbers were very low at B8 and no seasonal trend emerged. At B6 numbers increased until November, while at B7 numbers were high in both September and November. All four species were very low in abundance before September at B6, with only 24 individuals captured.

## 5.3.4 Corixidae of Fin Lough and Pallas Lake

Six species of Corixidae were found in both Fin Lough and Pallas Lake and these are listed in Table 5.7. The corixids recorded in the cutaway wetlands are also presented in the table, but it must be noted that the sampling efforts at natural and artificial waterbodies are in no way comparable. Species richness recorded from a single sample would be expected to be lower than that recorded from extensive seasonal sampling. With the exception of *Cymatia bonsdorffii* (Sahlberg), all species captured on 2<sup>nd</sup> July 1999 had previously been found at both Turraun and Tumduff. Only *Sigara distincta* and *Sigara fossarum* were abundant in Turraun and Tumduff.

Table 5.7Corixidae species captured in Fin Lough and Pallas Lake, Co.<br/>Offaly on 2<sup>nd</sup> July 1999 and in Turraun and Tumduff between<br/>January 1997 and April 1999. The number of animals in the<br/>qualitative samples from Fin Lough and Pallas Lake is given. The<br/>percentage abundance of each species at Turraun and Tumduff is<br/>supplied.

species	Fin Lough		Pallas Lake		Turraun	Tumduff
		%		%	%	%
Cymatia bonsdorffii (Sahlberg)	1	2	1	3		
Callicorixa praeusta (Fieber)	3	6	1	3	0.07	0.70
Corixa panzeri (Fieber)	5	11			0.78	0.14
Arctocorisa germari (Fieber)			3	9	0.01	0.05
Sigara distincta (Fieber)	10	21	13	39	24.90	17.34
Sigara falleni (Fieber)	6	13			0.34	0.09
Sigara fossarum (Leach)	2	4	10	30	49.45	15.09
Sigara lateralis (Leach)			1	3	0.01	0.05
Corixid Nymphs	20	43	4	12	6.57	29.11
Corixa punctata/iberica					0.01	
Hesperocorixa castanea (Thomson)					0.03	0.19
Hesperocorixa linnaei (Fieber)					0.01	0.05
Hesperocorixa ?moesta (Fieber)					0.01	0.05
Hesperocorixa sahlbergi (Fieber)					0.01	
Sigara dorsalis (Leach)					7.25	28.04
Sigara scotti (Douglas & Scott)					10.56	8.88
Sigara semistriata (Fieber)						0.23
Total captured		47		33	13,864	2,147

## 5.4 Discussion

Firstly, the ecology of the corixid species found in Turraun and Tumduff will be explored, each of the fifteen species considered in turn, following taxonomic order. The species composition of the study sites will be discussed and suggestions made for the high abundance of some species. Reasons for the diversity and abundance of corixids in the study sites will then be investigated and the spatial variability in corixids considered. Corixid life cycle and temporal variability of the different corixid species will be examined. Finally the corixids of the natural lakes will be discussed.

*Callicorixa praeusta* is commonly found in lakes and is associated with high organic content in the substratum (Popham 1943, Macan 1954, Savage 1994). It was also found to be correlated with vegetation cover and fine substrata in the Corrib catchment (Tully *et al.* 1991). *C. praeusta* is a ready migrant, capable of colonising new areas rapidly (Brown 1951, Southwood & Leston 1959, Tully *et al.* 1991) and has been recorded from cutover pools in Northern Ireland (Nelson 1995). This species appears to have colonised early in the history of the study sites, where the high percentage vegetation cover and peat sediment probably facilitated establishment. The abundance of *C. praeusta* remained low in Turraun and Tumduff throughout the study. A similar trend found by Williams (1993) in artificial mining subsidence ponds in Northumberland.

*Corixa panzeri* seems to have a coastal distribution in continental Europe and in Northern Ireland (Nelson 1995), although, it frequently occurs inland in the midlands and south of Ireland. Its typical habitats include alkaline ponds and small lakes (Southwood & Leston 1959). *Corixa panzeri* was also correlated with high vegetation cover and fine substrata in the Corrib survey (Tully *et al.* 1991). Williams (1993) found *C. panzeri* only at the oldest mining subsidence pond and considered it to have poor colonisation ability. The presence of this species in the study sites probably indicates *C. panzeri* is present in surrounding water bodies and may be a better coloniser of new habitats than supposed by Williams (1993), as it colonised Tumduff within five years of creation.

*Hesperocorixa linnaei* was found in ponds on bog and fen, lakes and a flooded quarry in Northern Ireland (Nelson 1995) and in high altitude soft water sites in the Corrib catchment (Tully *et al.* 1991). It is often associated with reed-beds in nutrient-rich lakes

(Macan 1965c). *H. linnaei* appeared to increase in abundance over time in Turraun, possibly in response to increasing trophic status and vegetation cover. *Hesperocorixa sahlbergi* is a widespread species, often associated with vegetation in alkaline ponds and fen (Macan 1954), but it has also been found in the Clara Bog soak (Reynolds 1984). It has been recorded from many sites in Northern Ireland including pools on cutover and fens and is tolerant of eutrophic conditions (Nelson 1995). Although the conditions in Turraun would appear to fit the requirements of *H. sahlbergi*, it did not appear to be a permanent member of the corixid fauna. It probably owes its presence at the wetland to its ability to colonise new water bodies (Brown 1951).

*Hesperocorixa castanea* is a species of small base-poor ponds (Macan 1965c), but can also occur in more base-rich pools (Brian Nelson personal communication). It is strongly associated with dense vegetation (Macan 1976) and Southwood & Leston (1959) found it in many peat based habitats. It has also been found in the soak at Clara bog (Reynolds 1984) and in peat cuttings in Northern Ireland (Nelson 1995). Although *H. castanea* numbers were low in Turraun and Tumduff, it is possible that it was resident in the wetlands and that peat sediment and well developed macrophyte community facilitated establishment. *Hesperocorixa moesta* is rather rare in the British Isles, where it is associated strongly with vegetation in ponds (Southwood & Leston 1959, Macan 1965c). There are only four definite records of *H. moesta* in Ireland, from Counties Dublin, Clare, Kilkenny and Down (Nelson 1995, Brian Nelson personal communication). Because of its rarity, confirmation of the presence of *H. moesta* in the cutaway ponds is of great interest.

The preferred habitats of *Arctocorisa germari* include large calcareous lakes and upland base-poor water bodies (Macan 1954, 1965c, Tully *et al.* 1991, Nelson 1995). Popham *et al.* (1984b) record that it prefers large bodies of water with steeply sloping sides. It was found in eutrophic lakes in Northern Ireland (Nelson 1995). While Turraun and Tumduff would appear to be suitable habitats for *A. germari*, it was only taken once in each wetland and did not appear to be resident.

*S. falleni* is a lake species, associated with medium to high conductivities and alkaline, eutrophic conditions (Macan 1954, Savage 1994, Nelson 1995). It is flies readily and has successfully colonised many reservoirs in Northern Ireland (Nelson 1995). Williams (1993) found it to be present in the older mining subsidence ponds studied. *S. falleni* 

appeared to be one of the first corixid species to colonise the calcareous cutaway wetlands, though it did not reach high abundance.

Sigara dorsalis is closely related to S. striata (Linnaeus) and was first separated from S. striata in 1954 by Macan (Savage & Feakes 1991). S. dorsalis is predominantly a British species, also found in western Scandinavia and parts of France and Italy (Savage & Feakes 1991). It occurs frequently in lakes and rivers (Macan 1965c, Nelson 1995). S. dorsalis is characteristic of oligotrophic waters with low percentage organic matter in the substratum (Macan 1954, Savage & Pratt 1976), although it can occur over a wide range of conductivities (Savage 1989). S. dorsalis has been associated with exposed conditions in English meres (Savage & Pratt 1976), the Killarney lakes (O'Connor et al. 1986) and the Corrib catchment (Tully et al. 1991). Savage (1989) indicated that S. dorsalis may be associated with marginal vegetation owing to predation by fish (Savage 1989).

*S. dorsalis* may have been associated with less vegetated stations in the cutaway wetlands where its greatest relative abundance was found at T1 and T2. Both of these sampling stations were exposed to wind and waves. The lowest relative abundance was found at T4, which had dense macrophyte cover. *S. dorsalis* was the most abundant corixid at Tumduff, and formed 2.8% of the entire faunal abundance between January 1997 and February 1998. This species, however, was more numerous at Turraun than Tumduff and the greatest average abundance per sample was found at T3, a well vegetated station. The average abundance at the most densely vegetated sampling station, T4, was only slightly lower than at Tumduff. *S. dorsalis* may be capable of surviving in more exposed conditions, such as those found on the western side of Turraun (T1, T2 and T3) or at Tumduff, but it is also regularly found in dense vegetation (T3, T4 and T2 in summer). Tully *et al.* (1991) found *S. dorsalis* to be common on marl and gravel substrata and the gravel texture of the peat, may explain its importance at T2.

Southwood & Leston (1959) considered *S. dorsalis* is a poor flyer, although it sometimes occurs in great numbers in light traps. *S. dorsalis* appeared to have little problem colonising Turraun and Tumduff and may fall into the category described by Fernando (1959) of species that migrate at dusk and are stimulated to fly by triggers other than high temperature and high light intensity.

S. distincta is abundant in Ireland and is found in a variety of habitats from calcareous lakes to upland acid tarns (Southwood & Leston 1959). It is typical of small mesotrophic to mildly eutrophic lakes and pools on cutover in Northern Ireland (Nelson 1995). S. distincta is associated with reed-beds and accumulation of organic matter (Macan 1965c), and Macan (1976) suggested that S. distincta abounds where terrestrial flooded peat exhibited some decomposition. S. distincta is also abundant in open water in peat-floored tarns (Macan 1973). It has been associated with increasing trophic level in Killarney (O'Connor et al. 1986) and Windermere (Savage & Pratt 1976). Savage & Pratt (1976) found S. distincta in eutrophic lakes Windermere and Esthwaite formed 27% and 32% of the population respectively. S. distincta may have responded to the high trophic status in Turraun, where it comprised 25.8 % of the corixid fauna and was the second most abundant corixid species. The flooded fen and reed-swamp peat provided suitable sediment for the species. S. distincta is significantly associated with S. fossarum (Popham 1943, Macan 1954, Southwood & Leston 1959), and is associated with more species than any other corixid (Macan 1954, 1976). It certainly occurred in abundance with S. fossarum, S. dorsalis and S. scotti in the study sites.

The average abundance of *S. distincta* was far greater at T3 and T4 than at other sampling stations, although, it had its greatest percentage abundance at T1. The abundance of *S. distincta* at different sampling stations may be related to productivity, food availability and the presence of peat; and the influence of vegetation may be minimal.

Tully *et al.* (1991) claimed that *S. distincta* has non-flying morphs, Popham (1964) noted that *S. distincta* migrated within 30 minutes of the start of an experiment. All four dominant species, including *S. distincta*, were observed to fly from sorting trays in the laboratory during this study.

S. fossarum is a lake species, found in base-poor to slightly eutrophic sites (Nelson 1995) particularly in thick vegetation (Macan 1965c). Southwood & Leston (1959) found S. fossarum where there was high percentage organic matter in the substratum. Others have associated S. fossarum with lower percentage organic matter (Macan 1938, Savage 1989), as well as with lower conductivities (Savage 1982). Tully et al. (1991) suggested that S. fossarum preferred hard water with high percentage vegetation cover and fine substrata. This seems to be the case at Turraun, where S. fossarum comprised 16.4% of the entire

fauna between February 1997 and February 1998 and was not only the most abundant corixid, but also the most abundant taxon in the wetland. It was extremely abundant at T3, a station with dense vegetation and very fine peat sediment. As T3 was dominated by detritus, it is possible that *S. fossarum* was a deposit feeder. *S. fossarum* was only the third most abundant corixid at Tumduff, where detritus was not abundant. The presence of *S. fossarum* in the cutaway wetlands indicates that this species is capable of surviving in very high numbers over very organic sediment.

*S. fossarum* was found at the two oldest mining subsidence ponds studied by Williams (1993) and he considered it might have limited dispersal abilities. Fernando (1959) was unable to induce flight in *S. fossarum* and Popham (1943) noted it did not readily take flight. It was however, observed to fly readily in the laboratory during sorting.

*S. scotti* is predominantly a species of upland base-poor lakes in Ireland, although it also occurs at base-rich sites (Tully *et al.* 1991, Savage 1994, Nelson 1995). Macan (1965c) states that it is generally associated with shallow water, although, others claim *S. scotti* is a species of deep open water (Macan 1976, 1965a, 1973, Savage 1989, Tully *et al.* 1991). It is often found over peat and where vegetation is sparse or absent (Macan 1938, 1954, 1965a and b, 1976, Southwood & Leston 1959). Savage (1982) states *S. scotti* is found in water bodies with low conductivity. It appears to be strongly associated with organic matter in the substratum and was found over peat in Killarney (O'Connor *et al.* 1986), in deep peat ponds in N.I. (Nelson 1995) and may replace *S. distincta* in flooded peat cuttings, where organic matter is accumulating but not decomposing (Macan 1954). *S. scotti* has been recorded from lowland bogs such as Roundstone Atlantic blanket bog (Crisp & Heal 1958) and was dominant in the upper lake at Killarney, but its importance decreased with increasing trophic status (O'Connor *et al.* 1986). Popham (1943) noted in experiments that *S. scotti* did not readily take flight.

The presence of organic matter in the substratum appears to be very important to the distribution of *S. scotti*, and the peat sediment was probably largely responsible for the high abundance found in Turraun and Tumduff. It was reasonably abundant at Tumduff and had high percentage abundance in T1 and T5. The average catch per sample, however, was far greater at the densely vegetated station T3. *S. scotti* appeared to be most abundant at sampling stations with shallow water over peat. The presence of vegetation did not

appear to be an important factor, although it was not found in the dense submerged vegetation at T4. Intolerance for eutrophic conditions might explain the decrease in average abundance of *S. scotti* in Turraun in 1997. The species was not severely affected, however, as percentage abundance did not change.

*S. lateralis* is a brackish water species with a coastal distribution in Ireland, although it also occurs in highly eutrophic inland ponds (Macan & MacFadyen 1941, Macan 1954, Nelson 1995). Its presence in Turraun and Tumduff may indicate that the high trophic status is exerting an effect on the fauna, although, its abundance was very low and it may not have been resident. *S. semistriata* is associated with alkaline peat cuttings (Macan 1954). It was found in small lakes and ponds in Northern Ireland, including two flooded quarries and marl lakes (Nelson 1995) and Tully *et al.* (1991) recorded *S. semistriata* from hard water sites in the Corrib catchment. The low abundance of *S. semistriata* in the alkaline cutaway ponds may reflect a low regional abundance of the species.

The corixid fauna at Turraun, indeed the entire heteropteran fauna, contained species found previously in many different ecological situations; lakes and ponds, vegetated and unvegetated habitats, upland, acidic, oligotrophic waterbodies and lowland, base-rich, productive lakes. This may indicate that many of the species found, have wider physico-chemical tolerances than previously expected. Species composition may be controlled by other ecological factors, such as colonisation or habitat.

The species composition in Turraun was very similar to that found at Montiagh's Moss, a cutover peatland with a variety of ponds, although it did not support rarer species. The fauna of both wetlands bore resemblance to that of pond sites in Northern Ireland, where *Sigara distincta, Hesperocorixa castanea* and *S. scotti* (over peat), along with *Notonecta glauca* and *Nepa cinerea*, were common (Nelson 1995). The Corixidae fauna at Turraun and Tumduff was also similar to that of the Corrib catchment, where *S. scotti*, *S. distincta* and *S. fossarum* were very abundant (Tully *et al.* 1991). Unlike this catchment *S. fallenoidea* (Hungerford) and *Cymatia bonsdorffii* were not present in the cutaway ponds. The absence of *C. bonsdorffii* from the cutaway wetlands may be owing to the species being slow to migrate as result of the dominance of non-flying forms (Brown 1951, Tully *et al.* 1991). As in Lough Corrib (Tully *et al.* 1991), corixid abundance appeared to be

highest in sheltered areas with fine sediment and a high percentage of vegetation cover (T3 and T4).

The number of species found in the study sites was very high, as was the overall abundance of Corixidae. 21 species of Corixidae were recorded for the Corrib catchment (Tully *et al.* 1991). Macan (1976) recorded 19 species in 21 years in Hodson's Tarn. 15 species of corixid were recorded in a South Dakota lake during a three year study (Applegate & Kieckhefer 1977). Istock (1973) found 14 species of corixid, at least 10 of which were breeding, in a Michigan pond. Only 11 corixids have been recorded from Windermere, which has been extensively sampled (Macan 1973). These were amongst the highest numbers of corixid species found in single waterbodies and Macan (1973) stated that is unusual to find more than eight species in a waterbody. Turraun with 14 species and Tumduff with 13 (both sites including *Hesperocorixa moesta*) had very high numbers of corixid species. Williams (1993) found that the number of species of corixid correlated significantly with the age of mining subsidence ponds, although this pattern did not arise in other macroinvertebrate groups such as Trichoptera. It is possible that the number of species found in Turraun and Tumduff may yet increase.

Macan (1962) noted that corixid species richness is generally related to habitat diversity or instability. The large number of different habitats found in Turraun encouraged high species richness in that lake. The temporal variability of both study wetlands, in terms of fluctuations in surface water level, macrophyte community and sediment type and distribution may create 'gaps', allowing new corixid species to colonise. A dynamic system such as this could support a high diversity of species.

The exact corixid species composition found at Turraun and Tumduff was rarely noted elsewhere and records of numerical dominance of communities by *S. dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* was not found in the literature. Macan (1938) recorded a high abundance of *S. scotti*, some *S. distincta* and some *S. fossarum* in tarns consisting of recently flooded peat. *S. dorsalis* was also present. He noted that *S. distincta*, *S. fossarum* and *S. scotti* were the dominant corixids in areas with diverse and dense vegetation, where silt deposition had led to some decomposition of the peat (Macan 1938). *S. scotti* dominated in areas where the peat had not decomposed and more organic matter may have accumulated (Macan 1938). Species composition and abundance was similar to that found

in some English lakes. S. dorsalis (57%), S. distincta (27%) and S. fossarum (12%) were the most abundant corixids in Windermere, while in Esthwaite, S. dorsalis (29%), S. distincta (32%), S. falleni (27%) and S. fossarum (10%) were dominant (Savage & Pratt 1976). Williams (1993) found a similar species composition to that in the cutaway wetlands in mining subsidence ponds in Northumberland. C. praeusta, S. dorsalis, H. linnaei, H. sahlbergi, S. lateralis, S. distincta, S. falleni, A. germari, S. scotti, S. fossarum and C. panzeri were recorded, but no mention of the relative abundance of the various species is given (Williams 1993). It would appear that the highly organic substratum (peat) along with the diverse and dense vegetation cover favoured the abundance of S. dorsalis, S. distincta, S. fossarum and S. scotti.

The four dominant species at the cutaway wetlands are typically found in permanent, stable habitats, which would suggest that their flight ability and migration rates would be reduced (Brown 1951, Savage 1989) and consequently, that they would be unlikely to be the first to colonise new ponds. Indeed, Brown (1951) found S. distincta, S. falleni and S. fossarum to be poor colonists of the Golding's Wood Pond. Other authors have considered the S. dorsalis, S. distincta, S. fossarum and S. scotti poor at flying (Popham 1943, Fernando 1959, Southwood & Leston 1959, Tully et al. 1991, Williams 1993). Evidence from the seasonal distribution of corixids (see below) and observations in the laboratory, suggest that Sigara dorsalis, S. distincta, S. fossarum and S. scotti were dominated by macropterous morphs here. The success of these four species must be owing to a combination of the regional distribution of Corixidae, prevailing winds, the migration ability of these species and their ability to adapt to and exploit the peculiar conditions in the cutaway wetlands. Williams (1993) suggested there is a strong element of chance controlling the corixid population of new water bodies and this is probably also a factor here. In Chapters 7 and 8 the hypotheses that food and habitat associations contributed to the dominance by Sigara dorsalis, S. distincta, S. fossarum and S. scotti in Turraun and Tumduff are investigated.

As indicated above, the number of corixid species found in Turraun and Tumduff was very high. Corixid abundance was also very high. Between January 1997 and February 1998 corixids comprised 34% of the macroinvertebrate population of Turraun and 12% of Tumduff. Macan (1938) noted that corixids were abundant in tarns with recently flooded, terrestrially formed peat. Diversity and abundance were also found to be high in other

artificial and temporary ponds associated with bog and fen (Tully *et al.* 1991, Nelson 1995). It may be that the high abundance of corixids in Turraun and Tumduff is related to a natural tendency for corixid numbers to be high after the creation of a new habitat. Macan (1962) indicated that instability led to great abundance and diversity of corixids in a reservoir. Variations in water level, sediment movements and macrophyte succession may have encouraged high corixid abundance in Turraun and Tumduff.

Popham (1943) noted that corixid numbers varied considerably between and within habitats. He concluded that the highest corixid numbers were found in ponds that were not surrounded by trees or buildings, that were found in the middle of a field or near the summit of a hill, that had little vegetation and had fine sediment. Williams (1993) also suggested that large open areas of water are colonised by corixids more quickly than small ones. Macan (1962) disputed that visibility from the air influenced corixid numbers, stating tarns surrounded by trees did not appear to have fewer corixids than open tarns. He suggested that some water-bodies become more densely populated with corixids because there are more corixids flying over the area. The density of corixids on the wing over a waterbody may be related to the number of aquatic habitats in the area (Macan 1962).

The study sites complied with most of Popham's (1943) conditions for high corixid densities. Both ponds were situated in flat open countryside, and would not have been obscured from the air by trees or buildings, both had reasonably large surface areas to attract corixids from the air and both had fine sediment. While vegetation was diverse, and in places dense, in Turraun, there were also large areas of open water. An abundance of corixids in the Irish midlands may also have influenced corixid numbers in Turraun and Tumduff. It seems that both wetlands had the potential to attract large numbers of corixids. Whether the wetlands were capable of supporting such high corixid numbers will be discussed later. The greater abundance of corixids in Turraun that Tumduff may be related to the surface area of the water bodies. It is also possible that there are more corixids in the air over Turraun than over Tumduff or that corixid abundance was related to the wetland.

Popham (1943) found that species that do not readily take to the wing, such as *S. distincta*, *S. fossarum* and *S. scotti*, are usually present in large numbers in habitats in which they occur. It is possible that once these species had colonised Turraun and Tumduff they

rapidly increased in abundance. However, it is argued below that these species regularly migrated into and out of the study sites.

Factors such as vegetation distribution, the nature of the substratum and water depth have been shown to influence corixid distribution (Scudder 1976, Savage 1989). As stated earlier, spatial variability was probably important to the success of corixids in Turraun and Tumduff, generating high diversity and abundance (Macan 1962). These factors may have encouraged the overall abundance of corixids in the study sites, and may have particularly favoured the four dominant species. Variations between sampling stations in terms of texture and type of sediment, cover and diversity of macrophytes, and probably also abundance of food may explain differences in corixid abundance between sampling stations. The greater habitat variability at Turraun may explain why corixid abundance was far greater at Turraun than Tumduff. There may also have been a greater availability of food at Turraun.

Diversity and abundance may also be linked to the low abundance of invertebrate and vertebrate predators and parasites. Fish are amongst the most important predators of Corixidae (Savage 1989) and can have a profound effect on corixid populations, in terms of numbers, distribution and species composition (Macan 1965b, Scudder 1976, Savage 1989). Fish predation has been shown to restrict the range of corixids within waterbodies and hence, to reduce corixid abundance (Savage 1989). The near absence of fish from Turraun and Tumduff may have allowed the high abundance of corixids and their seemingly ubiquitous distribution. Corixids were not found in stickleback gut contents in Turraun (Ger O'Brien personal communication), although, these fish may feed on corixid nymphs. Birds have also been reported to feed on corixids (Miller 1971) and water birds were often abundant at the wetlands. These may have been important predators of corixids at certain times of the year.

Other Heteroptera, such as Notonectidae are also very important predators of corixids. Egg cannibalism has been observed in Corixidae (Scudder 1976, Savage 1989, Pajunen & Pajunen 1991) and inter- and intra-specific predation on nymphs has been demonstrated (Pajunen & Pajunen 1992). Savage (1989) recorded *Gammarus tigrinus* Sexton feeding on *Sigara dorsalis*, *S. falleni* and *S. lateralis* nymphs. Nymphal and adult water mites feed on corixid eggs (Davids *et al.* 1978, Scudder 1983, Savage 1989) and Davids *et al.* (1978)

found that a mite consumed around 4.5 corixid eggs per day or 200 eggs over a season. While invertebrate predators, such as *Notonecta* and mites, were present in the study sites their abundance was very low relative to that of corixids and they were unlikely to have had a large effect on corixid abundance. Cannibalism may have taken place; however, as this it thought to supply energy or essential nutrients to reproducing female corixids, particularly where there is a food shortage (Pajunen & Pajunen 1991), it may have been of advantage to corixids.

One final factor, migration, may have been very important for the abundance of corixids in Turraun and Tumduff. Migration will be dealt with below in the discussion of temporal variations. The hypotheses that species abundance is influenced by corixid availability in local water bodies, low parasitism and feeding and habitat preferences are examined further in Chapters 6, 7 and 8.

The life cycle of Corixidae consists of an egg stage, five nymphal instars and the adult instar (Savage 1989). Species in the tropics breed all year round (Scudder 1976), however, the annual cycle generally consists of one generation in Britain and Ireland (Savage 1989). Maturation in corixids is induced by increasing day length (Pajunen 1977) and the ovaries develop between February and March (Savage 1989). In April-May, corixids aggregate near the shore and stridulate before pairing off (Savage 1989). Corixidae generally oviposit between April and August (Davids & Schoots 1975, Davids *et al.* 1978, Savage 1989). Most corixids attach their eggs directly to a fixed under water surface, such as stones or plants and the exact oviposition site may be species specific (Savage 1989).

An individual corixid can lay anywhere between ten and 1,000 eggs over an oviposition season (Savage 1989). Female *Sigara striata* produced a mean of 140 eggs over a season in the Netherlands (Davids *et al.* 1978), while *Arctocorisa carinata* (Sahlberg) and *Callicorixa producta* (Reuter) had oviposition rates of 8-9 eggs per female per day in Finland (Pajunen & Pajunen 1991). The rates of development of eggs and nymphs appear to be related to temperature (Scudder 1976, Davids *et al.* 1978, Savage 1989). Corixid nymphs typically appear in May/June and may be present up until September (Macan 1965a, Savage 1971a, 1989). Adults generally first appear in June and numbers reach a maximum in autumn (Savage 1989). There is some suggestion that British corixids can be bivoltine, but the second generation may be incomplete (Savage 1989).

Adult corixids were found all year round at both wetlands and the seasonal patterns were similar to those in other studies. Corixid numbers were low from April to August owing to the midsummer die back of adults. Few corixid nymphs appeared before June in either Turraun or Tumduff. Nymph abundance reflected the pattern reported by Macan (1965a) with peaks in June, July and August. It is possible that the earliest nymphal instars were not collected because they may have been distributed outside the littoral zone. The first two instars do not need to surface for air as they absorb dissolved oxygen through the integument (Scudder 1976, Savage 1989) and could be found the bottom of a water body.

Nelson (1995) stated that adults were inactive in winter and consequently more difficult to catch and Macan (1965a) stated that corixid numbers decline through the winter. Adult abundance did decrease at Tumduff after September where the animals may have become inactive owing to low food availability. This phenomenon was not obvious in Turraun, however, where Corixidae numbers were highest in late November 1997. High winter activity may have been linked to high water temperatures (8-10 °C, see Sections 3.3.1 and 3.4.1, Chapter 3). The November peak in abundance is slightly late for corixids, as numbers usually reach a distinct maximum in autumn (Savage 1989) and may be related to migration (see below).

Invasions have always been a hazard to researchers attempting to categorise the corixid fauna of a water body (Macan 1976). Macan (1962) suggests that all water-bodies are invaded by many species. The very large fluctuations seen in average catch per sample of all corixids (Figure 5.1) and of *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* (Figure 5.2) may be owing to migration (see also Tables 5.5 and 5.6).

Corixids disperse by flight (Scudder 1976), and wing muscles must reach a certain temperature before they can fly (Popham 1964). Consequently, migrations take place during anticyclonic weather (warm sunny days when the wind is less than force 2) (Fernando 1959, Popham 1964, Savage 1989). Two main dispersal periods are found in temperate regions, one in spring (April to early June), where overwintered adults disperse and one in late summer and autumn (August-September), where new generation adults disperse (Fernando 1959, Popham 1964, Macan 1973, Scudder 1976). Corixids, however, are capable of migrating at any time of the year, when conditions are correct (Macan

1973). During the spring migration, corixids often move to permanent water bodies to lay eggs (Popham 1964).

Before emigrating, corixids accumulate in the hotter water near the shore and surface frequently (Popham 1964, Savage 1989). Migration generally takes place in the afternoon (Fernando 1959, Popham 1964) allowing minimum temperatures for flight to be reached. Corixids generally migrate when a minimum air temperature of 12-18 °C has been exceeded (Popham 1964). Most corixid species are thought capable of surviving in the air for 2-3.5 hours (Scudder 1976) and may be able to travel 50-90 km per day (Popham 1964, Scudder 1976). Corixids that rise a few hundred feet can be carried much greater distances by upper atmosphere winds (Popham 1964). The direction of flight may be determined through the eyes, although wind may be the ultimate determinant (Popham 1964). Corixids are attracted to reflective surfaces and have been found on car tops, wet tar, greenhouses, wet streets etc. (Popham 1964, Scudder 1976, Savage 1989).

Although migration is controlled by climate, it may also be initiated by high population density and disappearance of habitat (Brown 1951, Popham 1964). Popham (1943) noted that corixids that did not harmonise with their background became restless and tended to migrate. Popham (1964) also suggested that migration could be instigated by lack of food. The ability to disperse may be an adaptation to temporary habitats (Scudder 1976) and migration rate increases exponentially in relation to habitat instability (Savage 1989). Corixids may migrate from temporary to permanent waters to reproduce as eggs and nymphs are confined to water, and teneral corixids may migrate to temporary habitats to overwinter.

Other authors have recorded migrations having large effect on corixid abundance. Popham (1943) noted that open air swimming baths become infested with corixids and that their abundance is mainly owing to migration. Macan (1962, 1973) described a concrete reservoir infested with corixids in which the most abundant corixid species was different on each sampling occasion, December 1938 and January, April and May 1939. Sixteen corixid species were taken in total and it was suggested that the reservoir attracted corixids to emigrate again (Macan 1962, 1973). Macan (1976) noted that numbers of *S. distincta* increased dramatically in Hodson's Tarn in 1969 and attributed this to a spring invasion.

Applegate & Kieckhefer (1977) found that migrant species made up 39% of the mean standing crop of corixids in Lake Poinsett. Immigration and emigration led to variations in population dynamics in a saline lake, as environmental conditions changed (Savage 1989). It has been suggested that where an established corixid population exists, immigrating species have difficulty establishing themselves and quickly leave (Macan 1962, 1973).

In Turraun and Tumduff, corixid migration did appear to occur during the spring and autumn anticyclonic periods, influencing the patterns in corixid abundance and contributing to the high overall abundance of corixids in the wetlands. *Sigara dorsalis* appeared to immigrate to Turraun during February or March generating a peak in abundance in March, but rapidly emigrated again in late March or April. It is also possible that high numbers in March 1997 represented the aggregation of adults in preparation for mating (Macan 1976, Savage 1989). This seems unlikely, as abundance was very low in April and as corixids also congregate near the shoreline in order to migrate (Fernando 1959, Popham 1964, Savage 1989).

S. distincta appeared to immigrate to Turraun in late February or March and again in late September or November, and into Tumduff in August/September. Again, the spring immigration seems to have been followed by an immediate emigration, while the immigrants from September and November may also have emigrated over winter, though it is more likely that they failed to survive the tough winter conditions. Like S. distincta, S. fossarum immigrated to Turraun in November and Tumduff in September. S. fossarum was observed swarming in the shallowest water at T3 in late 1997 and may have been aggregating in preparation for migration. S. scotti also appeared to immigrate to Turraun in March and emigrate in April.

These relatively large water bodies, lying in an open landscape would easily have attracted corixids from the air. While there are no large lakes in the region, there is an abundance of smaller water bodies, including small natural lakes (e.g. Pallas Lake and Fin Lough), the Grand Canal, the Boora River, drains and ponds on cutover and upland pools in the Slieve Bloom mountains. The river Shannon also lies c. 20 km west of the study sites. Corixids could potentially migrate to the study sites from this wide regional source of water bodies.

The most likely reason for emigration from the study sites was high corixid density or overcrowding. During monthly sorting in the laboratory, corixids readily took flight from the trays, especially on warm, bright days when corixids were densely packed. Other factors that could have initiated emigration from Turraun and Tumduff included changes in physico-chemical conditions, food shortages, reproduction or habitat changes. Sládeček & Sládečeková (1994) indicated high productivity was unlikely to negatively affect adult corixids as they respire atmospheric oxygen, have a protective chitinous cuticle and can migrate. Scudder (1976) suggested that food shortage was unlikely to affect corixid distribution.

Temperature was potentially an important factor in migration. Popham (1943) found that ponds at temperatures around 25 °C were devoid of corixids. Corixids were found in the study sites during July and August when water temperatures were above 25 °C, although, high summer water temperatures may have initiated corixid migrations. Pajunen & Sundbäck (1973) stated that short exposure to high temperatures can accelerate development in invertebrates or alternatively cause damage and retardation of development, and found that the rate of development of corixids increased with temperature up to certain critical values after which it was retarded. It is possible that high summer water temperatures in Turraun and Tumduff reduced corixid productivity, through damage to reproducing adults or destruction of eggs and nymphs. Pajunen (1975) showed that populations of Arctocorisa carinata in rock pools had a wider temperature tolerance than the same species from other water bodies and the corixid population in the study sites may have been adapted to high water temperatures. Fernando (1959) stated that S. dorsalis is relatively insensitive to high temperatures. The optimal range of temperature for S. distincta is 25-30 °C, although in nature it avoids temperatures of greater than 25 °C (Southwood & Leston 1959). It is possible that the more abundant species in the cutaway ponds owe their success to an ability to survive a wide range of temperatures.

Temporal changes at individual sampling stations, provide more evidence for possible immigration to and emigration from Turraun and Tumduff. All four species were abundant at T1 in March 1997 suggesting that immigrating species arrived at the open part of the western shore. All species, except *S. scotti*, were also abundant at T2, which is adjacent to T1, in March. Alternatively the high March catch may have been an aggregation of corixids on the exposed, gently sloping shore in preparation for emigration. March

immigrations and/or emigrations of *Sigara dorsalis* may also have taken place from T3, T4 and T5 and of *S. scotti* from T3, T4 and T5. Internal movements of corixids within Turraun did not appear to contribute to seasonal differences in abundance among sampling stations. This will be discussed further in Chapter 6, in terms of corixid length distribution.

Corixids, particularly *S. distincta* and *S. fossarum* were abundant at T5 in September, and appeared to immigrate to this station at this time, although, the abundance was not maintained and some corixids may have migrated again. The drop in corixid abundance at T4 in October could have been caused by emigration following September immigration. *S. dorsalis* and *S. distincta* also appeared to immigrate to Tumduff in September. Corixids appeared to immigrate to T4 again in November. The October low may alternatively be a result of the sudden rise in surface water level between September and October.

The location at which corixids immigrated to the wetlands was probably influenced by wind direction. Easterly winds may have led to immigration to T4 and T5 on the east of Turraun, while westerly winds may have led to immigration to T1, T2 and T3. Strong winds may also have influenced the distribution of species within the wetlands, and weakened or dying *S. fossarum* and *S. scotti* adults may have been blown to T1 and T2 in June 1997, generating the high average catch at these stations in this month.

Popham (1964) found that wave disturbance caused corixids to move to the bottom at the centre of a small pond and in the winter months corixids may have been distributed away from the shore to avoid waves. Redistribution of corixids may have been in part responsible for the decrease in corixids abundance in winter. Wave disturbance may explain the low abundance or absence of *S. distincta* from T1 between September and November 1997 and from T2 and T3 in September. During these months *S. distincta* was reasonably abundant in T4 and T5. *S. dorsalis* abundance was low at T1 and T2 from September to February and at T3 in September, and *S. fossarum* abundance was low at T1, T2 and T3 in September. T1 and T2 were the most exposed sampling station and T1, T2 and T3 lay on the western side of the wetland where they were exposed to winter easterly winds.

The temporal variations in average catch at the eight sampling stations also gives some insight into corixid habitat preferences/associations. The low numbers of corixids at T1 in

September, October and November 1997, when abundance was very high elsewhere, indicates that the habitat was essentially unsuitable for corixids. Corixid abundance was low in September at T3 relative to other sampling stations. This may have been owing to low water levels at the station. Few specimens of *S. scotti* were found anywhere but T3 in October. This was possibly linked to the availability of food at the station in this month. The reduction in corixid numbers at T5 after September may indicate that they suffered high mortality and that the station did not have sufficient food and shelter for the winter months. The abundance of all species was low at B7 in October and some species showed a drop in numbers at B6 and B8 in that month. This may be linked to the rise in surface water level between September and October leading to displacement and migrations in corixids.

It is clear from Figures 5.1 and 5.3 and Table 5.2 that the average corixid catch per sample decreased over time in Turraun. Istock (1973) demonstrated that the overall abundance of corixids remained the same over four years in a stable pond, but varied at the individual sampling stations. Corixid abundance at Turraun and Tumduff varied both among sampling station and over time, reflecting the high spatial variation and temporal instability. The decrease in corixid numbers in 1998 and 1999 is probably a product of artificially high values produced by immigrations in 1997. Macan & MacFadyen (1941) stated that the abundance of corixids decreases with increasing vegetation density in dewponds and increasing macrophyte cover may have been responsible for the drop in corixid number in Turraun in 1998 and 1999. The decrease in corixid abundance over time may also have been linked to egg predation by mites or egg cannibalism by corixids. It is believed that the intensity of egg cannibalism increases with increased density of adults and reduced availability of adult food, and may be a mechanism for population regulation (Scudder 1976).

Istock (1973) indicated that corixid species were not constant from year to year in a North Michigan pond and over a four year study, four species declined while two increased. Macan (1973, 1976), however, stated that the corixid species composition of a waterbody does not generally change much with time and indeed, species composition did not appear to alter in either Turraun or Tumduff. *S. dorsalis, S. falleni* and *Corixa panzeri* did decrease in relative abundance in 1998 and 1999. Further sampling is necessary to determine if these species are declining in terms of absolute abundance and if any decrease

will be sustained over time. The fact that the percentage composition of *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* changed little over time, suggests that biotic or abiotic factors may have favoured these species. *S. fossarum* appeared to be the most successful corixid in the cutaway ponds and may have out competed other species.

Fin Lough and Pallas Lake, which lie about 25 km apart, had very similar Corixidae species compositions. This is unsurprising as both are shallow, alkaline lakes with extensive reed-beds and the species found, especially *Callicorixa praeusta*, *Sigara distincta* and *S. falleni*, are typical of small, lowland lakes (Nelson 1995). The full corixid fauna could not have been recorded on just one sampling visit and other species that may occur in these calcareous lakes include *S. fallenoidea* (Nelson 1995).

All species found in the two natural lakes, with the exception of *Cymatia bonsdorffii*, were also recorded in Turraun and Tumduff. The absence of *Cymatia bonsdorffii* from Turraun and Tumduff is most likely because it is a brachypterous species and consequently does not migrate (Popham 1943, Brown, 1951, Tully *et al.* 1991). Of the dominant species in the cutaway wetlands two, *Sigara distincta* and *S. fossarum*, were present in both natural lakes. It seems likely that the corixids found in all four waterbodies were members of the same regional population and migrations may have occurred between them.

The limited data suggests the Corixidae faunas of Fin Lough and Pallas Lake were less diverse than those of Turraun and Tumduff. Although this cannot be confirmed on the basis of just one visit to Fin Lough and Pallas Lake, it is in keeping with the findings of Nelson (1995) and Tully *et al.* (1991), who both showed that artificial and temporary ponds had the greatest heteropteran species richness.

Causes for the high corixid species richness and abundance, along with reasons for the species composition are investigated in Chapters 6, 7 and 8. A summary discussion is given at the end of Section C.

Chapter 6

# SEX RATIOS, LENGTH DISTRIBUTIONS & PARASITISM OF CORIXIDAE AT TURRAUN & TUMDUFF

## 6.1 Introduction

Male corixids can be readily distinguished from female and are more easily identified. The sexes differ in a number of respects. The male frons is flat or concave, whereas it is convex in females, the terminal abdominal segments are asymmetric in males and symmetric in females and male palae are flattened with specialised pegs (Scudder 1976, Savage 1989). The shape of the pala and the number and arrangement of pegs provide important diagnostic characteristics (Savage 1989). Male corixids also have a mushroomshaped structure on the sixth abdominal tergite, known as a strigil, which can also be used in identification (Popham *et al.* 1984a). The strigil is involved in replenishing air supply during copulation (Popham *et al.* 1984a). Thus, sexual dimorphism has been documented in corixids.

Little comment, however, is made in the literature on sex ratios in corixid populations. Pajunen & Jansson (1969) investigated sex ratios in rock pool corixids and found that they varied over the seasons. Applegate & Kieckhefer (1977) made note of the sex ratios in *Palmacorixa buenoi* Abbott and *Trichocorixa borealis* Sailer during a study of corixid life cycles in South Dakota. Owing to the paucity of sex ratio data in the literature, it was decided to record the sex of each adult corixid identified. It was envisaged that these data would make a significant contribution to the knowledge of overall and seasonal changes in sex ratios of *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti*.

Savage (1989) reports a range of sizes for British corixids. Size differences may exist between sexes as females are heavier than males of the same species (Pajunen 1977). Corixid lengths can also vary between locations. Pajunen & Sundbäck (1973) found that high temperatures lead to smaller corixids and Pajunen (1977) found nymph size decreased with increased density. Pajunen (1977, 1979) also suggested lack of food leads to smaller nymphs. Therefore, length data gives an insight to corixid sexual dimorphism and ecology.

Corixidae act as host to a number of parasites. Endoparasitic Nematoda have been found and appear to cause castration of the female corixids (Crisp 1959, Davids & Schoots 1975). Endoparasitic protozoans have also been reported, while cestode cysts, epiphytic algae and protozoan colonies are sometimes found externally (Scudder 1976). Larval water mites are the most important ectoparasites of corixids (Scudder 1976, Savage 1989). Crisp (1959) claimed that all ectoparasitic mites identified from corixids belonged to the genus *Hydrachna*, although, Scudder (1983) reports that larval *Eylais* parasitised *Cenocorixa bifida hungerfordi* Lansbury and *C. expleta* (Uhler) in Western Canada. Davids & Schoots (1975) reported that *Hydrachna conjecta* Koenike and *H. cruenta* Müller larvae parasitise *Sigara* spp. in the Netherlands.

Parasitism by larval mites appears to reduce fecundity (Crisp 1959, Davids & Schoots 1975, Scudder 1983) and life expectancy in female corixids (Davids & Schoots 1975). Savage (1989) stated that parasitism may be an important factor in the ecology of water bugs. Many years of study by G.G.E. Scudder and his students into the physiology and ecology of *Cenocorixa bifida* and *C. expleta* revealed that their distribution was in part controlled by parasitic Hydracarina (Scudder 1983). The number of larval mites was recorded in order to establish the relative susceptibility of corixid species to these parasites. The possibility that mite parasitism influenced corixid species distribution and overall abundance was considered.

Mites can affect corixids by methods other than parasitism. Nymphal and adult water mites feed on corixid eggs (Davids *et al.* 1978, Scudder 1983, Savage 1989). Davids *et al.* (1978) found that a mite consumed around 4.5 corixid eggs per day or 200 eggs over a season. Data on temporal variations in abundance of free-living mite stages was given in Section 4.3.2.7, Chapter 4.

The overall sex ratio in the four dominant corixid species, *Sigara dorsalis, S. distincta, S. fossarum and S. scotti*, was examined along with seasonal changes in sex ratio. The length of male and female *Sigara dorsalis, S. distincta, S. fossarum and S. scotti* at Turraun and Tumduff was measured to examine if there is a significant difference in size between the sexes. The length of the various species at the two wetlands and different sampling stations was also compared to investigate if some habitats are more favourable to corixid growth than others. Turraun and Tumduff corixids were examined for larval mite parasites to explore whether parasitism explains corixid abundance or distribution in the wetlands.

## 6.2 Materials and Methods

#### 6.2.1 Sampling and laboratory analysis

The study sites, Turraun and Tumduff wetlands were sampled for Corixidae on a total of 16 occasions each between 1997 and 1999. Both wetlands were sampled almost monthly between January 1997 and February 1998, and less frequently after that. The sampling dates are detailed in Section 5.2, Chapter 5. Five replicate samples were taken from the eight sampling stations on each date (see Section 4.2.2.2, Chapter 4 for details). Samples were returned live to the laboratory in plastic bags, before being sorted and transferred to alcohol filled storage jars (see also Section 4.2.2.3).

The animals were subsequently identified under a dissection microscope, using the FBA key to aquatic Heteroptera (Savage 1989). As each individual corixid was identified, it was also sexed and measured. Total length was measured from the top of the head (frons) to the posterior tip of the hemielytra using a microscope graticule. Measurements were accurate to  $\pm 0.1$  mm. Presence and location of parasitic Hydracarina on corixids was also noted.

### 6.2.2 Data processing and statistical analysis

Species, sex, length and parasite data were saved as a Microsoft Excel 97<sup>®</sup> Worksheet. Length frequency histograms and summary statistics were generated for both sexes of each corixid species in each wetland on Data Desk 6.0<sup>®</sup>. Pooled t-tests were used to compare wetland means and one-way ANOVA used to test between sampling station differences.

## 6.3 Results

#### 6.3.1 Comparison of sex ratios at Turraun and Tumduff

The proportion of male to female specimens captured varied between species. Female *Sigara dorsalis* were more abundant than male over the entire sampling period (January 1997 to April 1999) (See Table 6.1). *S. fossarum* numbers were relatively even and there were more male *S. scotti* than female. There were more male than female specimens of *S. distincta* at Tumduff and the situation was reversed at Turraun.

Table 6.1Sex ratio of the four most abundant Corixidae species at Turraun and<br/>Tumduff. The total number of male (♂) and female (♀) specimens is also<br/>given. Values are calculated on the basis of animals captured between January<br/>1997 and April 1999.

		Turraun			Tumduff	
species	3	Ŷ	3:9	3	9	3:2
Sigara dorsalis	363	611	1:1.68	250	344	1:1.38
Sigara distincta	1616	1820	1:1.13	226	147	1:0.65
Sigara fossarum	3665	3312	1:0.90	155	169	1:1.09
Sigara scotti	752	677	1:0.90	111	79	1:0.71

Females appeared to be more abundant than males in the early months of the year (Figures 6.1 and 6.2). This was very noticeable in March 1997 for *S. dorsalis*, *S. distincta* and *S. fossarum*. There is also a suggestion that females were more abundant than males in June/July and that males were more abundant than females in September/October.

Males were far more abundant than females in April for *S. dorsalis, S. fossarum* and *S. scotti* in Turraun (Figure 6.1), although, numbers were low in this month. *S. dorsalis* numbers were also low for July, August and September 1997 and for all of 1998.

The seasonal patterns were somewhat irregular at Tumduff (Figure 6.2) and it must be noted that numbers were generally low at Tumduff.

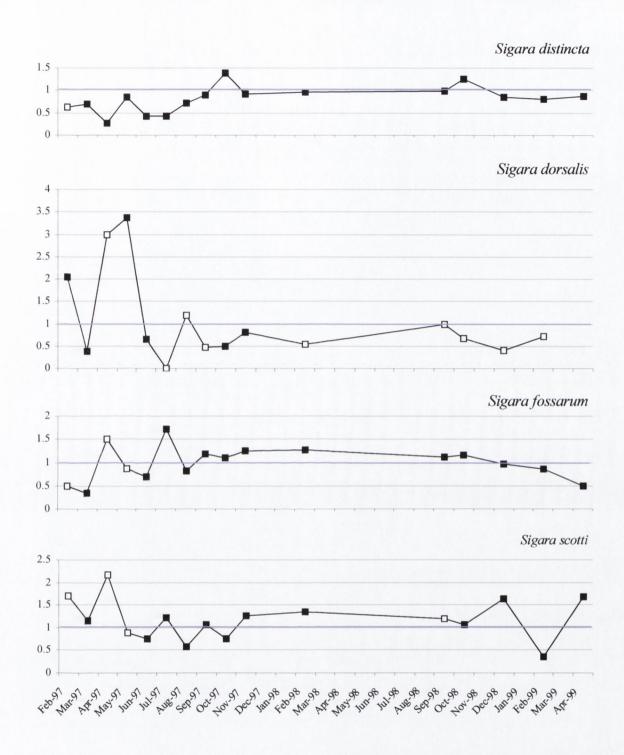
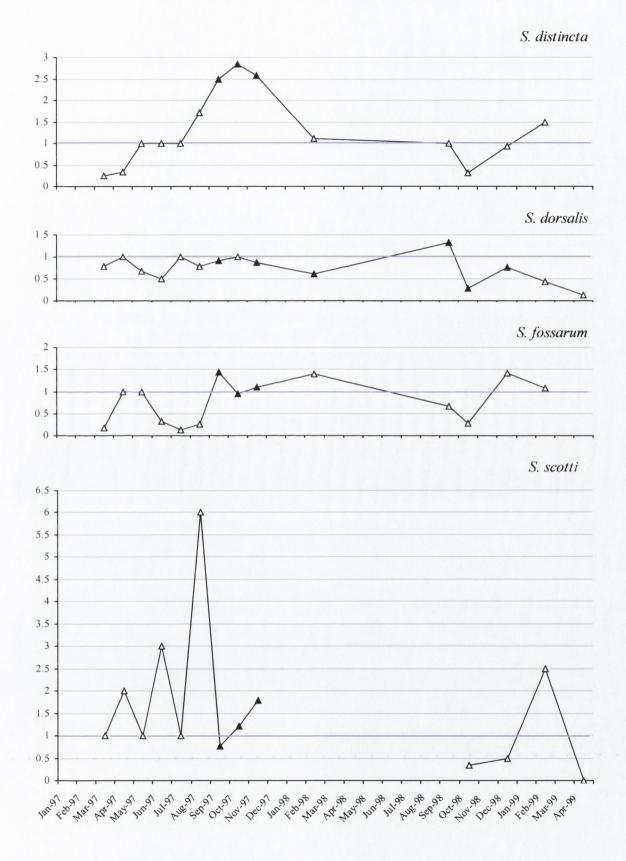


Figure 6.1 Seasonal sex ratios (proportion of males to females) in Corixidae at Turraun. >1, males were more abundant than females. Unfilled squares indicate months in which n was <30.



**Figure 6.2 Seasonal sex ratios in Corixidae at Tumduff.** >1, males were more abundant than females. Unfilled triangles indicate months in which n was <30.

# 6.3.2 Comparison of length at Turraun and Tumduff

A total of 13,868 individual corixids (including nymphs) were captured in 385 samples at Turraun and 2,147 in 240 samples at Tumduff between January 1997 and April 1999. Only adults of the four most abundant, breeding species, *Sigara dorsalis, Sigara distincta, Sigara fossarum* and *Sigara scotti*, were numerous enough to allow comparison of body length between wetlands. The sexes of each species were separated for Turraun and Tumduff and length frequency histograms constructed for each population. These along with summary statistics (mean and median, skewness and kurtosis) indicated that all populations, with the exception of female *Sigara distincta* at Tumduff, were normally distributed. On examination of the latter data two outliers were discovered; when these were removed, a normal distribution was produced.

Summary statistics were computed for each sex of the four species in both wetlands (see Table 6.2). The greatest ranges in length were found in *S. dorsalis* (e.g. males at Turraun, 2.5 mm) and *S. distincta* (e.g. males at Turraun 2.7 mm). The ranges for the *S. fossarum* and *S. scotti* populations were generally smaller (e.g. 1.1 mm for female *S. fossarum* at Tumduff and 1.2 mm for male *S. scotti* at both wetlands). Standard deviations varied between 0.15 and 0.4 mm.

Table 6.2 Average lengths of the four most abundant corixid species in	Turraun
and Tumduff, between January 1997 and April 1999. $\vec{C}$ = adv	lt males,
Q = adult females. Lengths are given in millimetres.	

T-11 ( ) A

species	wetland	sex	n	mean	s.d.	min.	max.
Sigara dorsalis	Turraun	3	363	6.7	0.37	5.4	7.9
	Turraun		611	6.6	0.37	5.4	7.7
	Tumduff	07 FD	250	7.2	0.35	6.0	8.3
	Tumduff	Ŷ	344	7.2	0.37	6.2	8.5
Sigara distincta	Turraun	3	1616	7.1	0.27	5.5	8.2
	Turraun	9	1820	7.4	0.35	6.1	8.7
	Tumduff	07+00	226	7.5	0.25	6.5	8.1
	Tumduff	9	147	7.8	0.37	6.4	8.6
Sigara fossarum	Turraun	3	3665	5.7	0.19	5.0	6.9
0	Turraun	Ŷ	3312	5.9	0.23	5.0	7.2
	Tumduff	0440	155	5.9	0.18	5.1	6.4
	Tumduff	9	169	6.1	0.24	5.5	6.6
Sigara scotti	Turraun	3	752	5.0	0.21	4.5	5.7
	Turraun	Ŷ	677	5.3	0.25	4.7	6.2
	Tumduff	07 40	111	5.3	0.21	4.7	5.9
	Tumduff	Ŷ	79	5.6	0.24	5.0	6.3

With the exception of *Sigara dorsalis* at Tumduff, females were found to be significantly larger than males in both wetlands (Pooled t-tests,  $\alpha = 0.001$ ;  $p \le 0.0001$ ). Pooled t-tests were also computed on each sex of like species between wetlands. All four species were found to be significantly larger in Tumduff than in Turraun (Table 6.3).

Table 6.3Results of pooled t-tests for difference in corixid body<br/>length between Turraun and Tumduff. In all cases  $\alpha$ <br/>= 0.001. t = test statistic; d.f. = degrees of freedom.  $\Diamond$ <br/>= males,  $\heartsuit$  = females.

species	sex	t	d.f.	р
Sigara dorsalis	8	17.56	611	≤ 0.0001
	9	23.77	953	$\leq 0.0001$
Sigara distincta	3	18.06	1834	$\leq 0.0001$
	9	14.99	1965	$\leq 0.0001$
Sigara fossarum	3	11.77	3818	$\leq 0.0001$
0	9	8.32	3479	$\leq 0.0001$
Sigara scotti	3	11.83	861	$\leq 0.0001$
	9	8.83	754	≤ 0.0001

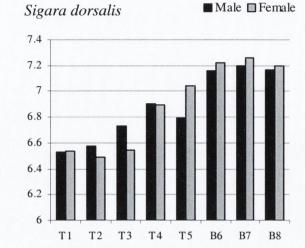
ANOVAs were run on the length data for the eight sampling stations. Results were significant for each sex of all four species and are presented in Table 6.4. LSD post-hoc tests showed that for most groups, corixids from the Tumduff stations were significantly larger than those from all Turraun stations.

# Table 6.4Results of ANOVA for difference in corixid body<br/>length between the eight sampling stations. $\mathcal{J} =$ <br/>males, $\mathcal{Q} =$ females.

species	sex	test statistic	probability	
Sigara dorsalis	3	$F_{7,699} = 52.22$	≤ 0.0001	
	9	$F_{7,853} = 101.03$	$\leq 0.0001$	
Sigara distincta	3	$F_{7,1828} = 70.64$	$\leq 0.0001$	
	9	$F_{7,1961} = 49.69$	$\leq 0.0001$	
Sigara fossarum	3	$F_{7,3826} = 162.69$	$\leq 0.0001$	
	9	$F_{7,3459} = 52.99$	$\leq 0.0001$	
Sigara scotti	3	$F_{7,823} = 93.96$	$\leq 0.0001$	
	9	$F_{7,780} = 9.51$	$\leq 0.0001$	

Corixids, with the exception of *Sigara scotti*, were longer at the Tumduff stations than at all Turraun stations. The lengths of corixids at the three Tumduff stations (B6, B7 and B8) did not vary significantly. The average length of corixids at each sampling station are illustrated in Figure 6.3 and significant differences as indicated by LSD post hoc tests are given in Table 6.5.

8 7.8 7.6 7.4 7.2 7 6.8 6.6 6.4 6.2 **T**1 T2 **T**3 **T4 T5 B6 B7 B8** 



**B6** 

**B7** 

**B**8

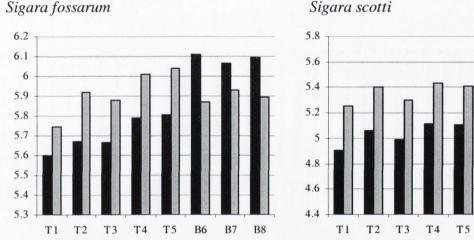


Figure 6.3 Average length of Corixidae at each of the eight sampling station.

Male and female S. scotti at T4 (the diverse station over marl) and T5 (the station adjacent T4, with mixed peat and Carex) were longer than those at most other stations (including those at Tumduff). Corixids at T4 and T5 were generally larger than corixids at T1, T2 and T3. Corixid lengths at T2 (the Typha stand with gravel-like peat) and T3 (the station with diverse vegetation and fine peat sediment and abundant macroinvertebrates) were generally similar. The smallest corixids, for each sex of each species, were generally found at T1 (the sampling station with no vegetation over compacted peat) than elsewhere.

Some stations have been omitted for certain groups in Table 6.5, as they do not fit the general pattern. Male Sigara dorsalis from T5 did not differ significantly from T4 or T3 males. Male S. distincta at T5 were not significantly different to those at T4 or T2. T2

Sigara fossarum

Sigara distincta

male *S. scotti* were not significantly different to T4 or T5 animals, and T2 and B8 female *S. scotti* were not significantly different to T4 or T5 animals. It was not possible to test, either statistically or graphically, if the significant relationships in body length among sampling stations and between wetlands were constant over time, owing to the very low abundance of corixids at some stations on many dates.

Table 6.5	Significant relationships in corixid body length between sampling stations,
	based on LSD post-hoc tests.

species	sex	significant relationships
Sigara dorsalis	50 Ot	B8 = B7 = B6 > T4 > T3 > T2 = T1 B8 = B7 = B6 > T5 = T4 > T3 = T2 = T1
Sigara distincta	fo 07	B8 = B7 = B6 > T4 > T3 = T2 > T1 B8 = B7 = B6 > T5 = T4 > T3 = T2 = T1
Sigara fossarum	~0 O+	B8 = B7 = B6 > T5 = T4 > T3 = T2 = T1 B8 = B7 = B6 > T5 = T4 > T3 = T2 > T1
Sigara scotti	<b>10</b> 07	T5 = T4 > B8, B7, B6, T3, T1; B8 = B7 = B6 > T3, T2, T1 T5 = T4 > B7, B6, T3, T1; B8 = B7 = B6 > T3, T2, T1

#### 6.3.3 Parasitism

1.24% (172 individuals) of the total corixid catch at Turraun were infected with larval mites. Of these, 149 corixids had only one larval mite attached, 17 had two mites, three had three mites, two had four mites and one had five mites (see Figure 6.4). 88 *S. dorsalis* (9%) were infected, five *Corixa panzeri* (4.9%), 43 *S. scotti* (3%), 19 *S. fossarum* (0.3%), ten *S. distincta* (0.3%) and also seven corixid nymphs (0.8%) (see Figure 6.5). The heaviest parasite loading, therefore, was found in *S. dorsalis*, where 7.9% of females and 11% of males were infected.

Parasitism was heavier at Tumduff than at Turraun, with 8.5% (182 individuals) of corixids having larval mite parasites. 130 corixids had one attached larva, 29 had two larvae, 18 had three larvae, four had four larvae and one had five larvae (Figure 6.4). Again parasite loading was highest in *S. dorsalis* (108 individuals or 18.2%), with 16% of females infected and 21% of males. 64 corixid nymphs (10%) were infected, five *S. distincta* (1.3%) and two *S. fossarum* (0.6%) (see Figure 6.5). Two of the 15 *Callicorixa* 

*praeusta* individuals captured and one of the four *Hesperocorixa castanea* individuals had parasites.

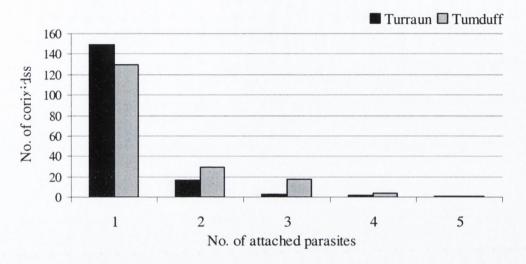
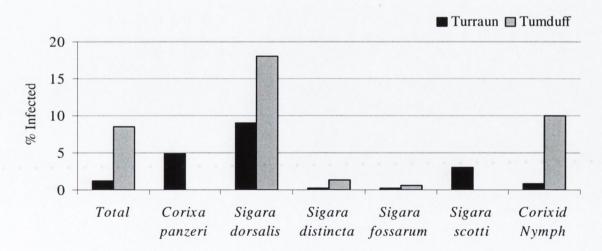


Figure 6.4 The number of parasitic mites per corixid host in Turraun and Tumduff

Parasite loading was highest at sampling station B8 at 13% (78 individuals). Infection was also high at B7 with 6.4% or 54 individuals affected. T2 had more parasites than the other Turraun stations, with 3.7% (31 individuals) infected. The percentage of corixids with parasites was between 0.7 and 1.9% at the remaining stations (Figure 6.6).





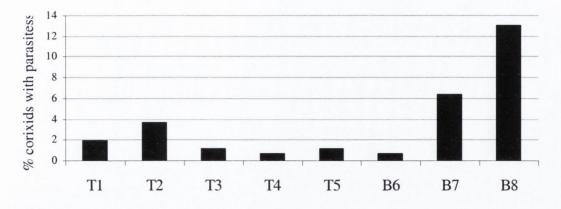


Figure 6.6 The overall percentage of corixids infected with parasitic mites at each sampling station

There were seasonal differences in the level of parasites in both wetlands, with parasites most common between October and March/April in both wetlands (Figure 6.7). The percentage of corixids with parasites was highest in February 1997 at Turraun, and decreased between March and May. It was low at Tumduff at this time, but this may be related to the near absence of corixids. Both wetlands had peaks in parasitism in June 1997, followed by a decrease to September. The percentage of infected animals then increased in autumn/winter. The pattern appeared to be similar in 1998, although the data were not complete. Larval mites appeared to be less common in summer at Turraun than at Tumduff. The highest percentage of corixids with parasites was in December 1998 in Tumduff. Corixids appeared to be more frequently parasitised by more than one mite between June and December.

Larval mites were found on the head near the maxillary plate, on the ventral side of the thorax and abdomen, attached to the underside of the hemielytra, on the pronotum and on the legs (see Appendix 6.3.3). Mites attached to all segments of the legs, including the palae.

In Turraun, 60% of infected corixids had larvae attached to the legs, 21% to the ventral side of the thorax, 18% to the ventral side of the abdomen and 12% to the hemielytra (remember a number of corixids had more than one attached parasite). Turraun corixids also had parasites on the head, pronotum and the wing buds of nymphs (Appendix 6.3.3).

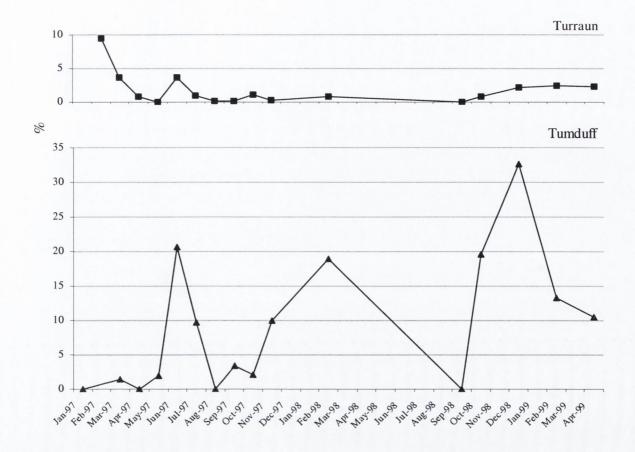


Figure 6.7 Seasonal changes in the percentage of corixids infected by parasitic mites in Turraun and Tumduff

Of the parasites found on corixid legs at Turraun, 46% were attached to the hind legs, 29% were attached to the fore legs and 25% to the mid legs. All segments, except the palae had some attached parasites and parasites were well dispersed around the segments. The tibiae of the forelegs were most heavily infected, having 15% of all leg parasites. The hind limb coxae, trochanters, femurs and tibiae, the mid limb trochanters and femurs and the fore limb coxae each had more than 7% of leg parasites. Appendix 6.3.3 gives the percentage of leg parasites found on each segment.

In Tumduff, 71% of parasitised corixids had larvae attached to the legs, 29% to the ventral side of the thorax, 19% to the ventral side of the abdomen and 6% to the head. The hemielytra, pronotum and wing buds of nymphs had few parasites (Appendix 6.3.3).

As at Turraun, parasites were most abundant on the hind legs of Tumduff corixids, where 72% of all leg parasites were found. The fore and mid legs contained 15% and 13%

respectively. The femurs of the hind legs were more heavily parasitised than any other leg segment, having 39% of the larvae found on the legs. The coxae, trochanters and tibiae of the hind legs, the femurs of the midlegs and the femurs and tibiae of the fore legs each had greater than 7% of leg parasites (Appendix 6.3.3). All segments except the coxae and tibiae of the fore legs had larval parasites.

The distribution of the larval mites in Turraun and in Tumduff did not appear to be affected by season or host species, although most *Sigara distincta* were infected on a hemielytron. No relation between parasite loading and corixid length could be discerned.

# 6.4 Discussion

#### 6.4.1 Comparison of corixid sex ratios at Turraun and Tumduff

Applegate & Kieckhefer (1977) found that male *Palmacorixa buenoi* were significantly more abundant than female, having sex ratios of 1.4:1 ( $\mathcal{E}$ : $\mathcal{P}$ ) and 1.5:1 in different years. *Trichocorixa borealis* sex ratios varied over three years (1:1.5, 1:1 and 1:1.2), however females were dominant overall (Applegate & Kieckhefer 1977). The overall sex ratios of *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* in Turraun and Tumduff, were generally dominated by females. Sex ratios varied slightly between species, and also between sites.

Pajunen & Jansson (1969) showed that similar numbers of male and female corixids are recruited to the population each year. They also noted there were far fewer male than female *Arctocorisa carinata* and *Callicorixa producta* in rock-pools in spring and attributed this to male corixids suffering higher mortality than female (Pajunen & Jansson 1969). Alan A. Savage (personal communication) has indicated that males overwinter less well than females and die off more quickly than females during the first part of the breeding season (April-May). Brian Nelson (personal communication) has also noted that females become more numerous than males in early summer, as over-wintered adults die off.

The sex ratios in Turraun and Tumduff appeared to follow a similar pattern, with female *S. dorsalis*, *S. distincta* and *S. fossarum* more abundant than males in March 1997. Female corixids were also generally more abundant in April, May, June and July. It is possible that females have greater fat stores, allowing them to survive the winter better than males, or they may live later into the year for reproductive and oviposition purposes. These seasonal factors suggest females are not naturally more abundant that males, rather they dominate the overall sex ratio owing to their ability to survive longer.

Brian Nelson (personal communication) has also indicated that sex ratios other than 1:1 may reflect differences in behaviour between the sexes, making females more common in certain samples. Females may move into shallow littoral water to lay eggs. Oviposition in corixids takes place between April and August (Savage 1989) and could explain the

abundance of females in samples from April and May 1997. Segregation of the sexes may be related to feeding behaviour (Chapter 7) or to habitat preferences (Chapter 8).

Male corixids tended to be more abundant than female in September/October. Male *S. distincta* were more abundant than female between August and November in Turnduff. *S. fossarum* males dominated in Turraun between September and November 1997. Male *S. scotti* outnumbered female by more than 2:1 in March 1997 and also dominated in November at Turraun. In Chapter 5 it was suggested that the very high abundance of corixids between September and November 1997 in Turraun and Turnduff, was supplemented by immigration from other water bodies. It is possible that male corixids migrate more readily than female in autumn, resulting in a high abundance of males at this time. Pajunen & Jansson (1969) also suggested that there could be a difference in the tendency to migrate between the sexes, although they believed females were more likely to migrate in autumn.

Female *S. dorsalis* were more abundant that male in both lakes. Seasonal factors appeared to influence the overall sex ratio. *S. dorsalis* was very abundant in Turraun in March 1997 (refer to Section 5.3.3, Chapter 5), a month in which females were more abundant than males in samples. Abundance was considerably lower in all other months. Despite the disproportionate influence of March abundance, females were more abundant than males in most months, suggesting the natural sex ratio for *S. dorsalis* is slightly dominated by females.

Female *S. distincta* were dominant in Turraun, while male were dominant in Tumduff. The low overall abundance of this species in Tumduff suggests the sex ratio for Turraun may be most accurate. Seasonal changes in corixid abundance also have influenced the overall sex ratio for *S. distincta*. The species was abundant in March, September and November 1997 and February 1998 at Turraun, when females outnumbered males to a greater or lesser extent, leading to the overall sex ratio of 1:1.13. In Tumduff, *S. distincta* was most abundant in September, October and November 1997, a time when males were far more abundant than females.

The overall sex ratio in *S. fossarum* was more or less 1:1, with slightly more males in Turraun and slightly more females in Tumduff. The sex ratio was close to even in most

months at Turraun. The abundance of *S. fossarum* in September, October and November 1997, when males were more numerous, was probably the main cause of the 1:0.9 sex ratio. The pattern was similar at Tumduff, with females abundant in March and summer 1997 and males dominating in September, November 1997 and February 1998.

Male *S. scotti* were more abundant than female. The sex ratio fluctuated closely around 1:1 at Turraun, however, males were more often dominant than females. *S. scotti* was abundant in March and November 1997, two months in which males were more abundant than females and these may have generated the 1:0.9 ratio. *S. scotti* numbers at Tumduff were generally low and the sex ratio fluctuated greatly.

The natural sex ratio in all four species appears to be 1:1, however the overall sex ratio varies with ecological and possibly behavioural factors. Females appear to be more abundant than males between March and summer, when mating and oviposition are occurring. This biases the overall (yearly) sex ratio in the favour of females. It is most likely that the dominance of females in spring results from females being more long-lived than males. Seasonal evidence suggests that new male recruits may migrate more readily than female, and that males will be more abundant that females in autumn in waterbodies affected by immigration.

### 6.4.2 Comparison of length at Turraun and Tumduff

Female corixids were generally longer than male and Tumduff corixids were larger than Turraun. Significant differences in corixid length between sampling stations were also recorded. In terms of the populations involved in length calculations, it must be noted that corixids were far more numerous at Turraun than at Tumduff, even when sample number was taken into account. Corixid abundance has been dealt with at length in Chapter 5.

Females, except *S. dorsalis* at Tumduff, were significantly larger than males. The reason for this exception was not clear. It may have been owing to the large range in lengths encountered in both sexes, combined with the relatively low number of *S. dorsalis* individuals. It is also possible that sexual size dimorphism does not truly exist in this species. Sexual dimorphism in corixids may be linked to egg development in females. Female corixids can lay between ten and 1,000 eggs and *S. dorsalis* and *S. scotti* females,

supplied with abundant food in the laboratory have laid 300-400 eggs each (Savage 1989). Obviously production of this number of eggs requires a large abdominal cavity and large food storage ability. Pajunen (1977) also noted sexual dimorphism in corixids and stated that mature and callow females of the same species had different weights.

Corixid length varied between wetlands and among sampling stations. Generally corixids of each species were smallest at T1, slightly larger at T2 and T3, significantly larger at T4 and T5 and largest at the Tumduff stations. Length differences may be owing to a number of factors discussed below.

Corixids also appeared to be either smaller than published lengths or at the lower end of the published range. It is noteworthy that *Sigara distincta* in particular appeared to be smaller than expected (8.0-9.0 mm) and that *S. dorsalis* from Turraun is at the lower end of the published range of lengths (6.5-8.0 mm) (Savage 1989). Alan A. Savage (personal communication) has noted that specimens of *S. distincta*, and *S. dorsalis* from the Scottish Isles are shorter than the range given in Savage (1989). This may reflect speciation in the peripheral populations of north-west Europe or a set of environmental conditions common to parts of Ireland and Scotland.

A number of environmental reasons may be suggested for variation in adult size. Tham *et al.* (1997) found that humic substances in a German raised bog stream had a toxic effect on *Halesus digitattus* (Schrank), a trichopteran larva. He also suggested that the increased energetic costs of cellular reactions to combat humic substance toxicity, could lead to reduced growth rates (Jochen Tham personal communication). As humic substances appeared to have a slightly higher concentration in Tumduff (63 mgl<sup>-1</sup> PtCo) than in Turraun (53 mgl<sup>-1</sup> PtCo), (see also Chapter 3), humic substance toxicity could not have been responsible for between wetland differences in corixid size. The presence of humic substances may, however, explain why corixids in these cutaway wetlands and in Scotland were smaller than expected.

High temperatures can lead to rapid development in corixids, but resulting adults may not reach their full size (Pajunen & Sundbäck 1973). Littoral summer temperatures were high in both wetlands and may explain why corixid were smaller than expected from the literature. Temperature did not vary significantly between sampling stations and seems

unlikely to have been responsible for size differences between wetlands or sampling stations.

Pajunen (1977) found an obvious decrease in the mean size of later instar larvae as density increased, and suggested that high densities slow growth. Macan (1973) mentions a study of pacific salmon in which the growth of the fish was retarded by over-crowding, and not food availability as was suspected. Overcrowding in Turraun may have caused corixids to be shorter than at Tumduff, and as corixid density varied between sampling stations it may also explain length differences within the wetlands.

Pajunen (1977, 1979) suggested that developing nymphs were smaller when food was in short supply. Food availability and nutritional quality may also have contributed to length differences between wetlands and sampling stations, with larger corixids found where there is a high abundance of preferred food items. Corixid feeding is investigated in Chapter 7 and this topic will be returned to in the overall discussion for Section C.

The individuals captured in Tumduff may have been immigrants from waterbodies that supported larger corixids, while many of those found in Turraun may have been produced within the wetland. Corixids were either absent from or in low numbers in Tumduff in early 1997 and appeared only to colonise the wetland at that time (refer to Section 5.3.3, Chapter 5). On the other hand, corixids were reported from Turraun in summer 1996 (Fay *et al.* 1996), and observed by the author in October and December 1996 (refer to Section 4.3.1, Chapter 4). Among sampling station differences in Turraun may also be linked to immigration from different sources.

Corixids were smallest at T1, the sampling station with the lowest abundance of epiphyton, detritus and macroinvertebrates. Here Corixidae may have been in competition with species like *Caenis luctuosa* and *Mystacides longicornis* for any available epipelic organisms or detritus (see also Chapter 4 and Chapter 6). It is odd that T3, the station with the greatest abundance of other macroinvertebrates had relatively small corixids. T3 also had the greatest abundance of corixids. It is possible that overcrowding and intra- and inter-specific competition for available resources at T3, stunted corixid growth. High food quality may have been responsible for the large corixids found at T4 and T5.

Patterns in corixid length within Turraun, reflected patterns in diversity and taxon richness (Section 4.3.3), all three factors being greatest at T4 and T5. The differences in corixid length between sampling stations at Turraun, suggests that animals did not move between sampling stations. The most significant length differences existed between T1, T2 and T3 on the western shore and T4 and T5 on the eastern shore, suggesting that migration across the width of the lake was highly unlikely. Wide expanses of open water may act as barriers to corixid movements and individuals may restrict their movements to shallow, calm water within the littoral zone.

#### 6.4.3 Parasitism

The percentage of corixids parasitised by larval mites was low at Turraun and moderately low at Tumduff. Crisp (1959) found that half of the Sigara scotti captured in Lough Fáda, Co. Galway, were infected with larval Hydracarina (probably Hydrachna c. cruenta Müller), whilst only 7% of those found in eight other waterbodies on Roundstone bog were infected. Davids et al. (1978) mentioned a parasitemia of 10% for S. striata in April in the Netherlands. Scudder (1983) found parasitism of Cenocorixa bifida in Western Canadian lakes was greater than 45% at times, however C. expleta was far more heavily parasitised where the two species coexisted. The greater percentage of corixids infected at Tumduff than at Turraun, was probably a result of the far greater abundance of adult Hydracarina in Tumduff. It is also possible that other animals acted as hosts to larval mites in Turraun, and larvae were occasionally observed attached to beetles from this wetland. The incidence of parasites was higher in the populations of Sigara dorsalis, S. distincta, S. fossarum, Callicorixa praeusta, Hesperocorixa castanea and corixid nymphs at Tumduff than in Turraun. Only S. scotti and Corixa panzeri had higher percentage infection at Turraun. The low abundance of *C. panzeri* in Tumduff (only three individuals captured) may explain why no infected specimens were captured in this wetland.

Most corixids had only one larval mite attached, none had more than five and the number of parasites did not appear to be linked to species, sex or size of the corixid. Crisp (1959) found up to three larval mites on some individual *Sigara scotti*. Davids & Schoots (1975) reported that there was generally only one larva per host in spring, when parasite growth was greatest. Scudder (1983) found up to 15 larvae on specimens of *Cenocorixa expleta* but only one on *C. bifida*. Up to 205 larval *Limnochares* sp. per host were found on *Gerris* 

spp. in Ontario, although heavy infestation by larval mites are rare (Fernando & Galbraith 1970). It is possible that an individual corixid cannot support more than one or two parasites to maturity and that surplus larvae may eventually fall off or die. This theory is supported by the fact corixids were seldom infected with more than one mite between December and April.

S. dorsalis appeared to be the species most susceptible to parasitism, with 9% infected at Turraun and 18% at Tumduff. In The Netherlands, S. striata, a close relative of S. dorsalis, was the main corixid host of Hydrachna conjecta (Davids et al. 1978). Different species have been documented as being more or less susceptible to infection, with S. falleni described as immune to Hydrachna conjecta larvae (Savage 1989). Larvae of four mite species significantly preferred Cenocorixa expleta to C. bifida (Scudder 1983). Behavioural traits may make S. dorsalis interact and overlap with larval mites more frequently than other species or physiological characteristics may make it less effective in fighting infection.

It is possible that the importance of *S. dorsalis* was reduced over time at Turraun owing to parasitism (see also Section 5.3.3, Chapter 5). Many years of study by G.G.E. Scudder and his students into the physiology and ecology of *Cenocorixa bifida* and *C. expleta* revealed that their distribution was in part controlled by parasitic Hydracarina (Scudder 1983). *C. expleta* occurred only where the salinity tolerance of parasitic mites (13,000  $\mu$ Scm<sup>-1</sup>) was exceeded (Scudder 1983). As *C. expleta* was physiologically capable of surviving at low salinity, it was suggested that it was differential susceptibility to mite parasitism that excluded it from lakes with lower salinity (Scudder 1983).

10% of the 630 corixid nymphs examined at Tumduff were parasitised, but only 0.8% of the 887 at Turraun. This may have been owing to nymphs being more abundant at Tumduff than at Turraun or perhaps the summer generation of larval mites used hosts other than corixids in Turraun. Davids & Schoots (1975) stated that *Hydrachna cruenta* but not *H. conjecta* infects corixid nymphs and that infection may cause mortality. It is possible that the parasitic mites found in Turraun were different to those found in Tumduff and were incapable of infecting nymphs. The low number of infected nymphs would also account for the low parasitism of adult corixids over summer in Turraun. The reduction in abundance of corixids, particularly of more susceptible species such as *S. dorsalis*, may

have been owing in part to the destruction of nymphs by larval parasites. Mites may also have affected corixid abundance through predation on eggs by adult and nymph mites. Such predation by mites could have contributed to the reduction in corixid numbers in 1998 and 1999 in both wetlands.

Observations on *S. scotti* and *S. striata* suggested that female fecundity was reduced owing to parasitism (Crisp 1959, Davids & Schoots 1975, Savage 1989). Davids & Schoots (1975) found that few eggs developed in corixids infected with *H. conjecta*, while the effect of *H cruenta* was not as severe and that this varying impact was linked to larval mite growth. Davids *et al.* (1978) calculated that an infection rate of *Hydrachna conjecta* of 10% led to a 25-35% reduction in egg production in the spring generation of *Sigara striata*. The body size of the corixid infected also affects egg development and parasite growth, with smaller corixids producing no eggs and smaller parasites (Davids & Schoots 1975).

It has also been suggested that parasitism reduces life expectancy, with infected bugs disappearing from the population quicker than uninfected ones (Davids & Schoots 1975). Fernando & Galbraith (1970) report on a personal communication from Harris that indicated mortality was increased in corixids infected with mites and kept in the laboratory with limited food. Leston (1955, cited Fernando 1959) found that mite infested specimens died earlier in spring and suggested that the presence of mites on the abdomen interferes with the dorsal air film.

Larval parasites were most abundant at B8, which was also the station with the greatest abundance of adult Hydracarina. Adult mites were also numerous at B7 and the percentage of infected corixids was high. The incidence of parasites was very low, however, at B6, which had more adult mites than B7 and similar relative abundance of *S. dorsalis* to B7 and B8. It is not clear why this occurred, although, the coleopteran fauna was more diverse and abundant at B6 than B7 or B8, and larval mites may have preferentially parasitised beetles at B6. The number of infected corixids was also low at T4, which had the highest number of adult mites of any Turraun station. In Turraun, the percentage of corixids with parasites was highest at T2, although adult abundance was relatively low. The percentage abundance of *S. dorsalis*, however, was higher at T2 than at any other sampling station (see Section 4.3.3.1) and the availability of this susceptible

species may have increased the percentage of parasitised animals. The distribution of parasitised corixids may also have been related to a specific distribution of parasitic mite.

It is also interesting to note that the percentage abundance of *S. dorsalis* was lowest at T4 and that its total abundance there was relatively low. The abundance of adult Hydracarina and hence, the high probability of larval infection at T4 may have contributed to the low abundance of *S. dorsalis* at that station. It is also important to stress the influence of environmental factors, such as open water, on *S. dorsalis* distribution.

The seasonal pattern exhibited by parasitic larval mites in Turraun and Tumduff was similar to that recorded in other studies (Davids & Schoots 1975, Davids *et al.* 1978) and followed the life cycle of the host corixids (see Chapter 5). Nymphs of *Hydrachna conjecta* and *H. cruenta* leave the corixid host near the end of April (Davids & Schoots 1975, Davids *et al.* 1978) and develop into adults by late May, these mites produce a second generation of adults by mid-July (Davids *et al.* (1978). In Turraun, the larval mites overwintered on the corixids and dropped off between February and April. The mites would then have entered the resting stage, emerged as free living nymphs and developed rapidly into adults, producing the abundance of adult and nymphal mites found from March to May at both wetlands (see Section 4.3.2.7, Chapter 4). This first generation of adult mites dropped off, matured and reproduced between late June and July. These larval mites dropped off, matured and reproduced between late June and August, before dying off. The larvae produced by this second generation of adult mites, infected corixids from August onwards. When the free-living stages were abundant, the percentage of infected corixids was naturally lowest.

The point of attachment of larval mites is also interesting. Crisp (1959) found that mites were usually attached to the underside of the hemielytra. Davids (1975) found that *Hydrachna conjecta* attached to the underside of the hemielytra, while *H. cruenta* was found most often on the legs. Fernando & Galbraith (1970) found that *Limnochares* sp. attached to the area around the eyes, the pro- and mesonotum and the base of the rostrum in *Gerris comatus* Drake & Hottes and *G. buenoi* Kirkaldy and suggested that different preferred sites of attachment exist for different host and parasite species. Larvae appeared to be capable of surviving almost anywhere on the body of corixids in Turraun and Tumduff. The distribution of larvae on the head, thorax, abdomen, hemielytra and legs of

the corixids in both wetlands, suggests that more than one species of parasite infected the animals. It is probable that there were at least two parasitising species, one that preferentially attached to the hemielytra and body, one that attached to the legs. It is possible that larvae attaching to the hemielytra and body were also different species. Should each location support a different mite species, then the species attaching to corixid legs must have been the most prevalent in Turraun and Tumduff. The size of the leg segment may have affected the distribution of larvae, with the larger segments of the hind legs (Miller 1971, Scudder 1976) used in both wetlands.

Chapter 7

# LABORATORY FEEDING TRIALS

# 7.1 Introduction

The feeding biology and diet of Corixidae has been the subject of considerable investigation for over eighty years, but despite this the diet of corixids remains disputed (Reynolds 1975, Savage 1989). Observational evidence exists of predation and phytophagy in corixids (Reynolds 1975, Savage 1989). They have been described as omnivores, carnivores, detritivores and algal feeders by a variety of authors (Savage 1989). Dietary studies are complicated by the fact that gut contents are largely fluid (Reynolds 1975).

Corixids can feed by piercing and sucking and can also masticate solid food with the buccopharyngeal teeth (Sutton 1951, Elliott & Elliott 1967, Jansson & Scudder 1972, Popham *et al.* 1984b, Savage 1989). Hungerford (1919) found that corixids fed on algal filaments by piercing each cell with protrusible stylets and sucking the contents. Corixids feed on animal prey in a similar fashion (Sutton 1951, Popham *et al.* 1984b, Pajunen & Pajunen 1992). Sutton (1951) documented that corixids ingest *Spirogyra* filaments whole. They also gather flocculent material with the palae and sweep it into the mouth (Hungerford 1919, Scudder 1976, Popham *et al.* 1984b).

Hungerford (1919) concluded that corixids are primarily herbivorous and that their food is derived from the abundant and constant supply of organic ooze on the bottom of a pond or lake. He also found oligochaetes, nematodes, rotifers and protozoans in corixid guts (Hungerford 1919).

Southwood & Leston (1959) described corixids as mainly herbivorous, feeding on bottom algae. Fernando (1959) also considered corixids herbivores, stating that they feed on algae and detritus and that records of carnivory were 'special cases'. Other authors have said that corixids have a predominance for phytophagy (Puchkovo 1969, cited by Jansson & Scudder 1972 and Popham *et al.* 1984b, Miller 1971).

Sutton (1951) described corixids as omnivores. During her study of the diet of four British species, she found that corixids fed on animals only when exceptionally hungry and noted that they displayed a marked preference for algal filaments over detritus. Istock (1973) said evidence suggested that North American species of *Hesperocorixa* and *Sigara* are

omnivorous, feeding on algae and animals in the sediment and in biofilm. Dodson (1975a) described Corixidae as generally omnivorous or herbivorous. Bakonyi (1978) considered *Sigara striata*, and *S. falleni* omnivores, although the guts of both contained mainly animal body fluid.

Popham (1964) stated that most British corixids feed on algae and detritus on the bottom of the habitat. It has been theorised that corixids were originally entirely carnivorous and evolved into omnivorous species and subsequently specialised detritus and algal feeders developed (Popham 1964, Popham *et al.* 1984b). Through examination of gut contents, Popham *et al.* (1984) described the feeding habits of twenty-one species of British corixids and divided them into detrital and algal feeders, carnivores and omnivores. They also indicated that feeding patterns could be deciphered through the functional morphology of the head and fore legs, and the ecological distribution of the species.

A large number of authors have reared corixids on animal prey in the laboratory. Zwart (1965) (cited in Jansson & Scudder 1972 and Reynolds & Scudder 1987a) found that both adults and nymphs of several European corixids survived longest when fed on animal prey such as *Tubifex*, daphniids and chironomids and suggested that animal food may be necessary for corixid reproduction. Davids *et al.* (1978) found that corixids were best reared in the laboratory on *Tubifex* worms. Jansson & Scudder (1972) reared *Cenocorixa bifida* and *C. expleta* on live and frozen brine shrimp and all north European species of *Sigara*, *Arctocorisa* and *Callicorixa* on Enchytraeid worms cut into small pieces. They also observed that *Sigara alternata* (Say) fed on frozen brine shrimp did not reproduce, although it reproduced when fed on freshly killed mayfly. Pajunen & Sundbäck (1973) successfully reared *Arctocorisa carinata* and *Callicorixa producta* on chopped, live enchytraeid worms, and Pajunen (1975) found development rates in *A. carinata* were slower when reared on dead chironomid larvae than on enchytraeids. Pajunen (1977) described both species as predators, feeding mainly on bottom dwelling fauna.

There is evidence that most genera of corixids are predaceous (Scudder 1976). Early studies (Walton 1943 by cited Popham *et al.* 1984b and Savage 1989) classified *Cymatia bonsdorffii* and *Glaenocorisa propinqua* (Fieber) as carnivores. Sokol'skaya & Zhitereva (1973, cited by Popham *et al.* 1984b) found species of *Cymatia* and *Sigara* to be predators of fish fry in southern Russia. Reynolds & Scudder (1987a) showed two *Cenocorisa* 

species to be carnivorous and actively predaceous. *Cenocorixa bifida* and *C. expleta* fed on a variety of animal prey in experimental feeding trials, but both took chironomid larvae most frequently (Reynolds 1975, Reynolds & Scudder 1987a). In serological studies corixids taken from the field contained up to five different prey items (Reynolds 1975, Reynolds & Scudder 1987b). Both *Cenocorixa* species and a Canadian *Sigara* sp. concentrated on chironomids and zygopterans (Reynolds 1975, Reynolds & Scudder 1987b). Reynolds (1975) stated that while feeding on plants was negligible in *C. bifida* and *C. expleta*, certain corixids do utilise bottom ooze and others feed on algal cell contents.

Corixids have been shown to be cannibalistic on eggs (Pajunen & Pajunen 1991) and nymphs (Pajunen & Pajunen 1992). Egg cannibalism was observed in *Arctocorisa carinata* and *Callicorixa producta* (Pajunen & Pajunen 1991) and in captive *Cenocorixa bifida* and *C. expleta* (Reynolds & Scudder 1987a). Corixids did not distinguish between their own eggs, eggs of con-specifics or eggs of other species (Pajunen & Pajunen 1991).

Work on the diet of *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* is limited. *S. dorsalis* has been described as omnivorous (Sutton 1951, Southwood & Leston 1959, Popham *et al.* 1984b). Sutton (1951) noted that it preferred algal filaments to detritus, and fed on animals when exceptionally hungry. Southwood & Leston (1959) said *S. dorsalis* mainly feeds on detritus, but also ingests living animal material, diatoms and algal filaments. Popham *et al.* (1984b) noted that at times it fed predominantly on algal or detrital material. Popham *et al.* (1984b) said that *S. distincta* was mainly omnivorous, however, some animals took mainly detritus. Popham (1943) reared *S. distincta* on algal and protozoal infusions in the laboratory. *S. fossarum* and *S. scotti* have been described as predominantly omnivorous (Popham *et al.* 1984b).

The four dominant species in Tumduff have been rather vaguely described as omnivores. In order to record specific prey items consumed by *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti*, laboratory feeding trials were conducted. While Sutton (1951) has used *S. dorsalis* in observational feeding trials, this represented a novel approach for *S. distincta*, *S. fossarum* and *S. scotti*. The main aim of the experiment was to establish the potential food sources for all four species at the study sites. All prey items offered were taken from or available at Turraun and Tumduff. A further aim was to establish if the four corixid species were capable of predation, and which invertebrate species they fed upon. It was hoped that knowledge of the diet of the four species would help elucidate their role in community food webs and contribute to the understanding of the ecology of the species at the study sites.

# 7.2 Materials and Methods

Feeding trials were performed between  $22^{nd}$  October 1998 and  $3^{rd}$  December 1998, and on  $26^{th}$ ,  $27^{th}$  and  $28^{th}$  August 1999. 1998 experiments were carried out in the Freshwater Laboratory, Trinity College Dublin, and those performed in 1999 took place in a house adjacent to the study sites, in Leabeg, Boora, Co. Offaly. In 1998, all Corixidae came from Turraun or Tumduff Wetlands and all test animals in 1999 came from Tumduff. Animals kept in the laboratory were stored at 8 °C in a constant temperature room; those tested at the house were stored at ambient temperature in an open shed. Corixids were starved for between 24 and 120 hours before the experiment and kept in water filtered through a 63  $\mu$ m sieve. Starvation took place in plastic aquaria (320 x 220 x 200 mm) filled to 30-50 mm or white buckets (140 mm radius, volume 12,000 ml) filled to 100-150 mm. Corixids were given white plastic net (1 mm mesh) to rest on and the aquaria or buckets were covered to prevent escape.

Feeding trials were conducted at room temperature. Corixids were isolated in white plastic tubs (45 mm radius, volume 340 ml) with between two and three centimetres depth of filtered home-wetland water. Animals were given a short period of time to adjust to the temperature and light of the room. During the 1998 trials, animals were also given a piece of white plastic mesh (c. 40 x 20 mm) to perch upon. Corixids were found to be capable of perching anywhere on the sides and base of the tubs and, consequently, the mesh was not used in 1999. In most cases the corixid was placed in the experimental tub before the prey item was added, although, for periphyton on *Chara*, mayflies and caddis fly larvae, the prey was added first.

Potential food consisted of biota occurring frequently in the wetlands and was collected from Turraun and Tumduff by sweep net and by hand. This material was supplemented by animals taken from laboratory cultures at the Zoology Department (*Daphnia*) and a tank at the rear of the Zoology Department in TCD. The prey items used in 1998 were phytoplankton, periphyton on *Chara* and *Myriophyllum*, Oligochaeta, live and dead *Daphnia*, *Asellus aquaticus*, *Crangonyx pseudogracilis* Bousfield, *Caenis luctuosa*, *Cloeon simile*, zygopteran nymphs, cased caddis larvae and chironomid larvae. Dead *Daphnia* were obtained by brief immersion of prey in hot water. Corixids were also offered drops of hay infusion that had been colonised by algae and protozoans. Phytoplankton, periphyton on *Myriophyllum*, Oligochaeta, chironomid larvae and adult Coleoptera (*Noterus clavicornis*) were the prey items offered to corixids in 1999.

Feeding experiments took place between 09:00 and 19:00. Between five and 25 corixids were tested individually at any one time. The tubs were covered with plastic mesh to prevent escape. Despite this some corixids did escape, and were not included in the analyses. During 1999, the trials were of two types. In the first, the animals were monitored constantly and the offered prey items were phytoplankton or periphyton. Experiments involving constant monitoring lasted between 20 and 40 minutes. In the second type of feeding trial, corixids were offered animal prey. These were conducted over a number of hours, generally overnight, with animals being checked regularly. In 1999 the experimental procedure was refined and the duration of all trials was 20 minutes with tubs being checked every 2 minutes.

Feeding on algae and biofilm was determined to have occurred when animals rapidly brushed the front palae over the mouth. Death and shrinkage of soft-bodied prey provided evidence of feeding. Some dead prey was subsequently examined under the microscope for corixid puncture marks. Pajunen & Pajunen (1992) found that corixid nymphs that had been fed on by adult corixids, had multiple triangular shaped puncture marks where they had inserted the sucking mouth parts. During the trial, note was taken of any observations made on feeding or general behaviour.

On completion of the feeding trial, each corixid was identified and sexed under a dissecting microscope. In 1998 animals were then transferred to an aquarium in the constant temperature room, containing conspecifics, plants, substrate and food. In 1999 corixids were placed in a bucket with food and eventually returned to their wetland of origin.

Data were sorted, subtotals calculated and graphs plotted on Microsoft Excel 97<sup>®</sup>. Statistical tests were performed using Data Desk 6.0<sup>®</sup>.

# 7.3 Results

### 7.3.1 Experimental results

During the feeding trials, 336 animals were tested including one *Callicorixa praeusta* and three corixid nymphs that were accidentally tested. 63 or 19% of corixids fed on the prey items offered. *Sigara distincta* and *S. fossarum* were the most abundant corixids in Turraun and Tumduff and, hence, were more available for feeding trials (Table 7.1). The number of *S. dorsalis* and *S. scotti* tested was low, owing to their low availability in the wetlands and their low survival rate in culture. For all species tested, more male than female corixids fed. Significantly more male than female *S. distincta* fed (pooled t-test, p = 0.01 at  $\alpha = 0.05$ , t = -2.5).

Table 7.1	The number of individuals of the four corixid species used in the
	feeding trials. The total number of animals that fed is given along
	with the percentage of total, males and females that fed.

	total	fed	total %	% 8	% ♀
Sigara dorsalis	24	4	17	20	18
Sigara distincta	167	27	16	28	9
Sigara fossarum	132	28	21	25	18
Sigara scotti	9	3	33	66	33

For the purposes of analysis, the prey items were divided into four main groups. The first group, 'algae and biofilm', included phytoplankton, hay infusion and periphyton on *Chara* and on *Myriophyllum*. The second group, 'soft-bodied animals', was made up of Oligochaeta and chironomid larvae and the third, 'mayfly nymphs' had both *Caenis luctuosa* and *Cloeon simile*. 'Hard-bodied animals' was the fourth group and contained animals with strongly chitinous exoskeletons, cases or shells (i.e. *Asellus aquaticus, Crangonyx pseudogracilis*, zygopteran nymphs, cased caddis larvae and Coleoptera). Experiments conducted with *Daphnia* sp. were kept separate from the four main groups, as these animals bear little resemblance in size or distribution to the other animals tested.

Significantly more corixids fed on algae and biofilm than on the other three food groups  $(F_{3, 307} = 8.53, p \le 0.001, and LSD post-hoc tests)$ . The difference between the number feeding on algae and biofilm and mayfly nymphs (p = 0.016, LSD post-hoc test) was not as marked as between algae and biofilm and soft-bodied or hard-bodied animals.

Of the 128 animals that were offered algae and biofilm 64 were Sigara distincta, 55 S. *fossarum*, five S. dorsalis, three S. scotti and one Callicorixa praeusta. 25% of S. distincta and 35% of S. fossarum fed on algae and biofilm. Figure 7.1 illustrates the percentage of these two species that fed on each prey group and Table 7.2 lists the total number tested and feeding. Two female S. dorsalis fed, one male and one female S. scotti fed and the single C. praeusta did not feed.

	total	fed	total 3	∂ fed	total ♀	$\bigcirc$ fed
Sigara distincta						
Algae & Biofilm	64	16	31	11	33	5
Soft-bodied Animals	67	7	39	6	28	1
Mayfly Nymphs	10	2	6	2	4	0
Hard-bodied Animals	21	0	11	0	10	0
Live Daphnia	3	2	2	1	1	1
Dead Daphnia	1	0	0	0	1	0
Sigara fossarum						
Algae & Biofilm	55	19	30	10	25	9
Soft-bodied Animals	36	7	13	5	23	2
Mayfly Nymphs	17	1	8	0	9	1
Hard-bodied Animals	14	0	6	0	8	0
Live Daphnia	3	0	2	0	1	0
Dead Daphnia	7	1	5	1	2	0

 Table 7.2
 The number of Sigara distincta and S. fossarum feeding on the four main prey groups. The number of males and females that fed is also given.

In all, 40 corixids were offered phytoplankton and 13 (32.5%) fed. 70 animals were offered periphyton and 19 (27%) fed. 46% of animals tested fed on periphyton associated with *Chara* and only 9% fed on periphyton on *Myriophyllum*.

67 *S. distincta*, 36 *S. fossarum*, three *S. scotti*, two corixid nymphs and one *S. dorsalis* were offered soft-bodied animals. 10% of *S. distincta* and 19% *S. fossarum* accepted the animals offered. One corixid nymph fed, but neither *S. scotti* nor *S. dorsalis* did. 8% (5) of corixids offered chironomid larvae fed and 21% (10) of corixids offered Oligochaeta fed (see Appendix 7.3.1).

32 animals were tested with mayflies and 12.5% fed. No corixid fed on *Caenis luctuosa*. Four animals fed on *Cloeon simile* representing 19% of animals tested. Six *S. distincta*, four *S. dorsalis* and 11 *S. fossarum* were offered *Cloeon simile*. Two *S. distincta*, one *S. dorsalis* and one *S. fossarum* fed.

42 corixids were offered animal prey with hard exoskeletons, cases or shells and none fed. The corixids tested included *S. distincta*, *S. dorsalis* and *S. fossarum*. Three of the 11 corixids tested fed on live *Daphnia*, including one *S. dorsalis* and two *S. distincta*. One *S. fossarum* and one *S. scotti* fed on dead *Daphnia* out of the twelve corixids tested.

Figure 7.1 graphs the percentage of *S. distincta* and *S. fossarum* offered each prey item that fed. As individual corixids were offered a single prey item the percentages do not sum to 100. Both *S. distincta* and *S. fossarum* appeared to express a preference for algae and biofilm over other prey items. *S. distincta* fed on significantly more algae and biofilm ( $F_{3,158} = 3.38$ , p = 0.02) than on soft-bodied animals (p = 0.02, LSD post-hoc test) or hard-bodied animals (p = 0.006, LSD post-hoc test). There was no significant difference in the numbers feeding on algae and biofilm and on mayfly nymphs, however, only 11 *S. distincta* were tested with mayfly nymphs, with 2 feeding.

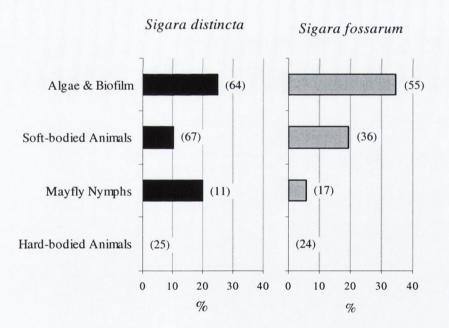
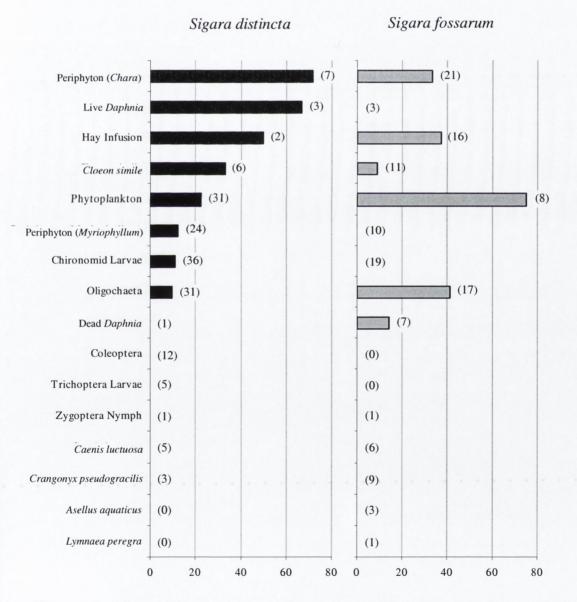


Figure 7.1 Percentage acceptance of four main prey groups offered to adult Sigara distincta (black) and S. fossarum (grey). n, the total number of corixids tested for each prey group, is given in parenthesis at the end of each bar.

*S. fossarum* fed on significantly more algae and biofilm ( $F_{3,118} = 4.15$ , p = 0.008) than on mayfly nymphs (p = 0.01, LSD post-hoc test) or hard-bodied animals (p = 0.005, LSD post-hoc test). There was no significant difference between the numbers of *S. fossarum* feeding on algae and biofilm and on soft-bodied animals (p = 0.08, LSD post-hoc test) and

soft-bodied animals were the second most frequent prey taken. No significant differences were found between *S. distincta* and *S. fossarum* in terms of the numbers feeding on each prey group.

Figure 7.2 details the percentage of *S. distincta* and *S. fossarum* feeding on each individual prey item. Results are arranged in order of acceptance by *S. distincta*. As the percentages are based on different sample sizes, averages are inappropriate and will not match percentages in Figure 7.1. Appendix 7.3.1 details the numbers offered and feeding on all prey items.



# Figure 7.2 Percentage acceptance of prey items offered to adult *Sigara distincta* (black) and *S. fossarum* (grey). n, the total number of corixids tested for each prey group, is given in parenthesis at the end of each bar.

Periphyton and hay infusion were amongst the most popular prey items for *S. distincta*. 71% of *S. distincta* offered periphyton on *Chara* fed, 12.5% offered periphyton on *Myriophyllum* fed and 50% offered hay infusion fed. These three prey items also appeared to be important elements of the diet of *S. fossarum*, although a smaller percentage fed on each. 33% of *S. fossarum* tested fed on periphyton on *Chara* and 37.5% offered hay infusion fed. *S. fossarum* took phytoplankton more frequently than any other prey item, with 75% of corixids tested feeding. Phytoplankton was less popular with *S. distincta* with only 33% feeding.

Two of three *S. distincta* tested, fed on *Daphnia* and on 33% fed on *Cloeon simile. S. distincta* also fed on chironomid larvae and oligochaete worms. *S. fossarum* did not feed on chironomid larvae but accepted more than 41% of oligochaete worms offered. *S. fossarum* also fed on recently killed *Daphnia. S. distincta* fed on a greater variety of animal prey than *S. fossarum*. None of the *S. distincta* or the *S. fossarum* tested fed on 'hard-bodied animals'. The feeding patterns should be treated with a degree of caution owing to low numbers of animals involved.

Females of both *S. distincta* and *S. fossarum* appeared to prefer algae and biofilm to animal prey (Figure 7.3, see Table 7.2 for numbers tested). In contrast, a higher percentage of males of both species fed on animal prey (combining soft-bodied animals, mayfly nymphs and hard-bodied animals) than on algae and biofilm. In keeping with the findings that more male than female corixids fed, a greater percentage of male than female *S. distincta* fed only on algae and biofilm and soft-bodied animals. A greater percentage of female than male *S. fossarum* fed on algae and biofilm and mayfly nymphs. Male *S. fossarum* consumed considerably more soft-bodied animals than female.

A greater percentage of male *S. distincta* than male *S. fossarum* took mayfly nymphs, while the reverse was true of soft-bodied animals. Similar percentages of male *S. distincta* and male *S. fossarum* took algae and biofilm. More female *S. fossarum* than female *S. distincta* fed on each prey group. Male *S. distincta* appeared to prefer algae and biofilm and mayfly nymphs to other prey groups. Male *S. fossarum* appeared to prefer soft-bodied animals to algae and biofilm.

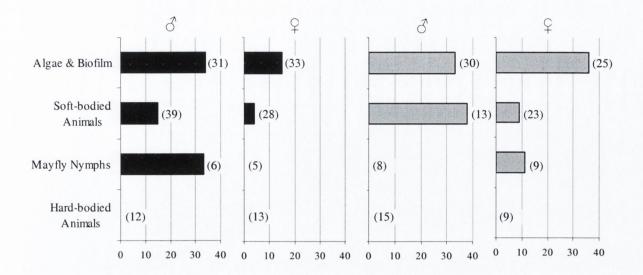


Figure 7.3 Percentage acceptance of four main prey groups offered to male and female Sigara distincta (black) and S. fossarum (grey). n, the total number of corixids tested for each prey group, is given in parenthesis at the end of each bar.

# 7.3.2 General observations

A large number of observations were made during the feeding trials. When feeding on algae and biofilm, the palae were alternatively wiped across the functioning mouth and the motion was vigorous and fast. When feeding on *Chara* and *Myriophyllum*, corixids used their middle legs to crawl along the branches, while scraping the periphyton off with their palae. Some corixids feeding on algae and biofilm fed constantly throughout the trial, while others fed intermittently. Corixids that were not feeding frequently used *Myriophyllum* and *Chara* to perch on. The corixids did not appear to search out phytoplankton and hay infusion, but rather fed if they came in contact with the food particles.

Feeding corixids appeared to hold Oligochaeta and chironomids very tightly with the palae. Of the corixids feeding on soft-bodied animals, some fed vigorously, leaving only the integument, while others emptied only a fraction of the body contents. The corixids fed methodically, sucking the contents out of a section of the body and then passing the chironomid or oligochaete through their palae and feeding on the next section.

Hind limb movements often accompanied feeding. Corixids regularly beat their hind legs in a swimming type motion. This motion was sometimes harmonised with the rhythm of the palar movement. Corixids also rubbed the head and hemielytra with one hind leg or with both together. This motion often became quite rhythmic and appeared to be more frequent in corixids feeding on algae and biofilm. Feeding corixids appeared to be entirely unaware of the observer, and moved about more frequently than those that were not feeding.

Corixids were observed to sometimes hold onto animal prey, particularly chironomids or oligochaetes, but not to feed on them. On one occasion (25<sup>th</sup> November 1998) a corixid (female *Sigara fossarum*) was observed to collide with a *Caenis* nymph. The corixid responded by grabbing the nymph and held onto it until the mayfly struggled away from its grasp. After this the corixid swam vigorously, as if in search of the lost prey. Animal prey, particularly beetles, sometimes disturbed the corixids, causing both corixid and prey to swim. Corixids and beetles were also observed to perch on each other. Corixids showed no interest in *Asellus aquaticus* and zygopteran nymphs nor vice versa.

Corixids were sometimes disturbed by the presence of the observer, particularly when fast or jerky movements were made. Apart from the activities associated with feeding and swimming, however, corixids spent most of the observation time perched quietly. The prey animals, particularly mayfly and beetles appeared to be more disturbed by observation and artificial surroundings than were corixids.

Individual corixids took different lengths of time before beginning to feed, with some corixids feeding immediately and others feeding only after the trial was completed. Occasionally corixids were observed to feed on animal prey that had died after completion of the experiment.

Observations suggested that animals were more likely to feed in the afternoon, though this may have been a function of the number of animals tested at the different times. Comparing the numbers of corixids that were observed to feed, when offered algae and biofilm or soft-bodied animals and were constantly monitored, a greater percentage of test animals fed between 14:00 and 17:00 (See Figure 7.4).

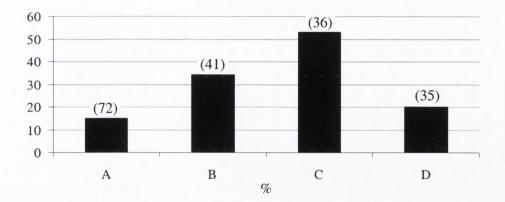


Figure 7.4 The percentage of corixids that fed at different times of the day. A is 09:00 to11:00, B is 11:00 to 13:00, C is 14:00 to 17:00 and D is after 17:00. Figures in brackets indicate n, the total number of observations.

The length of the starvation period did not appear to affect feeding, although this could not be tested statistically because of the large number of variables involved (corixid species and sex, prey item etc.).

# 7.4 Discussion

All four species tested have been described as omnivorous (Sutton 1951, Popham *et al.* 1984b). Results of experiments on Turraun and Tumduff corixids support these views. The four species appeared to be capable of ingesting detritus, phytoplankton, periphyton and a variety of aquatic macroinvertebrates. Algae and biofilm was the most popular prey group overall and probably represented a large component of the diet of Turraun and Tumduff corixids. Corixids fed on phytoplankton, hay infusion and appeared to prefer the biofilm associated with *Chara* over that on *Myriophyllum*. The feeding trials showed that soft-bodied animals, such as oligochaete worms and chironomid larvae were acceptable prey.

Sutton (1951) found that *S. dorsalis* fed on small free swimming animals, but noted that it preferred detritus over animal prey, and algae over both. Popham *et al.* (1984b) described *S. dorsalis* as mainly an omnivore that at times feeds mainly on algae or detritus. Popham *et al.* (1984b) suggested that corixids were originally carnivores and that morphological adaptations of the front legs indicate various species are evolving towards a detritus feeding or algal feeding habit. Popham *et al.* (1984b) also recorded that *S. dorsalis* shows more adaptations to algal feeding than the other three species studied here. *S. dorsalis* from the study wetlands fed on *Cloeon* nymphs and *Daphnia*, indicating that the species was capable of ingesting live prey. Two of the five *S. dorsalis* tested with periphyton on *Chara* fed. It is possible that Turraun and Tumduff specimens have a preference for biofilm on plants, feeding on the algae and associated animals and detritus.

*S. scotti* has also been described as omnivorous (Popham *et al.* 1984b) and in this study it fed on algae and biofilm and *Daphnia*, but was not properly tested with soft-bodied animals or mayfly nymphs.

*S. distincta* is predominantly omnivorous but some individuals are said to concentrate on detritus (Popham *et al.* 1984b). Detritus was not tested here, so no conclusions can be drawn on its importance in the *S. distincta* diet, though it is unlikely to be a preferred food as, owing to the high inorganic content, corixids feeding on detritus need to ingest large quantities to fulfil energy needs (Sutton 1951). In these trials, *S. distincta* fed on algae and biofilm, soft-bodied animals, mayfly nymphs and *Daphnia*. Algae and biofilm appeared to

be the most important dietary constituent for the species, with mayfly nymphs a close second. Periphyton on *Chara* and hay infusion were amongst the most frequently accepted prey items. Corixids have been shown to feed on *Daphnia*, mayfly nymphs, chironomids and oligochaetes in laboratory feeding experiments (Sutton 1951, Reynolds & Scudder 1987a) and chironomid larvae were important elements of the diets of *Cenocorixa expleta* and *C. bifida* (Reynolds 1975, Reynolds & Scudder 1987a & b). A high percentage of *S. distincta* accepted live *Daphnia*, *Cloeon simile*, chironomid larvae and oligochaetes. Animals may thus be an important element of the diet of *S. distincta*.

Popham *et al.* (1984b) described *S. fossarum* as omnivorous and it fed on algae and biofilm, soft-bodied animals, mayfly nymphs and dead *Daphnia* during the trials. *S. fossarum* also showed a preference for algae and biofilm over the other prey groups. Oligochaeta were the most important animal prey. These worms could have been favoured as they swim slowly, have soft cuticles and may have been easier prey for *S. fossarum* than other animals. One *S. fossarum* fed on dead *Daphnia* and a number of individuals were observed to feed on animal prey that had died during the course of the feeding trial. Other corixids have been recorded to feed on dead animals (Sutton 1951, Reynolds 1975) and *Cenocorixa expleta* actually showed a preference for dead over live prey (Reynolds 1975, Reynolds & Scudder 1987a). It is possible that *S. fossarum* is primarily a scavenger, feeding on any available material. The fact that a higher percentage of *Sigara fossarum* fed than of any other species suggests that it may be opportunistic and efficient in adapting to new conditions. These qualities could explain the success and abundance of *S. fossarum* in Turraun and Tumduff.

While algae and biofilm appeared to be important to the diets of both *S. distincta* and *S. fossarum*, a greater percentage of *S. fossarum* fed on this food group. This may be linked to palar adaptations making *S. fossarum* better at collecting these prey items than *S. distincta*. A higher percentage of *S. distincta* than *S. fossarum* fed on mayfly nymphs and looking at the individual prey items it can be seen that a greater percentage of *S. distincta* fed on all animal prey except oligochaete worms. This possibly indicates a more carnivorous lifestyle in *S. distincta*, or that being larger, it was better able to capture and handle the animal prey offered.

The differences in acceptance of the various prey items between *S. distincta* and *S. fossarum* may reflect differences in the behaviour of the two species. The apparent preference of *S. distincta* for periphyton, *Cloeon simile* and *Daphnia* suggests that this species may be distributed amongst macrophytes and in the water column, where these prey can be found. A high percentage of *S. fossarum* consumed phytoplankton and oligochaete worms, suggesting that this species favours a benthic lifestyle feeding on detritus, settled plankton, organic ooze and other benthic animals.

Popham *et al.* (1984b) found that male *S. falleni* are algal feeders, while females of the same species are predominantly omnivorous, and attributed these differences in feeding between the sexes to variations in the front legs. No feeding differences were found between the sexes of the other 19 British species studied (Popham *et al.* 1984b). Reynolds & Scudder (1987b) suggested that female *Cenocorixa bifida* and *C. expleta* had a more phytophagous or detritivorous habit than male, and found slight differences in feeding between sexes, that they also attributed to palar morphology. Females of both *S. distincta* and *S. fossarum* appeared to have a more herbivorous life style than their male counterparts. The fact that a greater percentage of females fed on algae and biofilm than on animal prey suggests that females have a sedentary, grazing lifestyle and that males are more truly omnivorous and more likely to be predators. Despite these differences, both algae and biofilm and animal prey appeared to be important to the diets of both sexes of *S. fossarum* and *S. distincta*.

More males than females accepted food and this may indicate that male corixids have a greater ability to adjust to new conditions than females. It may also indicate some differences in food and feeding behaviour between sexes. It is possible that females were not offered their preferred prey items, or that they are more secretive when feeding and had difficulty adapting to the conditions in the laboratory.

The large percentage of corixids feeding on phytoplankton suggests that these animals are capable of ingesting particulate matter from the water column and settled material from the pond bottom. Differences in the percentage of corixids accepting periphyton on *Chara* and on *Myriophyllum*, indicate that periphyton could vary with plant species in a way that is perceptible to corixids.

The feeding trials suggested that soft-bodied animals, such as oligochaete worms and chironomid larvae may be consumed by corixids in the new cutaway wetlands. Oligochaeta were reasonably abundant in both wetlands, representing 5.6% of the entire macroinvertebrate fauna in Turraun and 1.3% in Tumduff between January 1997 and February 1998. Chironomids were also reasonably abundant in Turraun during this period (6.2%) and exceptionally abundant in Tumduff (29.7%).

*Cloeon simile* mayfly were eaten, but not *Caenis luctuosa. Caenis* nymphs are slowmoving animals with a covering of fine detritus and algae that provides excellent camouflage from predators (Harris 1977) and corixids probably did not detect them. It is also possible that corixids do not feed on *Caenis luctuosa* nymphs because of the tough integument. The corixid species used in the trials did not feed on 'hard-bodied animals', perhaps because they were not capable of piercing the exoskeleton of *Asellus aquaticus*, zygopteran nymphs, beetles etc. It is also probable that many of the animals used in tests were too large for the corixids to attack and hold on to. Reynolds & Scudder (1987a) found that carnivorous *Cenocorixa* species rarely attacked large ephemeropteran larvae (or zygopteran nymphs) when alive but fed on them when dead.

The results suggest that the four corixid species examined here are opportunistic feeders, consuming whatever they are presented with or find. Sutton (1951) also concluded that *Corixa punctata, C. panzeri, Sigara dorsalis* and *S. falleni* feed on the 'easiest food'. The four species proved capable of attacking and feeding on live prey, such as *Daphnia, Cloeon* nymphs, chironomid larvae and Oligochaeta and *S. distincta* appeared to be more carnivorous than *S. fossarum. S. fossarum* would also seemed capable of scavenging on dead and moribund prey. If corixids are part predator, part scavenger, their regulatory role in the ecosystem could be considerable, depending on their abundance, and they could at times be the top carnivore (Reynolds 1975, Scudder 1976). Opportunistic feeding behaviour may have contributed to the success of corixids in the wetlands.

It must be cautioned that while feeding experiments can provide information on the fundamental feeding niche of a species, results may not directly reflect their realised feeding niche in nature. Reynolds (1975) found differences in the diets of *Cenocorixa bifida* and *C. expleta* between laboratory experiments and gut contents, which he suggested could be partly accounted for by the artificial experimental situation. It is also possible

that a preferred or optimal diet may not be offered in the laboratory (Reynolds & Scudder 1987a). The response of invertebrate predators generally varies with prey density and predator density can also be important (Young & Ironmonger 1980). Under natural conditions, corixid feeding could vary owing to the choice of prey and they may also feed in association with other corixids.

Many of the general observation made during the feeding trials have been noted elsewhere in the literature. Corixids can feed by piercing and sucking and can also masticate solid food with the buccopharyngeal teeth (Sutton 1951, Elliott & Elliott 1967, Jansson & Scudder 1972, Popham *et al.* 1984b, Savage 1989). Both feeding methods appear to have been used here, with, as Sutton (1951) found, animal prey fed on by piercing and sucking, while ingestion and mastication appeared to be favoured with algae and biofilm.

Popham *et al.* (1984b) noted that corixids moved the front legs out of phase with each other when feeding on algae and detritus, gathering the food material on the depressed median collecting surface of the pala. All four species fed on algae and biofilm in this fashion, gathering flocculent material and scraping periphyton with the palae before passing the food to the mouth.

Popham *et al.* (1984a) noticed *C. punctata* moving the front tarsi simultaneously to trap animal prey between the tarsal setae. Sutton (1951) stated that large chironomids frequently carried corixid around the jar. Sutton (1951) also observed that prey was passed ventrally as the corixid fed and all contents were not always removed. Others have noted that corixids may abandon partially eaten prey (Reynolds 1975, Reynolds & Scudder 1987a). It has been suggested that corixids feeding by piercing and sucking first remove the blood, then muscles and finally alimentary canal contents (Sutton 1951). The findings of the feeding trial support the above observations. It is also indicated that corixids grip 'wriggly' invertebrates, such as Oligochaeta and chironomids firmly to prevent escape. Sutton (1951) suggested that corixids might inject a paralysing agent. Alternatively corixids may inject enzymes into the prey to initiate extra-intestinal digestion.

Popham *et al.* (1984a) concluded that prey detection in *Corixa punctata* is by sight, however, it is also suggested that grooves present on the labium have a chemosensory

function. Reynolds & Scudder noted that *Cenocorixa* could detect moving prey at a distance of up to 70 mm, but did not react to dead prey until within 1.5 mm.

Sutton (1951) found that *Corixa punctata*, *C. panzeri*, *Sigara dorsalis* and *S. falleni* did not swim away at the sight of food, while Reynolds & Scudder (1987a) found that *Cenocorixa* species actively attacked prey by lunging at and capturing it. Living and continuously moving prey elicited more directed activity in *Cenocorixa* than dead or sedentary types (Reynolds 1975). These Canadian species attacked many live prey, sometimes abandoning partially eaten food to do so (Reynolds 1975, Reynolds & Scudder 1987a). Corixids did seem aware of live animal prey during these experiments, and were probably alerted to its presence by the animal's movement. Corixids never appeared to deliberately chase prey and were not predators like *Cenocorixa* species. They appeared to adopt a sit and wait posture, grabbing prey that came in close contact. The behaviour of corixids towards animal prey and particularly algae and biofilm suggests that these species may not search out particular prey items in the wild, but rather feed on whatever they chance upon.

Popham (1964) says moving corixids are likely to jostle other corixids and stimulate them to move. Dodson (1975) noted that feeding corixids can be disturbed by the movement of other insects, stimulating them to swim. Movement of and contact with living prey items stimulated the test corixids to swim during feeding trials. Reynolds & Scudder (1987a) noted that corixids reacted to jerkily moving prey and irregular movements of pipettes or blunt needles. Sudden movements by the observer appeared to be detected by test corixids, causing them to swim.

The response of the individual corixids to food varied, and many animals did not feed at all. The number of corixids that fed and the amount eaten may have been related to the level of hunger of the individual. Those corixids that did not feed may not have detected the prey items. There were a number of other potential reasons why corixids did not feed under laboratory conditions. Pajunen & Sundbäck (1973) kept corixids in culture from autumn and by March 50-70% had died. Reynolds & Scudder (1987a) also found that mortality increased with length of time in captivity. Mortality was high during this study and weakened individuals may have been unable to or less inclined to feed. The corixids could also have been damaged in the handling involved in transferring them from the

storage container to the experimental tubs. It is also possible that corixids were weakened by long starvation periods.

Young & Ironmonger (1980) suggested the confined environment of dishes, without appropriate substrates may upset the behaviour pattern of test animals. The unnatural environment in the laboratory may have initiated atypical responses and as noted above, the presence of an observer may have caused disturbance. Despite the artificial conditions involved, a substantial percentage of animals accepted prey during the feeding trials. Feeding corixids may have been better adjusted to laboratory conditions than those that did not feed, or alternatively feeding may have allowed corixids to adjust to the conditions. Corixids that did not feed were either easily disturbed or remained stationary throughout the trial.

Sutton (1951) claimed that hungry *Corixa punctata*, *C. panzeri*, *Sigara dorsalis* and *S. falleni* showed an immediate positive reaction to food, facing the prey after 30 seconds or less and pouncing on it within two minutes. She stated that corixids which took up to half an hour to start feeding had little desire for food. The length of time before feeding was variable and could have been related to the hunger level of the corixid, the period taken by individuals to adjust to laboratory conditions or to the time taken to find prey.

Sutton (1951) found that the length of time spent feeding for corixids in the laboratory varied from 10mins to 3hrs 37mins and that feeding was generally continuous. She claimed that corixids that only fed for 10-15 minutes had little desire for food. Corixids fed for variable amounts of time during these experiments, however, 'hungry' corixids appeared to feed continuously or with short breaks, for 10 minutes or more.

Other authors have observed 'rubbing' and 'beating' in feeding corixids. Sutton (1951) observed corixids brushing the dorsal surface of the abdomen with the hind legs at irregular intervals and found that the movement could increase and become almost continuous. Reynolds (1975) and Reynolds & Scudder (1987a) also recorded regular hind limb motion in feeding corixids. Rapid palar and hind limb motion in response to abrupt movement of prey was observed in *Cenocorixa* spp. (Reynolds & Scudder 1987a). Sutton (1951) also observed beating or 'rowing' during feeding. Theories on the function of rubbing and beating will be discussed in Chapter 8.

**Chapter 8** 

# LABORATORY & FIELD BASED EXPERIMENTS ON HABITAT SELECTIVITY IN CORIXIDAE

## 8.1 Introduction

While much is written about the general habitat distribution of British species of Corixidae (see Section 5.4, Chapter 5 and below), little has been said about the niche or microhabitat in which each species dwells. Corixid distribution has been described in terms of climatic, physical, chemical and biotic factors.

Macan (1970, 1973, 1976) stated that each corixid species occupies distinct, sharply defined habitats, while Savage (1989) suggested that 'species specific patterns of ecological distribution exist among aquatic Hemiptera Heteroptera'. Fernando (1959) noted that corixid distribution is difficult to explain because of the mobility of the animals and problems in characterising aquatic habitats over time.

Popham (1943) suggested that the distribution of corixids changes with weather, time of day and season. He indicated that the controlling factor was temperature, and possibly also light intensity and hydrostatic pressure (Popham 1964). Temperature increased surfacing frequency, activity level and population density (Popham 1964), and on warm, windless days, corixids appeared to follow a thermal gradient to the shore where some migrated (Popham 1943, 1964, Fernando 1959). Dodson (1975) also claimed that temperature and its yearly pattern are important for corixid distribution. Corixids appeared to be negatively phototactic, remaining on the bottom of the pond most of the time, although, migrating animals appeared to be attracted to the light (Popham 1964). Popham (1964) also suggested that corixids move down a hydrostatic pressure gradient.

Different species of corixid are found at different conductivities. Sigara dorsalis appears to occur over a wide range of conductivity  $(50 - 5,000 \,\mu\text{Scm}^{-1})$ , S. distincta mainly occurs between 100 and 500  $\mu\text{Scm}^{-1}$ , S. fossarum occurs in a narrow band around 100  $\mu\text{Scm}^{-1}$  and S. scotti occurs at low conductivity (< 100  $\mu\text{Scm}^{-1}$ ) (Savage 1982, 1989, 1994, 1996). Dodson (1975), however, found that neither conductivity nor structural features explained the distribution of three corixid species in Colorado, but that altitude was the most important influence.

Comparisons have been made between corixid species and organic matter in the sediment (Macan 1938, 1954, Savage 1989). *S. dorsalis* occurs over a wide range of percentage

organic matter (om) in the sediment, *S. distincta* and *S. fossarum* are commonest between 10 and 50% om and *S. scotti* is commonest on sediments with more than 40% om (Savage 1989). Macan (1938) identified successions corresponding to different evolutions of percentage organic matter in the substratum.

Corixid species distribution is also significantly related to factors such as body morphometry, chemical composition, nature of the substratum and distribution of vegetation (Savage 1989). Scudder (1976) stated that the most important habitat requirements in corixids are availability of oviposition sites, water depth and salinity.

Savage & Pratt (1976) suggested that shelter was important to corixid distribution. Tully *et al.* (1991) considered chemical and structural variables more likely to have influenced corixid distribution indirectly, through biotic factors, than directly. Macan (1938) associated corixids with fine soil particles. Dodson (1975) indicated that microhabitats and food are also potentially important for corixid distribution. Laboratory investigations into corixid usage of different substrata and open water have yielded significant preferences in different species (Dodson 1975, Williams 1995).

Popham (1943) has shown that the colour of adult corixids is influenced by the colour of the habitat they live in before the final moult. He also suggested that habitat colour could affect corixid distribution, with animals selecting habitats they harmonise with. Habitat preferences can change during the lifecycle, as was found in *Cenocorixa bifida* and *C. expleta* (Scudder 1983).

Corixid distribution is probably also influenced by intra- and inter-specific interactions (Scudder 1976). Fish predation can alter corixid distribution, causing species to move out of open water to the safety of littoral vegetation (Macan1965b, Oscarson 1987, Savage 1989).

In large ponds and lakes, corixids are concentrated in the shallow water near the shore (Istock 1973), but in smaller, shallower ponds and tarns they can be found throughout the water body (Popham 1964, Macan 1965b, 1976). Corixids are predominantly shallow water animals (Popham 1964, Istock 1973, Scudder 1976, Applegate & Kieckhefer 1977). The maximum depth at which corixids can survive is restricted by the need to surface

periodically for air (Scudder 1976). Larger species, that are capable of swimming greater distances to the surface, can be found in deeper water than smaller species (Dodson 1975, Macan 1976). Applegate & Kieckhefer (1977) found that more than 87% of corixids in Lake Poinsett were at depths of 15-30 cm. Popham (1964) did not find corixids below 75 cm, but noted observations of corixids occurring at depths of up to 3 m. Popham (1964) also indicated that corixids tend to move to deeper water in the dark.

Laboratory based habitat selectivity experiments were designed to test the distribution of *Sigara dorsalis*, *S. distincta*, *S, fossarum* and *S. scotti* in macrophyte vegetation and open water. These were intended to further investigate the habitat niches exploited by the four species, in order to relate their high abundance in the wetlands to ecological information.

In order to accustom the investigator to observing corixids and to describe their range of activities, scoping experiments were first conducted. These supplemented knowledge acquired during the feeding trials (Chapter 7). In the habitat selectivity experiments all four species were tested in an aquarium with both *Myriophyllum* sp. and open water. During these experiments the activity, and the location of each animal with respect to depth, were also recorded.

A set of field based experiments was designed to supplement the laboratory habitat selectivity experiments. These investigated the use of macrophytes by corixids under natural conditions, and whether this use varied with macrophyte species and structure. Two different macrophyte types were studied. Differences in the abundance and species composition of corixids between the two plants were investigated.

# 8.2 Scoping Experiment for Habitat Selectivity

#### 8.2.1 Materials and methods

Twenty one scoping experiments were carried out between  $17^{th}$  December 1998 and  $14^{th}$  January 1999 in a constant temperature room at the Zoology, Department Trinity College Dublin, to look at behaviour of individual corixids. Corixids were collected from Turraun and Tumduff on  $2^{nd}$  December 1998 and  $9^{th}$  January 1999. The animals were stored and experiments were conducted in a room maintained at 15 °C and 12 hours light. Two different vessels were used to establish which shape and depth would be most appropriate for the habitat selectivity experiments. Sixteen experiments were performed in a 5000 ml beaker filled to a depth of 200-250 mm. Five experiments were conducted in a 240 x 320 x 60 mm white plastic tray. The number of each species and sex used in scoping experiments is presented in Table 8.1. Activity of two male *S. distincta* and two male and one female *S. fossarum* were observed in the tray.

Table 8.1The number of corixids tested in the scoping<br/>experiments for habitat usage

species	total	3	9
Sigara dorsalis	4	1	3
Sigara distincta	6	3	3
Sigara fossarum	8	6	2
Sigara scotti	3	2	1

A piece of vegetation was placed in the beaker or tray, along with some detritus and sediment. Corixids were introduced to the vessel at least 10 minutes before observations commenced. Scoping experiments, each lasting 30 minutes, were conducted at various times between 10:00 and 18:52. Focal animal sampling was used. This involved recording the duration of every behaviour occurring over the 30 minutes. A stopwatch was used to time behaviours. A sample of the recording sheet used is given in Appendix 8.2.1.

## 8.2.2 Results and discussion

Seven main activities or behaviours were identified and recorded (Table 8.2). These were perching, rubbing, beating, feeding, crawling, swimming and surfacing. Appendix 8.2.2

gives the amount of time spent by each test individual at each activity and also the frequency of occurrence of each activity.

Table 8.2The duration and frequency of seven activities during the scoping<br/>experiments. Duration of single events and total duration over experiment are<br/>given in seconds. Averages and ranges are given for animals that performed<br/>the relevant activity.

		duration of single event	total duration over 30 mins		freque over 30	-
	n	range	average	range	average	range
Perching	21	25-1800	1689	1273-1800	-	-
Rubbing	20	3-300	190	3-915	19	1-107
Feeding	17	5-300	171	3-765	7	1-43
Crawling	4	5-45	159	5-472	2	1-35
Beating	17	3-245	133	3-1215	10	1-61
Swimming	19	3-85	88	15-291	8	1-29
Surfacing	21	-	-	-	1	0-3

Corixids spent up to 100% of the experimental time perching. Perching involved the animal gripping a substratum (e.g. vegetation, sediment, vessel walls) with the claws of the mid limbs. Other authors have noted that the two slender tarsal claws of the mid legs are used to attach the corixid to underwater surfaces (Scudder 1976) and that anchoring is necessary, as their air stores make them extremely buoyant (Popham 1964, Scudder 1976). Corixids generally perched with the dorsal surface horizontal or sometimes with the head elevated above the abdomen or vice versa. Perching could be accompanied by other activities (rubbing, beating or feeding).

Rubbing was a complex procedure involving the hind legs, which were wiped repeatedly over the body. Generally both hind legs were rubbed simultaneously over the dorsal surface of the hemielytra. Corixids also rubbed greater areas of the body, moving from the ventral surface of the head to the dorsal surface and then down over the pronotum and hemielytra. On these occasions hind limbs were alternated or only one limb was used. Rubbing events lasted from 3 to 300 seconds (Table 8.2) and took up between 0.2 and 51% of the total experimental time in the 20 animals that engaged in the activity.

Rubbing appeared to be a form of grooming, perhaps used to remove particles of detritus or micro-organisms from the external surfaces. It is also possible that rubbing was a means of distributing secretions from the metathoracic scent gland around the body. Kovac & Maschwitz (1991) found that corixids use metathoracic gland secretions for grooming and suggested that they are used to kill micro-organisms on hydrofuge hairs and hence, prevent loss of air when submerged. It has also been suggested that these secretions are chemical defences against predators (Miller 1971, Scudder 1976, Savage 1989).

Rubbing almost always occurred in conjunction with feeding, though not all rubbing animals fed (see also Chapter 7). In most cases rubbing occurred directly after and/or immediately before a period of feeding. This suggests that rubbing may also be a method of removing food particles from the body surface before transferring them to the palae and ultimately the mouth. Reynolds and Scudder (1986a) also reported corixids rubbed or brushed the dorsal surface with the hind legs during feeding. Sutton (1951) suggested that it was in response to increased respiratory rate owing to digestive reactions.

Beating involved regular strokes of the hind limbs, resembling those used in swimming. It occurred while the animal remained perched in one location and was regularly intermingled with bouts of rubbing. 17 of the 21 animals tested performed this activity, which varied between one stroke and regular beating lasting up to 245 seconds. Beating was possibly used by corixids to remain balanced while perching. Beating often occurred when the animal was feeding (see Chapter 7) and may have generated currents connected with feeding or with gaseous exchange between the water and the physical gill. It was observed during the feeding trials (Chapter 7) that beating of the hind legs was often synchronised with palar movement. Sutton (1951) suggested that beating or 'rowing' was used to create a current to prevent the prey from escaping, although, as beating was observed to occur at times other than feeding this may not have been the exclusive reason.

Feeding was identifiable by alternate motions of the palae, in an anterior to posterior direction over the ventral surface of the head and maxillary plate. It has also been described in Chapter 7. Seventeen of the 21 test corixids fed during the course of the experiments and, as with rubbing and beating, the length of single feeding events was highly variable.

Feeding also accompanied crawling and indeed crawling appeared to be an activity restricted to the search for food. Corixids climbed along plant stems using the mid legs,

while scraping or removing biofilm with the palae. Only four corixids crawled, with crawling events lasting between 5 and 45 seconds.

When corixids were not perching or crawling they were swimming. 19 animals swam, with no individual swimming lasting more than one and a half minutes at a time. Corixids swam through the water column both in the beaker and the tray. Swimming may have been stimulated by the search for a perch, food or a secure hiding place.

Corixids also swam to the surface to facilitate respiration. Respiration in Corixidae is by means of trapped air bubbles and a thin layer of air held to the body by fine hairs (Popham 1964, Scudder 1976, Savage 1989). The size of the air bubble is increased by the fact corixids are dorso-ventrally flattened (Popham 1964). Corixids periodically visit the water surface, push the head and prothorax through the surface film and bend them forwards rapidly to refill these external air stores (Miller 1971, Scudder 1976, Popham *et al.* 1984a, Savage 1989). The trapped air also acts as a physical gill, with the diffusion gradient that develops as oxygen is respired and carbon dioxide released causing dissolved oxygen to be absorbed from the water into the air store (Popham 1964, Savage 1989). This allows corixids to survive entirely underwater at low temperatures (Popham 1964, Savage 1989). The first two instars do not need to surface, however, as they absorb dissolved oxygen through the integument (Scudder 1976, Savage 1989).

Animals surfaced between zero and three times during an experiment. Nine corixids did not surface. Surfacing generally involved swimming rapidly to the surface and down again, with most corixids returning to the same perch. Animals sometimes floated to the surface and swam back down. At least part of the time, this movement was accidental as animals floated upwards owing to buoyancy whilst clinging to broken pieces of vegetation. Corixids sometimes rested on the surface film and may have exposed themselves to the atmosphere for reasons other than respiration. Botjes (1971, cited in Popham 1964) indicated that corixids surface when the hydrostatic pressure is increased.

Another swimming activity that was identified during the scoping experiments may have resulted from the artificial conditions. This involved the animal swimming vigorously and repeatedly into the sides and bottom of both experimental containers. Corixids may not have detected these reflective surfaces.

The container used appeared to affect behaviour. Corixids tested in the tray generally spent more time swimming than other corixids, with the two *S. distincta* tested in the tray swimming for 165 and 145 seconds compared to a mean of 81 seconds for *S. distincta* in the beaker. The three *S. fossarum* tested swam for 15, 115 and 175 seconds, compared to a mean of 54 seconds in the beaker. All 16 test animals remained on or near the bottom of the beaker for almost the full duration of the experiment. Individuals used vegetation or sediment at the bottom to perch on. *S. fossarum* appeared to have a tendency to perch on detritus and sediment, while *S. distincta* perched on vegetation, however, this suggestion would need to be confirmed by experiment.

Looking at Appendix 8.2.2, it is clear that the amount of time spent at each activity was highly variable among individuals of the same species and even sex. Table 8.3 gives the average length of time spent by each species at each activity. Individuals that were tested in the tray were eliminated from these statistics. All species spent a lot of time perching, although, *S. fossarum* and *S. scotti* perched more on average than *S. distincta* and *S. distincta* and *S. distincta* and *S. fossarum* appeared to rub more than the other two species. *S. distincta* crawled and fed more than the other species.

species	sex	n	perching	rubbing	beating	feeding	swimming	crawling
Sigara distincta		4	1584	229	22	339	81	137
Sigara dorsalis		4	1677	142	325	158	102	21
Sigara fossarum		5	1745	259	92	178	54	1
Sigara scotti		3	1768	23	10	0	18	0
Sigara distincta	3	1	1725	337	65	25	75	0
	9	3	1538	193	8	444	83	182
Sigara dorsalis	3	1	1800	50	10	20	0	0
	9	3	1636	173	430	204	136	28
Sigara fossarum	3	4	1740	237	110	129	59	1
	9	1	1765	345	20	375	35	0
Sigara scotti	3	2	1765	15	3	0	15	0
-	9	1	1775	38	25	0	25	0

 Table 8.3
 The average duration in seconds of six activities for each species and sex, tested in the beaker.

Females of *S. distincta*, *S. dorsalis* and *S. fossarum* spent more time feeding than their male counterparts. *S. scotti* did not feed during the scoping experiments. Female *S. distincta* spent more time feeding than any other group. Male *S. distincta* and *S. dorsalis* 

appeared to perch more than female, however, only a single male individual of each was tested. The single male *S. distincta* also rubbed and beat more than the females. The male *S. dorsalis* spent less time rubbing, feeding and swimming than the three females. There were few if any marked differences between the sexes in *S. fossarum* and *S. scotti*, however, male *S. fossarum* beat more than female, and female *S. fossarum* rubbed more than male.

#### **8.3 Habitat Selectivity Experiments**

The seven activities described in Section 8.2 above (perching, rubbing, beating, feeding, crawling, swimming and surfacing) were easily detected and chosen for the habitat selectivity experiments. During the scoping experiments, corixids were found to use the bottom of the beaker frequently. The behaviour of animals appeared to be more 'natural' in the deeper beaker than in the shallow tray. Because of these facts, it was decided to use a 200 mm deep container. An aquarium was chosen over the beaker as the curved sides made observation difficult.

#### 8.3.1 Materials and methods

All corixids used in the habitat selectivity experiments were collected from Turraun and Tumduff between March and August 1999. Prior to the experiment, corixids were separated by species into  $325 \times 225 \times 200$  mm (volume  $1.5 \times 10^7$  mm<sup>3</sup>) aquaria with 50 to 100 mm of water, and provided with vegetation, peat and pebbles to perch upon. The aquaria were kept in a constant temperature room at 15 °C and 12 hours darkness, 12 hours light. Some corixids tested in the habitat selectivity experiments had earlier been used in the feeding trials (Chapter 7).

Experiments were conducted in a slightly smaller plastic aquarium (300 x 200 x 200 mm, volume  $1.2 \times 10^7 \text{ mm}^3$ ) kept at 15 °C in the same constant temperature room. Water was filled to 150 mm. The bottom and three sides of the aquarium were covered with brown and green coloured paper to reduce the reflectivity of the plastic and to mimic wetland conditions. The front of the aquarium was divided into a grid consisting of eighteen 50 x 50 mm squares (see Figure 8.1). The layer 0 to 50 mm deep was labelled 'A', 50 to 100 mm was 'B' and 100 to 150 was 'C'. Each 50 x 50 mm square was labelled 1 to 6 from left to right.

As corixids are considered bottom-dwelling organisms (Popham 1964, Scudder 1976), submerged plant species were thought most likely to have an influence on their distribution. *Myriophyllum* sp. was chosen for the experiments, as it was the most abundant submerged species in Turraun and as corixids were abundant at the sampling station with *Myriophyllum* (T4) (refer to Section 4.3.3, Chapter 4 and Chapter 5). Half of the aquarium was filled with *Myriophyllum* sp. (A1 to A3, B1 to B3 and C1 to C3) and half

kept as open water (A, B and C, 4 to 6). The plants were taken from Turraun and anchored in the aquarium using metal paper clips. Loose paper clips were also scattered around the open water half of the aquarium to eliminate any bias caused by their presence.

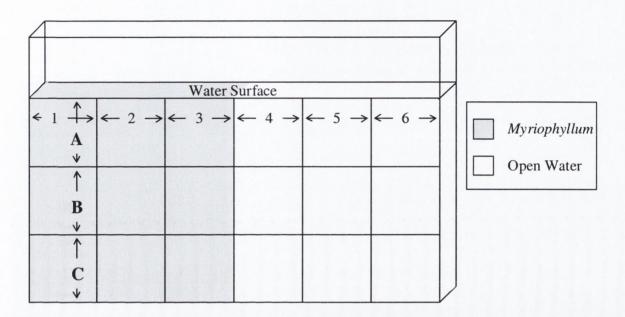


Figure 8.1 Schematic of the experimental set up for habitat selectivity investigations

Experiments were conducted between 2<sup>nd</sup> March and 10<sup>th</sup> August 1999, and between 11:00 and 13:00 each day to avoid the effect of any daily rhythms. The corixids were transferred from holding aquaria in the same constant temperature room to the test aquarium using a tea strainer with 1 mm plastic mesh. They were given a 10 to 30 minute period to adjust to the new conditions. Six corixids were tested in each individual experiment. This number was chosen as the largest number possible to observe in an instant, without confusing individuals and was also the figure chosen by Dodson (1975). Animals were observed for 30 minutes, scan sampling every minute to record location (e.g. A1, C4 etc.) and activity of each corixid. Thus, each experiment consisted of six animals with 31 scans or observations taken of each, totalling 186 observations per experiment.

On the recording sheet a column was assigned to each of the chosen activities (e.g. perching with rubbing, swimming on the surface, swimming into the walls of the aquarium). The location of the corixids at any one instant was recorded in the relevant cell. A sample of the recording sheets used is given in Appendix 8.3.1.

It generally took 15 seconds to complete a single scan of all six corixids, although individual corixids were sometimes so well concealed in the vegetation that it took the full minute to locate them. Corixids were removed from the aquarium directly after the experiment and examined under a dissection microscope to confirm species and to identify the sex. The corixids were then returned to a resting tank in the constant temperature room.

Initially it was intended to conduct six individual experiments for each species (i.e. 36 animals per species). Owing to the low abundance of *S. dorsalis* in Turraun and Tumduff and the mortality of corixids in captivity, only two experiments were conducted with *Sigara dorsalis*. Five experiments were completed and analysed for *S. distincta*, six for *S. fossarum* and six for *S. scotti*.

Data were sorted, subtotals calculated and graphs plotted on Microsoft Excel 97<sup>®</sup>. Statistical tests were performed using Data Desk 6.0<sup>®</sup>.

#### 8.3.2 Results

All four species spent more time in vegetation than in open water (Table 8.4). *Sigara dorsalis* showed the greatest affiliation with vegetation with 99% of observations coming from *Myriophyllum*. 53% of observations made on 30 *Sigara distincta* individuals tested were from vegetation and 55% of observations on 36 *S. fossarum*. 61% of observations on *S. scotti* were made in vegetation.

Table 8.4Average use of vegetation (Myriophyllum) and open<br/>water by four Corixidae species in the habitat<br/>selectivity experiments. V:O gives the ratio of<br/>observations in vegetation to those in open water. The<br/>percentage of observations made in vegetation and in<br/>open water is also given.

species	V	:0	% in V	% in O
Sigara dorsalis	1	: 0.044	99	1
Sigara distincta	1	: 0.896	53	47
Sigara fossarum	1	: 1.231	55	45
Sigara scotti	1	: 0.674	61	39

S. dorsalis spent significantly more time in vegetation than in open water (Mann Whitney U, z-statistic = -10.84,  $p \le 0.0001$  at  $\alpha = 0.05$ ). There was no significant difference in distribution of S. distincta between vegetation and open water and the percentages observed in vegetation were reasonably consistent in each of the experiments (Table 8.5). The results for 9<sup>th</sup> June 1999 did not follow the general trend, and when these were omitted significantly more of S. distincta observations were from vegetation (vegetation (paired t-test, t = -4.9, p  $\le 0.0001$  at  $\alpha = 0.001$ ).

Table 8.5Use of vegetation (Myriophyllum) and open water by four Corixidaespecies in each of the habitat selectivity experiments.V:O gives the ratio ofobservations in vegetation to those in open water.The percentage ofobservations made in vegetation and in open water is also given.

date	species	3	9	V : O	% in V	% in O
3 <sup>rd</sup> Mar 99	Sigara dorsalis	5	1	1:0.02	97.8	2.2
4 <sup>th</sup> Mar 99	Sigara dorsalis	0	6	1:0	100.0	0
25 <sup>th</sup> Mar 99	Sigara distincta	2	4	1:0.65	60.5	39.5
25 <sup>th</sup> Mar 99	Sigara distincta	1	5	1:0.84	54.3	45.7
31 <sup>st</sup> Mar 99	Sigara distincta	3	3	1:0.81	55.4	44.6
9 <sup>th</sup> Jun 99	Sigara distincta	3	3	1:1.19	45.6	54.4
10 <sup>th</sup> Aug 99	Sigara distincta	4	2	1:0.99	50.3	49.7
2 <sup>nd</sup> Mar 99	Sigara fossarum	4	2	1:0.38	72.6	27.4
3 <sup>rd</sup> Mar 99	Sigara fossarum	0	6	1:0.33	75.3	24.7
5 <sup>th</sup> Mar 99	Sigara fossarum	2	4	1:0.26	79.6	20.4
30 <sup>th</sup> Mar 99	Sigara fossarum	3	3	1:1.39	41.9	58.1
20 <sup>th</sup> Apr 99	Sigara fossarum	6	0	1:1.91	34.4	65.6
22 <sup>nd</sup> Apr 99	Sigara fossarum	4	2	1:3.13	24.2	75.8
5 <sup>th</sup> Mar 99	Sigara scotti	3	3	1:0.48	67.6	32.4
16 <sup>th</sup> Jun 99	Sigara scotti	2	4	1:0.48	67.6	32.4
19 <sup>th</sup> Jun 99	Sigara scotti	4	2	1:0.59	62.9	37.1
6 <sup>th</sup> Jul 99	Sigara scotti	2	4	1:0.62	61.8	38.2
9 <sup>th</sup> Jul 99	Sigara scotti	4	2	1:1.16	46.4	53.6
15 <sup>th</sup> Jul 99	Sigara scotti	1	5	1:0.72	58.1	41.9

S. fossarum spent significantly more time in vegetation (paired t-test based on time in seconds, t = -2.663, p = 0.0084 at  $\alpha$  = 0.05), although this difference was not significant at  $\alpha$  = 0.001 or using the Mann Whitney U test. Two different patterns emerged in the S. fossarum tested. In experiments conducted on the 2<sup>nd</sup>, 3<sup>rd</sup> and 5<sup>th</sup> of March 1999, an average of 76% of observations were from the vegetation. Significantly more observations were from vegetation on these dates (Mann-Whitney U, z statistic = -12.128, p ≤ 0.0001 at  $\alpha$  = 0.05). In experiments from 30<sup>th</sup> March, 20<sup>th</sup> April and 22<sup>nd</sup> April 1999, an average of only 33.5% of observations were from vegetation and S. fossarum spent significantly more time in open water (paired t-test, t = 11.18, p ≤ 0.0001 at  $\alpha$  = 0.001). Females were more

abundant than males in two of the three tests in which vegetation was utilised more than open water, and males were more abundant than females in two out of three tests in which open water was more utilised.

The percentages of *S. scotti* observed in vegetation were reasonably consistent in each of the experiments and it spent significantly more time in vegetation than open water (paired t-test, t = -10.52, p  $\le$  0.0001 at  $\alpha$  = 0.001).

Table 8.6 Use of differen	it depths by four	Corixidae specie	es in the habitat selectivity
experiments.	The percentage	of observations	made at the three depth
intervals is give	en. A was 0 to 50	mm, B 50 to 100	mm and C was 100 to 150
mm.			

date	species	3	9	% in A	% in B	% in C
3 <sup>rd</sup> Mar 99	Sigara dorsalis	5	1	3.8	19.9	76.3
4 <sup>th</sup> Mar 99	Sigara dorsalis	0	6	17.2	0	82.8
	Average			10.5	9.9	79.6
25 <sup>th</sup> Mar 99	Sigara distincta	2	4	1.6	1.1	97.3
25 <sup>th</sup> Mar 99	Sigara distincta	1	5	1.6	7.0	91.4
31 <sup>st</sup> Mar 99	Sigara distincta	3	3	0.5	3.2	96.3
9 <sup>th</sup> Jun 99	Sigara distincta	3	3	10.3	6.0	83.7
10 <sup>th</sup> Aug 99	Sigara distincta	4	2	14.6	36.8	48.6
	Average			5.7	10.8	83.5
2 <sup>nd</sup> Mar 99	Sigara fossarum	4	2	47.3	12.4	40.3
3rd Mar 99	Sigara fossarum	0	6	36.0	7.0	57.0
5 <sup>th</sup> Mar 99	Sigara fossarum	2	4	8.1	29.0	62.9
30 <sup>th</sup> Mar 99	Sigara fossarum	3	3	6.5	4.8	88.7
20 <sup>th</sup> Apr 99	Sigara fossarum	6	0	6.5	4.8	88.7
22 <sup>nd</sup> Apr 99	Sigara fossarum	4	2	11.8	10.8	77.4
	Average			19.3	11.5	69.2
5 <sup>th</sup> Mar 99	Sigara scotti	3	3	69.7	13.5	16.8
16 <sup>th</sup> Jun 99	Sigara scotti	2	4	19.4	15.7	64.9
19 <sup>th</sup> Jun 99	Sigara scotti	4	2	4.8	8.1	87.1
6 <sup>th</sup> Jul 99	Sigara scotti	2	4	12.4	32.8	54.8
9 <sup>th</sup> Jul 99	Sigara scotti	4	2	19.3	21.1	59.6
15 <sup>th</sup> Jul 99	Sigara scotti	1	5	10.2	21.0	68.8
	Average			22.6	18.7	58.7

In general all species used the lower depths (from 100 mm deep to the bottom of the aquarium at 150 mm) more than the top 100 mm (Table 8.6). *S. dorsalis* made use of all three layers, but used layer C significantly more than A or B ( $F_{2, 183} = 755.99$ ,  $p \le 0.0001$  and LSD post-hoc tests). *S. distincta* used this lower layer significantly more than layers A and B, and used layer B more than layer A ( $F_{2, 462} = 1027$ ,  $p \le 0.0001$  and LSD post-hoc tests). The pattern was similar in *S. fossarum* ( $F_{2, 555} = 585.15$ ,  $p \le 0.0001$  and LSD post-hoc

hoc tests). Again there appeared to be a difference in the use of depth between the *S*. *fossarum* individuals tested on  $2^{nd}$ ,  $3^{rd}$  and  $5^{th}$  of March and those tested on the  $30^{th}$  March and  $20^{th}$  and  $22^{nd}$  April, although it did not prove significant. Between 40 and 63 % of observations on the former dates were made in layer C, while up to 29% of observations were made in layer B and 47% in layer A. On the latter dates 77 to 89% of observations were made in layer C.

S. scotti made use of all three depth layers to a larger extent than other species, but spent significantly more time in C than A and B ( $F_{3, 585} = 42.064$ ,  $p \le 0.0001$  and LSD post-hoc tests). S. scotti spent significantly less time in layer C than all other species and S. fossarum spent significantly less time in C than S. distincta or S. dorsalis, B ( $F_{2, 555} = 182.87$ ,  $p \le 0.0001$  and LSD post-hoc tests).

Corixids spent a large percentage of all experiments perching (Table 8.7). Perching involved corixids gripping vegetation or the aquarium bottom with the claws of the mid legs, and was often accompanied by rubbing of the body with the hind limbs, beating of the hind limbs and/or feeding (refer also to 8.2 above and Chapter 7). *S. dorsalis* perched during 94-95% of observations, *S. distincta* during 56-91%, *S. fossarum* during 45-90% and *S. scotti* during 47-73%.

Rubbing was encountered in all experiments and in 1-17% of observations. Hind limb beating was found in 17 of the 19 experiments and during 1-19% of observations. During 13 of the 19 experiments, corixids fed and during three tests, corixids were observed to crawl along *Myriophyllum* stems while feeding. Feeding was always accompanied by rubbing and/or beating, however, both rubbing and feeding occurred in the absence of feeding.

Swimming was also frequently observed, and involved swimming to the surface to replenish air supply, swimming on the surface film or swimming around the aquarium. Some corixids were more active than others. During eight experiments, corixids were observed to swim repeatedly into the aquarium sides and bottom in an agitated fashion. This was particularly notable in *S. fossarum* (e.g. 2<sup>nd</sup> and 30<sup>th</sup> March). Corixids, particularly *S scotti* were noted to rest on the surface film during 11 of the 19 experiments.

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This occurred during a high percentage of observations for *S. fossarum* on 3<sup>rd</sup> March and for *S. scotti* on 5<sup>th</sup> March, 16<sup>th</sup> June and 9<sup>th</sup> July.

**Table 8.7** The percentage of observations made in which the four Corixidae species performed nine identified behaviours. n is 6 for all dates. P, perching; PR, perching with rubbing, PB, perching with beating; PF, perching with feeding;  $\Sigma P$ , sum of perching, CF, crawling and feeding; S, swimming; SS, swimming at the surface; SA, swimming into aquarium walls;  $\Sigma S$ , sum of swimming; RS, resting at surface.

date	species	Р	PR	PB	PF	ΣΡ	CF	S	SS	SA	ΣS	RS
3 <sup>rd</sup> Mar 99	Sigara dorsalis	63	12	19	0	94	0	5	0	0	5	0
4 <sup>th</sup> Mar 99	Sigara dorsalis	83	6	4	2	95	4	1	0	0	1	0
25 <sup>th</sup> Mar 99	Sigara distincta	81	2	2	2	87	0	11	1	2	14	0
25 <sup>th</sup> Mar 99	Sigara distincta	75	3	12	1	91	2	5	2	0	7	0
31 <sup>st</sup> Mar 99	Sigara distincta	66	3	1	8	78	0	16	1	6	23	0
9 <sup>th</sup> Jun 99	Sigara distincta	43	3	10	0	56	0	32	1	2	35	9
10 <sup>th</sup> Aug 99	Sigara distincta	52	1	12	0	65	0	34	0	1	35	0
2 <sup>nd</sup> Mar 99	Sigara fossarum	52	10	7	3	72	0	15	0	12	27	1
3 <sup>rd</sup> Mar 99	Sigara fossarum	58	1	12	1	72	0	10	0	0	10	18
5 <sup>th</sup> Mar 99	Sigara fossarum	66	17	6	1	90	0	6	1	2	9	0
30 <sup>th</sup> Mar 99	Sigara fossarum	41	4	0	0	45	0	23	0	31	54	1
20 <sup>th</sup> Apr 99	Sigara fossarum	37	8	1	1	47	0	52	0	0	52	2
22 <sup>nd</sup> Apr 99	Sigara fossarum	51	2	5	3	61	0	30	1	0	31	8
5 <sup>th</sup> Mar 99	Sigara scotti	54	5	0	0	59	0	10	0	1	11	30
16 <sup>th</sup> Jun 99	Sigara scotti	60	1	1	1	63	0	25	1	0	26	12
19 <sup>th</sup> Jun 99	Sigara scotti	43	1	1	2	47	0	50	3	0	53	0
6 <sup>th</sup> Jul 99	Sigara scotti	52	4	12	1	69	0	29	1	0	30	2
9 <sup>th</sup> Jul 99	Sigara scotti	46	6	9	12	73	4	12	0	0	12	11
15 <sup>th</sup> Jul 99	Sigara scotti	49	8	1	0	58	0	40	0	0	40	3

Corixid behaviour appeared to change over time. On 25<sup>th</sup> and 31<sup>st</sup> March 1999, *S. distincta* individuals were perching during 78 to 91% of scans. On 9<sup>th</sup> June and 10<sup>th</sup> August, *S. distincta* perched during only 56 and 65% of observations and correspondingly the time spent swimming increased (35% of observations). *S. fossarum* individuals were perching during a high percentage (72-90%) of scans on the 2<sup>nd</sup>, 3<sup>rd</sup> and 5<sup>th</sup> March 1999. On the 30<sup>th</sup> March, however, *S. fossarum* perched during 45% of observations and on 20<sup>th</sup> and 22<sup>nd</sup> April, during 47 and 61%. The percentage of observations in which the animals were swimming on these dates, was 54, 52 and 31% respectively. Little variation was seen over time in *S. scotti*, with the animals swimming during a large percentage of observations (11-53%) on all dates.

Looking at all three tables together (Tables 8.5, 8.6 and 8.7) a few interesting patterns emerge. On 10<sup>th</sup> August, *S. distincta* individuals used open water and layers A and B in significantly more observations than in other experiments (Layer A F<sub>1, 153</sub> = 41.4,  $p \le 0.0001$  and LSD post-hoc tests, Layer B F<sub>1, 153</sub> = 195.8,  $p \le 0.0001$  and LSD post-hoc tests). These individuals also swam and rested on the surface film more than most other *S. distincta*. *S. distincta* tested on 9<sup>th</sup> June also swam during a high percentage of scans (34%), although, they concentrated this in layer C, using layer A in only 10% of observations and layer B in 6%. *S. dorsalis* perched on vegetation in all three layers, but mainly in layer C, for most of the two experiments.

The *S. fossarum* individuals of  $2^{nd}$ ,  $3^{rd}$  and  $5^{th}$  March were observed most frequently in vegetation and used layers A and B significantly more frequently than those from the  $30^{th}$  March and  $20^{th}$  and  $22^{nd}$  April (Layer A F<sub>1, 184</sub> = 78.8, p  $\leq 0.0001$  and LSD post-hoc tests, Layer B F<sub>1, 184</sub> = 28.8, p  $\leq 0.0001$  and LSD post-hoc tests). *S. fossarum* from the former dates were perching during most scans. *S. fossarum* tested on the other three dates ( $30^{th}$  March,  $20^{th}$  and  $22^{nd}$  April), were more active and appeared to spend much of the experiment swimming through C5, 6 and 7 in the open water. With the exception of  $9^{th}$  July, approximately 60% of observations on *S. scotti* were from vegetation. On  $9^{th}$  July there was no significant difference between the number of *S. scotti* observed in vegetation and open water and individuals were perching during 73% of scans and resting at the surface during 11%. A number of these observations were made from open water. On  $5^{th}$  March, *S. scotti* individuals were resting at the surface during 30% of observations and this resulted in corixids frequently being found in layer A. *S scotti* swam very frequently (50% of scans) around layer C on 19<sup>th</sup> June.

#### 8.3.3 Discussion

All four species were observed more frequently in vegetation than in open water. Corixids may have preferred vegetation to open water, as it was a source of food and a perching substrate. In the wild, macrophyte beds would provide an abundance of animal and vegetable prey when compared with open water or bare sediment (see also Section 4.4.2, Chapter 4). Vegetation also provides an oviposition site (Scudder 1976). Plants may be associated with predator avoidance, and can provide protection to corixids from predators

such as *Notonecta* and *Dytiscus*, but not from others, e.g. *Aeshna*, *Enallagma* or *Ischnura* nymphs (Dodson 1975).

Sigara dorsalis showed the clearest preference for vegetation. This result must be treated with some caution, however, as only 12 individual *S. dorsalis* were tested. *S. dorsalis* individuals perched on *Myriophyllum* in all three layers but were most frequently found in the lower layer of the aquarium, suggesting that under natural conditions this species is associated with vegetation near the bottom of the littoral zone. Most *S. dorsalis* individuals perched in a single location, rubbing or beating with the hind legs or feeding. It is possible that these actions indicated that the corixids adjusted well to the experimental conditions. There was a slight suggestion that *S. dorsalis* beat more frequently than the other species in the scoping and habitat selectivity experiments, which may be related to feeding behaviour.

Williams (1995) tested *S. dorsalis* and *S. lateralis* in a white tray, filled to 20 mm, half covered in *Ranunculus aquatalis* and half open. The results showed that *S. dorsalis* was significantly associated with vegetation and that *S. lateralis* was significantly associated with open water. He attributed the former association to diet and presumed that *S. dorsalis* grazes algae off submerged vegetation. Williams (1995) also observed that *S. dorsalis* rarely rested in open water but settled whenever they made contact with vegetation. Dodson (1975) conducted similar aquarium experiments outdoors using sedges and mud and found that *Callicorixa audeni* Hungerford occupied emergent sedges more than *Cenocorixa bifida*.

S. distincta appeared to prefer vegetation to open water and it was most strongly associated with the lower layer of the aquarium. Many of the individuals perched on vegetation or paper clips at the very bottom of the aquarium. These results suggest that under natural conditions, S. distincta is associated with deeper water either on open sediment or in vegetation.

*S* distincta tested on 9<sup>th</sup> June and 10<sup>th</sup> August were very active, with those from 9<sup>th</sup> June more frequently observed swimming in open water than *S*. distincta from other dates. The six corixids tested on 10<sup>th</sup> August were found in layer A and B during a greater percentage of observations than other *S*. distincta tested. *S*. distincta was perching in a very large

percentage of observations in March. Swimming, particularly when it involved repeated collisions with the aquarium walls, may have indicated that corixids were agitated or disorientated. Both sets of corixids appeared to be very aware of the observer and to be disturbed by movement. Considering the time of year these experiments were conducted, these corixids were probably new recruits to the population and may have been more easily 'agitated' or 'disturbed' than more mature adults under experimental conditions. It is also possible that tenerals are naturally more likely to explore their habitats than are more mature adults or that the tenerals may have been stimulated to migrate. Migration, which was discussed in Chapter 5, can occur at minimum temperatures of 12-18 °C and frequently occurs in August and September (Fernando 1959, Popham 1964, Savage 1989). It is possible that *S. distincta* in June and August were attempting this migration.

Crawling appeared to be more frequent in *S. dorsalis* and *S. distincta* than in the other two species in both the scoping and habitat selectivity experiments. This could indicate that these species have an association with vegetation, either as a preferred habitat or a food source.

The distribution of *S. fossarum* was highly variable. Corixids from the experiments on  $2^{nd}$ ,  $3^{rd}$  and  $5^{th}$  March were found more frequently in vegetation than those of the  $30^{th}$  March,  $20^{th}$  and  $22^{nd}$  April. The former corixids appeared to spend most of the experimental time perched amongst vegetation at all depths and were also observed rubbing, beating and feeding. *S. fossarum* tested on  $30^{th}$  March and  $20^{th}$  and  $22^{nd}$  April were more frequently found swimming in the lower layer of the open water. These differences may reflect behavioural differences between the sexes, with females being more sedentary and associated with vegetation and males being more mobile and associated with open water. It is also possible that differences in distribution may be owing to differing food preferences between the sexes.

The lack of consistency in the distribution of *S. fossarum* may indicate that vegetation does not significantly influence the distribution of the species. Rather, sediment may be the governing factor. Certain corixid species may have a preference for open water and bare sediment because of low competition from other animals. Invertebrate predation would also be lower in these areas. Those *S. fossarum* which swam frequently did so at the bottom of the open side of the aquarium. *S. fossarum* also swam into the aquarium bottom

more than any other species. Dodson (1975) stated that corixids spend more time swimming and less perching when the substrate is unsuitable. These animals may have been agitated by the experimental conditions and it is possible that they were attempting to reach sediment on the bottom of the 'water body'. *S. fossarum* may be a species associated with bottom sediment in natural conditions.

*S. fossarum* perched during most of the observations in early March 1999, but swam during a high percentage of observations on 30<sup>th</sup> March and 20<sup>th</sup> and 22<sup>nd</sup> April. The activity on the latter dates may have indicated that these corixids were attempting to emigrate from the habitat, and a number of authors note that spring months are one of two main periods of migration in corixids (Fernando 1959, Popham 1964, Savage 1989). Mating behaviour could also be responsible for the increased activity. Corixids mate in April/May (Savage 1989), and these animals may have been searching for a mate or attempting to find the shoreline where corixids naturally pair off (Savage 1989).

S. scotti used vegetation slightly more frequently than open water and was well distributed at all depths. This species did not perch on the bottom of the aquarium as frequently as the other species. These facts suggest that S. scotti has less association with the bottom sediment of a water body than other species and that it is a species of shallow water, sometimes associated with vegetation.

S. scotti swam frequently during all tests. This was in contrast with the scoping experiments where S. scotti perched more than the other three species and spent little time swimming. The fact that S. scotti swam during the habitat selectivity experiments may represent a difference in behaviour between it and other species, possibly in relation to feeding strategies. S. scotti may have been actively searching for food or gathering suspended material from the water column. The fact that S. scotti also rested at the surface more frequently than other species may have indicated that it needs to surface to replenish air supplies regularly or that certain individuals were attempting to migrate. It is possible that the six corixids tested in March were attempting to emigrate.

The fact that corixids were most frequently found near or at the bottom of the aquarium, supports the assertion that corixids usually remain at the bottom of water bodies (Popham 1964, Scudder 1976). The amount of time spent perching reflects their need to anchor

themselves, as their air stores make them extremely buoyant (Popham 1964, Scudder 1976).

As in the feeding trials and scoping experiments, it was clear during the habitat selectivity experiments that behaviour was highly variable among individuals of the same species. Some corixids remained perched quietly, others fed and crawled amongst vegetation, whilst still others were very active. These differences reflect the complexity of corixids behaviour. The time of the year on which the experiment was conducted may have influenced corixid behaviour. Animals tested around March or August/September may have been attempting to migrate, while corixids tested during April/May could have been searching for a mate or for suitable oviposition sites. The corixids used later in the summer may have been new recruits, with greater energy levels and inclination to explore the habitat.

It is possible that perching quietly was a defensive strategy adopted to avoid notice and that corixids engaging in this activity were aware of the presence of the observer. Animals perching on vegetation may not only have used it as support, but also as a method of concealing the corixid from threats. Corixids that perched, fed, rubbed, crawled and swam amongst the vegetation appeared to be better adjusted to the experimental conditions (see also Chapter 6).

Animals that swam constantly or swam repeatedly into the sides and bottom of the aquarium could perhaps be considered 'agitated'. Agitation may have been a result of the animal's search for a perch on vegetation or sediment, and indeed some individuals settled once they found vegetation. Dodson (1975) found that corixid activity was high over unsuitable sediment. Popham (1943) found greater activity in corixids that did not harmonise with the colour of the background. Different colour and reaction could have been variable. Corixids regularly perched on paper clips and it appeared that they could not perch directly on the smooth aquarium bottom. Also, adjacent animals sometimes disturbed each other, as was found by Popham (1964) and Dodson (1975). In these respects differences in behaviour between individuals may have been very much related to chance. It is also possible that swimming animals were searching for food and that behavioural differences were owing to hunger level.

The artificial test conditions probably caused corixids to alter behaviour (Young & Ironmonger 1980, Reynolds & Scudder 1987a) and the reflective nature of the walls of the aquarium may have caused confusion. Corixids are attracted to reflective surfaces and have been found on car tops, wet tar, greenhouses, wet streets etc. (Popham 1964, Scudder 1976, Savage 1989). It is also possible that agitated corixids had become aware of an observer, while other animals had not. On a number of occasions individuals that were facing the observer directly were disturbed by movement. Reynolds & Scudder (1987a) also found that corixids reacted to jerky movements in water. This suggests that corixids use vision, or perhaps vibrations or pressure, to detect the presence of threats. Corixidae have relatively large compound eyes and reduced antennae (Scudder 1976) and Popham (1964) claimed they are almost entirely reliant on their eyes for orientation. Corixids become very active in bright light (Popham 1964) and the artificial lighting in the constant temperature room may have increased activity, particularly in corixids that were not sheltered by vegetation. Finally, factors such as the fan in the constant temperature room may have caused disturbance to the corixids. This was very noisy when in operation periodically and may have caused vibrations in the aquarium.

Laboratory based observation of corixids is invaluable to learning more about habitat usage and distribution of different species. Further experiments of this type could be conducted to investigate the effects of density, the time of experiment, competition and predation. Future work should concentrate on a small number of specific prey items, in order to identify significant differences in diet among species. Corixid behaviour is another area that merits further study, particularly in relation to the stimuli that induce different responses.

#### 8.4 Field Based Habitat Usage Studies

#### 8.4.1 Materials and methods

On 25<sup>th</sup>, 26<sup>th</sup> and 27<sup>th</sup> August 1999, samples were taken in four macrophyte stands at Turraun, two stands of *Myriophyllum* sp. and two of *Hippuris* sp. Each macrophyte stand was sampled at three sampling points along a transect perpendicular to the shore. At each sampling point, five replicate samples were taken parallel to the shore (Figure 8.2).

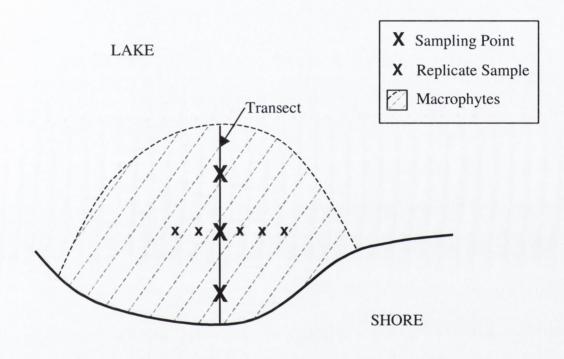


Figure 8.2 Arrangement of corixid transects

The distance between sampling points was chosen on the basis of depth, aiming to achieve a depth difference of 50 mm between each sampling point. *Hippuris* stands were less extensive than *Myriophyllum*, and this fact combined with the irregularity of the substratum under *Hippuris* made it difficult to achieve a regular 50 mm depth difference. As *Hippuris* grows in shallower water than *Myriophyllum*, there was a slight difference in the depths of the sampling points. A length of rope anchored to the shore defined the transect and the distance between the sampling points and the shore was measured.

The sampling method involved placing a plastic tube over undisturbed vegetation and removing all corixids retained within it. The 600 mm long tube had a radius of 155 mm

and a serrated bottom edge to allow it to cut through vegetation and lodge in the bottom sediment. This tube was chosen, as it was small enough to encompass a uniform patch of vegetation and sediment, while large enough to contain a number of corixids. A 125 x 100 mm aquarium-style fish net with 1 mm mesh was used to sweep the water and vegetation within the tube and to remove corixids. Istock (1973) employed a similar method, using a cylindrical, open ended dip net. Depth was measured with a metre stick at every replicate sample. Weather conditions, slope, sediment and other relevant factors were noted.

Wind direction and safety determined the order in which samples were taken. Samples were first taken upwind of the transect to ensure that any disturbance caused was not carried to the other sampling points. In most transects the point nearest the shore was sampled first and replicate samples were taken from right to left.

Corixids were transferred directly from the net to a white tray and carried back to shore. The sample was then sorted and corixids were placed in 30 ml plastic jars filled with 90% industrial methylated spirits. Samples were transported back to the laboratory and identified using Savage's FBA key to Heteroptera (1989).

All four transects were taken over peat to keep sediment constant, and away from the sampling stations used in the general macroinvertebrate and Corixidae surveys. *Myriophyllum* transect 1 was on the western side of Turraun about 10-20 m south of sampling station T1 (refer to Plate 3). *Myriophyllum* 2 was approximately 20 m south of *Myriophyllum* 1 on the western shore. *Hippuris* 1 was approximately 20 m south of *Myriophyllum* 2 and *Hippuris* 2 was on the east side of the wetland near the south east corner.

*Myriophyllum* 1 had very fine peat sediment with attached epipelic organisms and very dense vegetation. The sampling points at *Myriophyllum* 1 were labelled A, B and C. A was 200 mm deep and c. 3 m from the shore, B was 260 mm deep and c. 4.5 m from the shore and C was 300 mm deep and c. 9 m from the shore. A and B were taken on 25<sup>th</sup> August, C was taken on 26<sup>th</sup> August 1999.

*Myriophyllum* 2 had fine peat sediment along with granular peat. The sampling points were labelled D, E and F. D was 150 mm deep and c. 1.5 m from the shore, E was 210

mm deep and c. 3 m from the shore and F was 300 mm deep and c. 5 m from the shore. *Myriophyllum* 2 was sampled on 26<sup>th</sup> August 1999.

*Hippuris* 1 was a patch of mare's tail offshore of a stand of *Typha*. The sediment was very soft and quaking and consisted of granular peat. The sampling points were labelled G, H and I. G was 80 mm deep and c. 3 m from the shore, H was 110 mm deep c. 4 m from the shore and I was 200 mm deep and c. 5.5 m from the shore. The replicates were closely spaced as the vegetation was sparse. G and H were completed on 25<sup>th</sup> August and I was sampled on 26<sup>th</sup> August 1999.

*Hippuris* 2 consisted of a mixture of granular peat, with some pieces ranging up to large pebble size, and a solid compacted peat bank. The sampling points were labelled J, K and L. J was 100 mm deep and about 1 m from the shore, K was 130 mm deep and about 1.5-2 m from the shore and L was 180 mm deep and c. 3 m from the shore. *Hippuris* 2 was sampled on the 27<sup>th</sup> August.

Data were sorted, subtotals calculated and graphs plotted on Microsoft Excel 97<sup>®</sup>. Statistical tests were performed using Data Desk 6.0<sup>®</sup>.

#### 8.4.2 Results

Corixids were more abundant and a greater number of species was found in *Myriophyllum* than in *Hippuris*. No clear trends emerged between corixid abundance and depth or distance from shore (Appendix 8.4.2 gives a summary table of corixid abundance with depth and distance from shore).

531 animals were found in the two *Myriophyllum* transects as opposed to only 13 in the two *Hippuris* transects. Seven species were captured in *Myriophyllum*, while only three species were found in *Hippuris*; corixid nymphs were recovered from both vegetation types (see Table 8.8). The full data sheet, detailing the number of each species in each replicate of the four transects, is presented in Appendix 8.4.2.

There was a significant difference between transects in terms of total number of corixids ( $F_{3,56} = 56.3$ ,  $p \le 0.0001$ ). LSD post-hoc tests showed that both *Myriophyllum* transects

had significantly more corixids than the *Hippuris* transects. There was no significant difference between the two *Hippuris* transects, although, *Myriophyllum* 1 had significantly more corixids than *Myriophyllum* 2.

species	Myriophyllum	Hippuris
Callicorixa praeusta	11	1
Corixa panzeri	3	0
Hesperocorixa linnaei	2	0
Sigara dorsalis	83	2
Sigara distincta	16	1
Sigara fossarum	10	0
Sigara scotti	15	0
Corixid Nymphs	391	9

Table 8.8The total number of each corixid species<br/>captured in the Myriophyllum and<br/>Hippuris transects.

The abundance of *Sigara dorsalis* ( $F_{3,56} = 16.3$ ,  $p \le 0.0001$ ), *S. fossarum* ( $F_{3,56} = 8.3$ , p = 0.0001) and corixid nymphs ( $F_{3,56} = 41.7$ ,  $p \le 0.0001$ ) was significantly different between transects. There were significantly more of all three corixids in *Myriophyllum* 1 than in *Hippuris* 1 or *Hippuris* 2 (LSD post-hoc tests). There were also more of each in *Myriophyllum* 1 than in *Myriophyllum* 2, although the differences were less marked than with *Hippuris*. There were significantly more corixid nymphs in *Myriophyllum* 2 than in *Hippuris* 1 or *Hippuris* 2. Numbers of other species were too low to detect significant differences.

#### 8.4.3 Discussion

Many more species and more individuals were found in the *Myriophyllum* transects than in the *Hippuris* transects. This was probably owing to the different structures of the vegetation and their effect on water turbulence and the stability of the sediment. Applegate & Kieckhefer (1977) stated that corixids migrate from the littoral zone when the shallow water is turbulent. *Myriophyllum* has a dense, submerged growth form with many branches and many fine leaves. This would dissipate much of the wave energy and create calm, sheltered conditions for macroinvertebrates. *Hippuris*, on the other hand, has a more emergent growth form, consisting of single upstanding branches with some submerged leaves,. It appears that corixids preferred the more sheltered, undisturbed habitat provided by *Myriophyllum*. Popham (1964) noted that corixids concentrated on the bottom, near the

centre of a small pond on windy days and considered this was a method of avoiding wave disturbance. Shelter, habitat stability, vegetation and organic matter accumulation are considered important to distribution (Savage 1989).

*Myriophyllum*, a submerged plant, did not appear to flourish in very shallow water, whereas *Hippuris*, an emergent macrophyte, grew well with only a few centimetres of water. As corixids appeared to prefer water at depths of greater than 200 mm, this could contribute to the near absence of corixids from the *Hippuris* transects.

The sheltered conditions found in *Myriophyllum* stands also appeared to retain very fine sediment, whereas the peat found in *Hippuris* stands was gravel-like in texture. The finely branched leaves of *Myriophyllum* trapped a lot of suspended material. Fine sediment supports a greater abundance and diversity of micro-organisms, algae, protozoans and macroinvertebrates than coarse sediments and rocky shores. During sampling it was observed that there were generally more macroinvertebrate individuals and species in the *Myriophyllum* transects and that *Gammarus* and *Asellus* dominated *Hippuris*. Corixids, therefore, may also have favoured *Myriophyllum* owing to food availability. *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* from Turraun and Tumduff were found to feed on algae and biofilm and small and soft-bodied invertebrates (see Chapter 7).

The difference between *Myriophyllum* 1 and the *Hippuris* transects was more marked than that between *Myriophyllum* 2 and *Hippuris*. *Myriophyllum* 2 was observed to be more disturbed by wave action than *Myriophyllum* 1. This was probably owing to the former vegetation stand being more exposed than the latter. The wind also appeared to be stronger on 26<sup>th</sup> August when *Myriophyllum* 2 was sampled. Wind direction did not appear to be a factor. The sediment was also coarser at *Myriophyllum* 2 than at *Myriophyllum* 1, with gravel-like peat mixed with finer sediment. The greater exposure and coarser sediment may account for the differences between *Myriophyllum* 2 and *Myriophyllum* 1.

S. dorsalis was very significantly more abundant in *Myriophyllum* than in *Hippuris*. This would appear to support the provisional results presented in Section 8.1 above, which suggested that this species spends more time in vegetation than S. distincta, S. fossarum or S. scotti. Williams (1995) sampled open water, emergent vegetation and submerged vegetation in mining subsidence ponds for corixids. The ponds were similar to the study

sites in being shallow, having a good macrophyte cover and a moderate conductivity (390  $\mu$ Scm<sup>-1</sup>). He found that *S. dorsalis* was significantly associated with the submerged vegetation and *S. lateralis* with open water.

The experiment was conducted in August, a time of the year when teneral and mature adults are low in abundance and when corixids nymphs are common. A similar experiment conducted between September and November would probably have yielded higher numbers and might possibly have shown more significant differences in the distribution of individual species. Sampling over a greater range of depths may produce significant differences in the distribution of different species.

The results of field based habitat usage experiments suggest that many species of corixid prefer the calm, undisturbed water provided by macrophytes with fine leaves and dense foliage. This was the structure offered by *Myriophyllum* in Turraun. Sampling these types of habitats at a variety of depths may be essential to record a good representation of the corixid fauna of a waterbody.

**Chapter 9** 

# DISCUSSION ON CORIXIDAE ECOLOGY IN TURRAUN & TUMDUFF

Section C investigated why *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* were found in such high abundance in the cutaway ponds. This discussion chapter attempts to summarise the findings in terms of corixid migration, parasitism and feeding and habitat preferences/associations. A range of other ecological factors is also considered. Finally changes in corixid species composition with succession are predicted.

It seems probable that corixids colonised Turraun and Tumduff from regional sources. Because corixids are capable of travelling up to 90 km per day (Popham 1964), they may have colonised from as far afield as the Shannon lakes or the lakes of Westmeath. It is also possible that *S. distincta* and *S. fossarum* colonised from the local natural lakes, Fin Lough and Pallas Lake. It is evident that colonisation was an ongoing process and there was a regular, abundant supply of corixids on the wing over Turraun and Tumduff. The high abundance suggests that the cutaway ponds were particularly attractive to aerial corixids. This was probably because the ponds represent large, reflective areas of open water in a mainly dry peatland landscape, and are not obscured by vegetation, buildings or topography. Corixid invasions of other artificial large open areas of water have been recorded (Macan 1962, 1973), though the high abundance is often not sustained.

Species composition is also linked to the availability of colonists. *Sigara dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* may have been amongst the first species to colonise Turraun and Tumduff, owing to regional abundance, colonisation ability or chance. As all four are considered poor fliers (Popham 1943, Fernando 1959, Southwood & Leston 1959, Tully *et al.* 1991, Williams 1993), however, factors such as food availability and habitat preferences appear to have had greater influence on species composition in the study sites.

The incidence of parasitism was low in both wetlands, although the percentage of corixids infected with larval mites was higher in Tumduff than Turraun. While mite parasites can affect corixid fecundity and may lead to premature mortality (Crisp 1959, Fernando 1959, Fernando & Galbraith 1970, Davids & Schoots 1975, Davids *et al.* 1978, Savage 1989), parasitism was too low to have played a significant role in limiting abundance or determining corixid community structure

The percentage of corixids with larval parasites was to some extent governed by habitat overlap and interactions between the parasite and host. As corixids were abundant at all

sampling stations, the distribution of mites was probably the most important factor governing parasitism. Mites were generally more abundant in open habitats. Both adult mites and larval parasites were frequently found at B8 and B7. It seems likely that in complex habitats with dense and diverse vegetation, such as T3 and T4, the amount of interaction between mites and corixids is small.

The incidence of parasitism at the different sampling stations also reflected corixid species distribution. *S. dorsalis* was more susceptible to infection than other species, having the highest percentage of infected animals in both wetlands. Parasitism was high where this species had high relative abundance (T2) and low where it had low relative abundance (T4). Parasitism may have contributed to the low relative abundance of *S. dorsalis* at T4, B6, B7 and B8, though it is likely that habitat factors were also important. Parasitism of *S. dorsalis* may have been partly responsible for the apparent demise of this species in Turraun. This could act directly, through reduced fecundity and mortality or indirectly, by weakening corixids and reducing their ability to compete with other species for necessary resources.

The percentage of corixids with parasites increased after September 1997 in Tumduff and in November 1997 in Turraun. As September and November appeared to be periods of migration into Tumduff and Turraun respectively, it is possible that migrants carried further parasites into the wetlands. Larval mite infections may have contributed to the reduction in average corixid catch after these November 1997.

Opinions are mixed as to the effect of food on corixid abundance. Fernando (1959) believed that food limited corixid populations and Pajunen (1979) found high mortality of nymphs owing to lack of food, while Scudder (1976) stated that lack of food is rarely likely to limit corixids from a water body. It seems improbable that corixids could survive in a habitat without suitable food and likely that corixid abundance may increase with increased availability of food. It is also possible that the type and distribution of food available might favour particular species.

The four corixid species that were abundant in Turraun and Tumduff, fed on phytoplankton, periphyton and animal prey such as *Daphnia*, oligochaete worms, chironomids and *Cloeon* mayfly nymphs. Algae and biofilm appeared to be the most important food groups. Periphyton was well developed in Turraun, in association with the dense macrophyte vegetation and on the peat sediment. There were also dense phytoplankton blooms from late spring to early autumn in that wetland. Phytoplankton and periphyton were less well developed in Tumduff and this may explain the differences in corixid abundance between wetlands. Oligochaeta were relatively abundant at Turraun, and chironomid and other dipteran larvae were also present. *Cloeon simile* nymphs were abundant in both wetlands and Chironomid larvae were very abundant at Tumduff. At Tumduff, where algae did not appear to be abundant *Cloeon* nymphs and chironomid larvae may have formed a relatively large portion of the corixid diet.

Popham (1964) suggested that food distribution influences the internal distribution and movements of corixids. It is probable that corixids moved outside the defined sampling stations in the cutaway wetlands in search of food, though length data indicates these movements did not cover the entire area of Turraun. The fact that feeding trials indicated *S. dorsalis, S. distincta, S. fossarum* and *S. scotti* are omnivorous, contradicts Savage's (1989) assertion that omnivores and algal feeders tend to be associated with habitats containing little organic matter in their substrata. He indicates detritus feeders are associated with high concentrations of organic matter.

Corixids were most abundant at sampling stations with the most abundant 'food'. The greatest absolute abundance of corixids was found at T3. This sampling station had the greatest total abundance of macroinvertebrates and Oligochaeta were very numerous. Carnivores were scarce at T3 and it is possible that corixids (which were not included in the feeding guilds analysis) were the top predators at this station. Primary production was high at T3, probably in response to fertilisation that took place prior to flooding, and the fine peat sediment was covered in biofilm. Detritivores were relatively abundant, suggesting detritus was also an abundant source of food. While corixids were numerous at T3, they were also at the lower end of the length ranges expected (see Section 6.3.2, Chapter 6). It seems likely that overcrowding and competition for food, rather than food quality, were responsible.

T4, the sheltered sampling station with shell marl sediment, had the second highest absolute abundance of corixids. T4 also had the second highest macroinvertebrate abundance. The most plentiful supply of periphyton was found at T4 and it appeared to be

the main source of food for invertebrates at this station, as indicated by the very high percentage of scrapers. T4 was dominated by *Myriophyllum* and in feeding trials corixids preferred periphyton attached to *Chara* to that on *Myriophyllum*. Detritus appeared to be less abundant at T4 than T3 and could explain why corixid abundance was higher at T3 than T4.

Corixid abundance was low at T1, where macroinvertebrate abundance was low and the species that were abundant, e.g. *Caenis* nymphs and *Mystacides longicornis*, were not fed on by corixids during the feeding trials. Epipelic organisms and detritus were the only types of food found at T1 and corixids would have had to move to adjacent plant beds to feed. Corixid abundance was also low at the three Tumduff sampling stations. Chironomids and seasonally abundant periphyton may have been the main foods at T2 and T5.

Length data also suggested that food quality and abundance varied. Corixids were generally larger at Tumduff than Turraun, although *S. scotti* was larger at T4 and T5 than at Tumduff. Corixids at T4 were amongst the longest in Turraun and it is likely that food quality and abundance were sufficient to promote good growth, even with the high abundance of corixids. The fact that corixids were longest at stations where scrapers dominated suggests that algae and biofilm may promote good corixid growth. Food may not have been the most important factor governing corixid length, and growth may have been strongly affected by migration.

Food availability did not explain species distributions between sampling stations. Both *S. distincta* and *S. fossarum* had their highest average abundance at T3 and were also abundant at T4 followed by T5. This mirrored the general pattern in macroinvertebrate abundance in the wetlands. While *S. fossarum* and *S. distincta* overlapped considerably both in distribution and diet during laboratory trials, it is possible that they exploited different foods in sympatry in the field. *S. fossarum* favoured Oligochaeta after algae and biofilm and as these worms were abundant at T3. *S. fossarum* also fed on dead and moribund animals in the laboratory. It is possible that *S. fossarum* fed on a combination of oligochaete worms, dead prey and detritus and had a more benthic life style at T3, while *S. distincta* concentrated on other animals and periphyton in the water column.

Henrikson and Oscarson (1978) discovered that Corixidae became the top predators in acidic lakes and it is possible that corixids were the top predators, apart from sticklebacks, in both Turraun and Tumduff. *S. distincta* was more carnivorous than the other species tested during the feeding trials. As this was also the largest of the four species, size may have been an important factor governing attack success. Females of both *S. distincta* and *S. fossarum* appeared to have a more herbivorous life style than their male counterparts perhaps indicating a differences in distribution and/or behaviour between the sexes.

The habitat preferences of *S. dorsalis*, *S. distincta*, *S. fossarum* and *S. scotti* were suggested by data from the surveys of the eight sampling stations, the laboratory based habitat selectivity and the field based habitat experiments. Each species will now be considered in turn.

Sigara dorsalis has been associated with oligotrophic waters with low percentage organic matter in the substratum and exposed conditions (Macan 1954, 1965c, Savage & Pratt 1976, O'Connor *et al.* 1986, Savage 1989, Tully *et al.* 1991). Despite this Savage (1996) found that the abundance of *S. dorsalis* decreased in Watch Lane Flash, Cheshire with decreases in vegetation cover. While the greatest relative abundance of this species was found at the more exposed stations on the western side of Turraun (T1, T2 and T3) and at Tumduff, the greatest absolute abundance of *S. dorsalis* was found at the well vegetated station T3. Absolute abundance was also high at T2, which had dense vegetation growth in summer and at T4, which had the densest vegetation of any sampling station. *S. dorsalis* showed a very significant association with the submerged vegetation during laboratory trials and was significantly more abundant in *Myriophyllum* than in *Hippuris* in the field. *S. dorsalis* behaviour also suggested an association with vegetation and a preference for epiphyton as a food source. This species preferred algae and biofilm during the feeding trials and crawled and fed amongst vegetation more frequently than the other species during scoping and habitat selection experiments.

Savage (1989) indicated that *S. dorsalis* may be associated with marginal vegetation owing to predation by fish, although, the results of this thesis suggest that it has a strong natural association with vegetation that is probably linked to a grazing style feeding habit (Williams 1995). Williams (1995) also noted that *S. dorsalis* had a strong association with vegetation despite assertions that it is an open water species. *S. dorsalis* may use littoral

vegetation as oviposition sites. *S. dorsalis* may be out-competed in macrophyte stands by species such as *S. distincta* and *S. fossarum*, and forced into more exposed conditions such as those found at Tumduff and at T1. Southwood & Leston (1959) stated *S. dorsalis* is found in a wide range of habitats and its success of may be attributable to its ability to adapt to a wide range of conditions. Results presented in Section C indicate that under natural conditions in allopatry, *S. dorsalis* has a preference for vegetation near the bottom of the littoral zone.

*S. distincta* has been associated with stands of emergent vegetation (Southwood & Leston 1959, Macan 1965c) and with open water (Macan 1965b, 1976). Macan (1976) found that its numbers remained low in Hodson's Tarn until *Myriophyllum* died out. Oscarson (1987) found that in the absence of predators, *S. distincta* used intermediate depths, slightly away from the shore and that it was found in vegetation during the breeding season (Oscarson 1987). It is also associated with some accumulation of organic matter (Macan 1965c) and its wide range of pigmentation helps it to colonise a wide variety of habitats (Popham 1943).

The relative abundance of *S. distincta* was greatest in the open water at T1, but the absolute abundance was far greater at the well vegetated stations, T3 and T4, than at other sampling stations. *S. distincta* did not have a significant relationship with either vegetation or open water during the habitat selectivity experiments and it had low abundance in Turraun and Tumduff at the time of the field experiments, although it was more numerous in *Myriophyllum*. The results suggest *S. distincta* requires a combination of open water and dense vegetation. The apparent preference of *S. distincta* for periphyton and *Cloeon simile* and the fact it frequently crawled and fed on plants during habitat experiments, indicates it feeds amongst macrophytes. This species may have a particular affinity with the peat substratum found at Turraun and Tumduff. *S. distincta* is capable of living in deeper water than the other species as it is larger and a more powerful swimmer.

Macan (1965c) associated *S. fossarum* with thick vegetation (Macan 1965c). It is also associated with high percentage organic matter in the substratum (Southwood & Leston 1959). Tully *et al.* (1991) suggested that *S. fossarum* preferred hard water with high percentage vegetation cover and fine substrata.

*S. fossarum* was the most successful taxon in Turraun, comprising 16.4% of the entire fauna between February 1997 and February 1998. It was most numerous at T3, where its abundance was partly linked to the availability of food, particularly epipelic organisms, detritus and oligochaete worms. *S. fossarum* distribution was most strongly associated with fine undisturbed sediments, such as those found at T3 and T4. The organic nature of the substrata may have encouraged the high abundance of *S. fossarum*. Of all the species tested, *S. fossarum* appeared to have the most benthic lifestyle, feeding and perching on the sediment. The repeated swimming into the aquarium bottom observed during the laboratory experiments also suggests that this species is associated with the bottom sediments. It was significantly associated with vegetation in early March and with open water in late March and April during the habitat selectivity experiments. This behaviour could be associated with migration or oviposition. Female *S. fossarum*, which prefer algae and biofilm as a food source, may be more strongly associated with vegetation than males.

*S. scotti* is often associated with peat and sparse vegetation (Macan 1938, 1954, 1965a, b, c, Southwood & Leston 1959, O'Connor *et al.* 1986, Savage 1989, Reynolds 1998) and is generally found in shallow water (Macan 1965c). It seems to be positively associated with accumulating organic matter (Macan 1954), but negatively associated with increasing trophic status (O'Connor *et al.* 1986).

As with the other species, the average catch per sample of *S. scotti* was far greater at the densely vegetated station T3, although, the abundance was relatively low at the station with the densest vegetation, T4. *S. scotti* had high relative abundance at T1. Organic matter in the substratum and peat, in particular, appear to influence the distribution of *S. scotti* and would seem to be the most important factors controlling the presence and abundance of this species at the study sites. Water depth appears to be responsible for the distribution of *S. scotti* within the wetlands, where it is generally found in water of less than 200 mm. *S. scotti* appears to have a significant association with vegetation (presence at vegetated sampling station and habitat selectivity results), but avoids very densely packed vegetation. From its behaviour in the laboratory it appears that *S. scotti* uses the water column more than the other species tested.

Savage (1996) found a significant positive correlation between corixid abundance and vegetation cover. Vegetation was important to the distribution and abundance of all four

corixid species in Turraun and Tumduff. *S. dorsalis* seems to live amongst the stems and shoots of plants, while *S. distincta*, *S. fossarum* and *S. scotti* may be 'open water species' in the sense of Savage (1982, 1994). He suggested that these species are associated with the open water at the edge of macrophyte stands. The importance of vegetation to all four species may be largely owing to its ability to reduce water disturbance and turbulence. Dense fine leaved plant structures appeared to provide the greatest protection from wave disturbance and trap the finest sediment and, as a result, corixid abundance varied with plant structure. Corixids were significantly more abundant and species richness was higher in *Myriophyllum* than *Hippuris* in Turraun. It also seems likely that *S. distincta*, *S. fossarum* and *S. scotti* move into vegetation to feed, to hide from predators or to oviposite.

While nymphal habitat preferences may be influential, it is unlikely that corixids are restricted to a single habitat throughout their lives as both adults and nymphs are highly motile creatures. In Turraun, the number of corixid nymphs captured was low relative to the number of adults. It was concluded in Chapter 5 that adult numbers were supplemented by invasions, although, it is probable that in-wetland corixid production was higher than indicated by nymph numbers. This suggests that the distribution of nymphs was different to that of the adults. Corixid nymphs appear to have a more benthic lifestyle than their adult counterparts, as the first two instars do not need to surface and the others do so less frequently than adults (Scudder 1976, Savage 1989).

The effect of depth on corixids, which was briefly mentioned above, appears to be linked to the size of the animal. Corixids are generally found in shallow water (Popham 1964, Scudder 1976, Savage 1989) and the size of the corixid governs its power as a swimmer and, as a result, the distance it is capable of swimming to the water surface to replenish its air supply (Dodson 1975, Macan 1976, Oscarson 1987). Popham (1943) considered corixids to be detritivores and linked their presence in shallow water to feeding. Mating and migration may also affect the depth distribution of corixids (Fernando 1959, Popham 1964, Savage 1989).

Dodson (1975) stated that three species in Colorado preferred water less than 0.5 m. Popham (1943) collected corixids from different depths in five locations and found *Sigara distincta* and *S. fossarum* were most abundant at 152 mm (0.5 ft) and that their numbers decreased as depth increased. Macan (1976) stated *S. distincta* could live at all depths in

the tarn, while S. *scotti* was confined to shallow water. Macan (1965b) found S. *scotti* in water less than 750 mm and Oscarson (1987) found that in the absence of predators, S. *scotti* used the shallowest, most inshore habitat and it appeared to be most abundant at the shallowest depths during field experiments. During the field selectivity experiments, corixids were most abundant at c. 200 mm deep and during routine sampling corixids appeared to be most abundant in the shallowest water (less than 300 mm). Thus it appears that all four species preferentially used shallow water, with S. *scotti* confined to the shallowest water owing to its size, and S. *fossarum*, S. *dorsalis* and S. *distincta* capable of using progressively greater depths. The fact that much of the study sites is shallow may facilitated an abundance of corixids.

Other habitat factors, such as sediment colour could be influential for species distributions. Popham (1943) found a high correlation between the colour of *S. distincta*, *S. fossarum* and *S. scotti* and the colour of the ponds in which they occurred, and that the colour of *S. distincta* depended upon the colour of the habitat in which it lived during the process of moulting. All four corixid species dominating Turraun and Tumduff had dark dorsal patterns and may have chosen the peat floored wetland as a habitat with which they harmonised.

Temperature could potentially affect distribution and Popham (1964) claimed that corixid movements within a water body were determined by thermal and possibly light gradients. The efficiency of the 'physical gill' decreases with increasing temperature, owing to increasing oxygen consumption and decreasing dissolved oxygen concentration, and hence corixids need to surface more frequently (Popham 1964, Savage 1989). This would restrict corixids to shallow water in warm weather. It seems likely, therefore, that in high water temperatures, corixids will be distributed along the shore in the littoral zone. Popham (1964) noted that activity increases in response to temperature and illumination. Increased activity and density of corixids owing to increased temperature could stimulate emigration from a water body.

Predation has been shown to alter the distribution and abundance of corixids (Macan 1965b, Oscarson 1987, Savage 1989). Macan (1965b) noted that the ranges of *S. scotti* and *H. castanea* were restricted to very dense vegetation in the presence of fish. Savage (1989) reported that *S. dorsalis* was found in large numbers in the marginal vegetation of a lake

with a large population of perch. Oscarson (1987) found that the introduction of fish eliminated *S. scotti* and redistributed *S. distincta* to the inshore habitats formerly occupied by *S. scotti*.

It was hypothesised in the introduction to Section C that low numbers of predators and parasites may have supported corixid abundance. Two stickleback species, *Gasterosteus aculeatus* Linnaeus and *Pungitius pungitius* Linnaeus, were present in the wetlands, but do not appear to predate significantly on corixids. Only one corixid has been found in stickleback gut contents at Turraun (Ger O'Brien personal communication). Trout were released into Turraun in 1990 or 1991 and there were unauthorised fish releases into other cutaway ponds (Brendan Kavanagh personal communication). There was no evidence that game or coarse fish were present in either wetland at the time of study. The abundance of invertebrate predators was also low relative to that of corixids. It seems that predator pressure on corixids was very low in Turraun and Tumduff and the absence of such population control measures may have contributed to the very high corixid abundance.

Interspecific competition can affect the distribution and abundance of corixids. Although competition is very difficult to prove in field populations (Pajunen 1979) a number of authors have suggested its occurrence in corixid populations. Dodson (1975) recorded that *Cenocorixa bifida* was found in sedges in an aquarium experiment but not in field observations, and attributed differences to interspecific interaction with *Callicorixa audeni*. Pajunen (1979) found evidence for interspecific competition between *Arctocorisa carinata* and *Callicorixa producta*, with the smaller, competitively inferior *C. producta* surviving because of its ability to disperse more rapidly to small refilled rock pools in July. Oscarson (1987) suggested that there could be some interaction between the *S. distincta* and *S. scotti* in Swedish lakes. Pajunen & Pajunen (1993) found that *Sigara nigrolineata* (Fieber) was excluded from rock-pools by predation and competition by *Arctocorisa carinata* producta.

Competition between corixids may affect their feeding patterns and hence distribution (Scudder 1976). Istock (1973) looked at interspecific competition in two North American species and found that *Hesperocorixa lobata* (Hungerford) was out-competed by *Sigara macropala* (Hungerford) in lake enclosures. In sympatry these species appeared to have separate breeding periods (Istock 1973). Pajunen (1979) noted that food demand is

greatest or sometimes limited to the reproductive season, so segregation of reproductive periods can be an effective method of avoiding competition. It was suggested that two coexisting Canadian corixids could compete for food as the fundamental feeding niches overlapped considerably and the realised feeding niches were virtually identical (Reynolds 1975, Scudder 1983, Reynolds & Scudder 1987 a and b). Savage (1989) also suggested that diet could vary with competition. The four most abundant corixids in the study site may have been in competition with each other. Feeding trials indicated overlaps in their fundamental feeding niches. Regular sampling and laboratory and field habitat selectivity trials, suggested habitat overlap. Obviously much further study is necessary to investigate the existence and effects of competitive interactions.

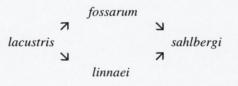
A number of authors have written about changes in corixid populations with time. Macan (1938) noted that where the rate of increase of percentage organic matter in the substratum is rapid, the following succession takes place in oligotrophic lakes:

$$\begin{array}{cccc} fossarum \\ \hline n & \searrow \\ poweri \rightarrow dorsalis & scotti \rightarrow castanea \\ \searrow & 7 \\ distincta \end{array}$$

Southwood & Leston (1959) found a similar pattern as vegetation and organic matter increased:

### poweri $\rightarrow$ dorsalis $\rightarrow$ falleni or distincta.

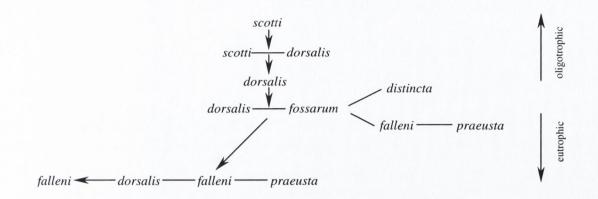
Macan (1954) found that as vegetation and organic matter accumulate in lime-rich, eutrophic conditions and the habitat develops into rich fen, the following corixid succession is found:



In eutrophic lakes in the north west midlands of England the corixid succession was found to be:

#### Sigara falleni $\rightarrow$ Callicorixa praeusta $\rightarrow$ Hesperocorixa linnaei $\rightarrow$ H. sahlbergi.

(Savage 1989). Savage and Pratt (1976) suggested that *H. linnaei* and *H. sahlbergi* do not always represent the end of the eutrophic series and identified the following oligotrophic and eutrophic successions:



According to these systems, the corixid communities found in Turraun and Tumduff are associated with the end of the oligotrophic series/beginning of the eutrophic series, although the presence of *S. scotti* is somewhat anomalous.

Macrophyte cover is definitely increasing in Turraun, but vegetation succession may be very slow at Tumduff owing to the shoreline morphology and the light, unconsolidated sediment. The percentage of organic matter in the substratum at Turraun and Tumduff is naturally high and it is not clear whether this is increasing, decreasing or remaining constant. It is possible that the presence of inorganic material, such as glacial till or shell marl, encourages decomposition (Macan 1938). It is also probable that where vegetation cover is high, organic matter is accumulating (Macan 1938). As Turraun appears to be highly eutrophic to hypertrophic, with total phosphorus concentrations of 0.076 mgl<sup>-1</sup> P and chlorophyll  $\alpha$  concentrations of 110  $\mu$ gl<sup>-1</sup> found in August 1999, it is most likely to proceed through the eutrophic succession. This would lead to a decrease in S. scotti, S. distincta and S. fossarum abundance as productivity and macrophyte cover increase (Savage 1982, 1994). S. falleni will also take over from S. dorsalis as vegetation and shelter increase (Savage & Pratt 1976). The overall corixid abundance could also decrease with time owing to increasing vegetation cover. H. linnaei was observed to be more abundant in Turraun during August 1999 and C. praeusta may also be increasing in abundance in the wetland.

In contrast Tumduff has high total phosphorus but low chlorophyll *a* concentrations (see also Chapter 3). If organic matter increases in Tumduff and the pond remains oligotrophic, *S. dorsalis* abundance could decrease and *S. distincta* and *S. fossarum* abundance increase. It is also likely that *S. scotti* may increase with time. It must be remembered that succession can sometimes vary among water bodies (Macan 1938) and changes in the corixid populations in these study sites may not reflect any of the above schemes.

In conclusion, corixid species distribution, composition and abundance in cutaway wetlands appear to be controlled by a number of factors. Corixid distribution was influenced by the distribution of vegetation, sediment and food, although shelter was probably the most important factor. The distribution of the corixid species in the laboratory habitat selectivity experiments appeared to reflect that found in the field. *S. dorsalis*, however, did not demonstrate the same strong association with vegetation in the field as in the laboratory and may have been influenced by competition from the other three dominant corixid species. Temperature may also have affected distribution, causing corixids to remain in shallow water, particularly during the summer.

The most important influence on species composition appeared to be colonisation and habitat. *S. dorsalis, S. distincta, S. fossarum* and *S. scotti* were probably better able to adapt to the environment of the study sites than other early colonists and increased rapidly in abundance. The dark colour of the sediment and the high percentage organic matter in the substratum seems to have favoured these four species. The type and abundance of vegetation along with the shallow water may also have influenced species composition. Food was unlikely to be a big factor as most British species would appear to be capable of surviving on the range of food found in the cutaway wetlands (Sutton 1951, Popham *et al.* 1984b).

The biggest factor controlling corixid abundance was migration, with massive invasions taking place in spring and autumn 1997. The very large fluctuations in corixid abundance indicate that Turraun and Tumduff may not be capable of sustaining very high corixid numbers. Turraun has a far larger surface area than Tumduff and may have attracted many more corixids from the air, accounting for the difference in corixid abundance between the study sites. Other factors such as the shallow nature of the water, the availability of sheltered habitats, fine sediment, macrophyte vegetation and open water may also have favoured an abundance of corixids. Food availability also appeared to be important and the low numbers of corixid predators and parasites may have given corixids a role as top predators in the two wetlands.

Chapter 10

# CONCLUSIONS ON BIODIVERSITY IN TURRAUN, TUMDUFF & OTHER CUTAWAY WATER BODIES

These concluding remarks attempt to briefly summarise the results of this research, concentrating on water chemistry and macroinvertebrates and the influence of abiotic and biotic factors on the macroinvertebrate communities. The future development of Turraun and Tumduff cutaway wetlands is predicted and some potential problems identified. The conservation value of these novel freshwater systems is evaluated and finally methods for maximising biodiversity in future cutaway wetlands are developed.

Water chemistry results show that Turraun is a moderately hard, coloured, possibly highly eutrophic to hypertrophic, groundwater wetland. Tumduff is a hard, coloured and probably oligotrophic ground water pond with high total phosphorus and low primary productivity. Conductivity, alkalinity and calcium concentration were higher in Tumduff than Turraun, suggesting that groundwater has a greater influence at Tumduff. pH was high in both wetlands, but was significantly higher at Turraun on most dates. Photosynthesis by macrophytes, periphyton and phytoplankton appears to have elevated pH in Turraun. MRP, total ammonia and nitrate concentrations for Turraun in August 1997 suggest that artificial enrichment occurred at this time, while chloride concentrations indicate it may have arisen from a point source between T1 and T3. The peat sediment may have contributed to the high total phosphorus concentrations in both wetlands. As a result of the dark peat sediment, high summer water temperatures were found in both wetlands.

The diversity and density of aquatic macrophytes was far greater at Turraun than at Tumduff. While age may have been the main element governing the differences in macrophyte communities between wetlands, morphological factors also appear to have been important. The loose unconsolidated peat sediment at Tumduff along with the steeply sloping sides, deep water and wave action probably slowed vegetation colonisation. Macrophyte cover appeared to increase rapidly in Turraun over the sampling period but only slowly in Tumduff.

118 aquatic macroinvertebrate taxa were found during the study. 108 taxa were captured in Turraun and 71 in Tumduff. Most lentic macroinvertebrate groups were represented in both wetlands, but notable absentees from Tumduff included *Lymnaea stagnalis, Planorbis* spp., *Gammarus duebeni* and *Sialis* spp. Eight species of Mollusca were captured in Turraun and five in Tumduff, 21 species of Heteroptera were found in Turraun and 17 in Tumduff, 10 species of Trichoptera were recorded in both wetlands and 38 species of Coleoptera were found in Turraun, while 16 were found in Tumduff. Most species identified are common and widespread in the British Isles. The presence of *Hesperocorixa moesta* is interesting, although, it could not be confirmed as no males were captured. This species is considered rare in Britain and there are only three definite records for Ireland. Two interesting beetles were recorded in Turraun; *Gyrinus caspius* which is typically a coastal species and *Haliplus variegatus* for which this record was only the second in Ireland since 1980. *H. variegatus* is rare in the UK, but probably under-recorded in Ireland.

The average catch per sample over the sampling period was 130 at Turraun and 85 at Tumduff, and average catch was higher in Turraun than Tumduff in all but two months. The most abundant taxa in Turraun were Corixidae followed by Mollusca and Trichoptera and in Tumduff, Diptera, followed by Trichoptera, Ephemeroptera and Corixidae. These latter four groups dominated the fauna at Tumduff, and consequently diversity was higher at Turraun than at Tumduff. Temporal variations in abundance of various macroinvertebrate taxa indicate that succession was ongoing in the wetlands and that invasions were having an impact, particularly on corixid abundance. Succession in Corixidae appeared to be led by a combination of habitat changes and food availability, although changes in wetland productivity may have been indirectly influential.

The older and larger water body, Turraun supported a greater diversity of both macrophytes and aquatic macroinvertebrates. This is in keeping with the findings of Barnes (1983) and Williams (1993). Age increases the length of time available for colonisation and also leads to changes in sediment, vegetation and food that can alter the macroinvertebrate community.

Friday (1987) found that pH was the most important variable governing invertebrate and plant species richness in ball clay ponds and that greater numbers of Ephemeroptera, Malacostraca, Mollusca and Hirudinea were particularly evident in ponds with above neutral pH. Lodge *et al.* (1987) also suggested that more snail species will be found in ponds with high alkalinity. It is clear, therefore, that the ground water influence in cutaway ponds is very important in promoting high biodiversity.

Habitat diversity is considered to influence macroinvertebrate species richness (Lodge *et al.* 1987, Death 1995). Habitat factors, particularly sediments and macrophytes, had a strong influence on macroinvertebrate taxon richness in the cutaway wetlands and may explain differences in macroinvertebrate distribution between wetlands and between sampling stations. Other authors have suggested that sediment type and texture are major factors for macroinvertebrates (e.g. Brinkhurst 1974, McLachlan & McLachlan 1975, Friday 1987). Fine sediments supported high abundance of macroinvertebrates, with the very fine peat at T3 having the greatest abundance of any sampling station and the fine marl at T4 also having very high abundance. Abundance was lowest on the compacted peat at T1 and was also low on the gravel sized peat pieces at T2. Despite the fine nature of the peat at the three Tumduff sampling stations, abundance was relatively low. The macroinvertebrate species found also varied between sediment textures, with *Gammarus* dominating over gravel sized peat pieces, burrowing forms (such as oligochaete worms) absent from compacted peat and a wide range of motile and sedentary taxa abundant over fine sediment.

Macrophytes are considered an important influence on macroinvertebrate communities by many authors (e.g. McLachlan & McLachlan 1975, Voigts 1976, Palmer 1981, Barnes 1983, Friday 1987, Cyr & Downing 1988, Hanson 1990, Savage 2000). At the cutaway wetlands, macrophyte species richness and cover appeared to be related to macroinvertebrate taxon richness. Macroinvertebrate taxon richness was greatest at T4, the sampling station with the greatest macrophyte density. A large number of macrophyte species were found at T4 and these varied structurally from submerged finely dissected *Myriophyllum* sp., to floating broad-leaved *Potamogeton* to tall emergents, *Typha* and *Phragmites*. Taxon richness was lowest at T1, the station from which vegetation was absent, and was also low at B6, B7 and B8, where vegetation was sparse and composed mainly of *Juncus* sp. or drowned terrestrial plants. Taxon richness was reasonably high and similar at sampling stations T2, T3 and T5, all of which were dominated by emergent species, but interspersed with more low growing or floating forms.

A number of invertebrate taxa appeared to exhibit a preference for T4 over other stations, including Lymnaea stagnalis, Cloeon simile, zygopteran nymphs, Gerris spp. and Limnephilus spp. Oligochaeta, Potamopyrgus jenkinsi and Pisidium sp. and some corixids appeared to prefer T3. These preferences may be directly linked to the presence of

different macrophyte species at the sampling stations. The influence of macrophytes on macroinvertebrates is probably through a combination of structure, which affects attachment and predator avoidance, and feeding, in terms of predatory behaviour or preferences for epiphyton associated with individual macrophyte species. Oxygen trapped within macrophytes may be important to some macroinvertebrates and chironomid larvae were frequently found in the aerenchyma of *Typha* leaves. Field based investigations of corixids suggest that fine-leaved submerged vegetation is very important in dissipating wave energy and providing constant sheltered conditions.

Exposure is another element that appears to influence macroinvertebrate communities, with taxon richness and particularly abundance, high in sheltered areas (T3 and T4) and low in more exposed areas (T1 and the Tumduff stations). Clearly these factors, sediment, macrophytes and exposure are closely interrelated. Fine sediment accumulates in sheltered areas, often beneath macrophytes with dense fine-leaved structure, and is often accompanied by an accumulation of detritus and periphyton. Hence, high abundance over fine sediment and/or in macrophytes may be linked to food abundance rather than direct structural factors. The presence of vegetation on flooded peat can also alter the sediment through further accumulation of organic matter, although the presence of silt may initiate peat decomposition (Macan 1938). Fine sediments in exposed areas, such as those found at Tumduff, are unusual and a function of the artificial nature of the waterbodies. Wave action has caused the fine sediments to be unconsolidated and the steep slopes compound the problem. This in turn may prevent many rooted macrophytes from establishing.

Biotic interactions appear to have an influence on small-scale invertebrate distribution in littoral zones (Friday 1987, Death 1995, Harrison & Hildrew 1998). While sediment and vegetation appear to be the major factors influencing the distribution of macroinvertebrates in the cutaway wetlands, biotic interactions are probably also important. Laboratory experiments established that *Sigara dorsalis* preferred submerged vegetation over open water and yet field investigations found the species was of greater relative importance in more open areas. Interspecific competition may be responsible for this shift in distribution.

It seems probable that shallow cutaway ponds with good macrophyte development, such as Turraun, may succeed towards fen. Macrophytes may gradually encroach until reed beds cover the entire water body and the wetland will in-fill with organic matter. The macroinvertebrate communities will change with such habitat developments and potential will exist for colonisation by highly desirable, rarer fen species. Depending on a number of factors, such as climate, disturbance and successful colonisation by *Sphagnum*, it is also possible that re-growth of raised bog will be initiated at these sites. Researchers have found that *Sphagnum*-dominated surfaces can develop rapidly within cutaway fens in the UK and the Netherlands, and have suggested fen may be the best starting point for bog regeneration (Wheeler *et al.* 2000). Tumduff, on the other hand, demonstrated few changes in macrophyte and macroinvertebrate conditions during the study period. It seems likely that morphological and sediment factors will greatly slow succession in this cutaway pond.

The study also revealed a number of potential future problems for the cutaway water bodies. Probably the greatest of these was eutrophication. Both total phosphorus and chlorophyll *a* were very high in Turraun in August 1999 and a plankton bloom was present for much of 1997, 1998 and 1999. This could be owing to properties of the peat sediment, but is more likely to have arisen from a pollution event. Eutrophication at Turraun could have a negative impact on the biodiversity, with reduction in floral diversity, high algal primary productivity leading to night-time depletion of dissolved oxygen, alteration of the food web and reduction in macroinvertebrate diversity. While the macroinvertebrate fauna was diverse and appeared unaffected by eutrophication between January 1997 and February 1998, the population was not monitored in 1998 or 1999 and deterioration may have occurred.

The high summer water temperatures, owing to the dark coloured sediment and shallow water, may prevent colonisation by some macroinvertebrate species. High temperatures may exert a physiological stress, preventing completion of the life cycle of some invertebrates and can also lead to low oxygen concentrations at night and generation of toxic NH<sub>3</sub>. The formation of ice sheets in winter, owing to the shallow water depth, may be problematic for species that respire atmospheric oxygen. Continued monitoring of wetland water chemistry, macrophytes and macroinvertebrate communities is fundamental to evaluating the environmental quality and conservation value of these water bodies.

The presence of artificial ponds on cutaway represents a diversification of habitats on developed midland raised bog. Before the creation of the water bodies, drains and pools

were the main source of freshwater and these generally have highly coloured, acidic water and an impoverished fauna (Whelan 1996). In contrast with these acidic waterbodies, the base-rich artificial ponds provide habitats with variable morphology and well developed macrophyte stands and contain more diverse macroinvertebrate and especially Corixidae communities. These special habitats can be considered as having a high conservation value.

The aquatic macroinvertebrate fauna of Turraun and Tumduff cannot be considered 'typical' of any natural habitat. A number of species associated with fens (e.g. *Hesperocorixa sahlbergi* and *Haliplus rufficollis*) were recorded, along with acidophilic species (e.g. *Anacaena lutescens* and *Hydroporus gyllenhalii*) and species frequently encountered on bog pools (e.g. *Gyrinus substriatus* and *G. minutus* Fabricius). Some opportunistic species, such as *Libellula quadrimaculata, Gerris lacustris* and *Hesperocorixa castanea*, which have also been recorded from intact raised bog, were found at the study sites. Some of the species recorded, have been associated with slightly eutrophic conditions (e.g. *Sigara lateralis* and *Noterus clavicornis*) or rivers (e.g. *Elmis aenea* and *Haliplus fluviatilis*). This unusual suite of macroinvertebrate species adds a new dimension to the Irish aquatic fauna.

The abundant and diverse macroinvertebrate fauna has been facilitated by the absence of large fish and encourages high wildfowl diversity. The top predators in the wetlands are invertebrates and possibly the most important of these are Heteroptera (including Corixidae), zygopteran nymphs and Coleoptera. This is a highly desirable situation and makes these wetlands worthy of note in an Irish and perhaps also European context. These wetlands afford an excellent opportunity to maximise macrophyte and macroinvertebrate biodiversity in a region of Ireland that has few wetlands or ponds. As such it is desirable that they be kept free of large fish. Also, it is unlikely that cutaway waterbodies would prove suitable to game and coarse fish owing to the high summer water temperatures and possible night-time deoxygenation.

Macan (1965a) stated that "the pioneer cannot do much more than put facts on record and leave explanations to those who, coming later, can make comparison". This pioneer comparative work on Turraun and Tumduff cutaway ponds provides a solid baseline, although, further investigations into temporal and spatial variability may be necessary

before a conclusive prescription for the creation of cutaway water bodies can be written. This study, however, did reveal a number of areas in which the design of future ponds can be improved.

The main factors to be taken into consideration when designing new wetlands are area, morphology and sediment. Ponds with large surface area are desirable as they can contain a greater range of habitats and may also receive more colonising species than smaller ones (Friday 1987). Larger ponds are also more likely to be more long-lived than small ponds. Despite this, it may also be valuable to construct a series of small and/or temporary ponds, as they may contain a different suite of macroinvertebrate species to large ponds. The most obvious solution to the question of surface area of future cutaway ponds is to follow the natural topography of the land, while ensuring that a range of sizes is created.

The most important areas of morphological design are shoreline, slope, depth and islands. An irregularly shaped shoreline, with bays, inlets and peninsulas should help to maximise biodiversity. Sheltered bays would allow accumulation of fine sediment and vegetation colonisation, and promote macroinvertebrate abundance and diversity. Peninsulas have an important function of shortening the fetch and reducing bank erosion, while exposed areas are essential to some macroinvertebrate species and help maintain stretches of open water.

Gently sloping littoral zones promote the growth of emergent species, while more steeply sloping shorelines facilitate floating leaved and submerged species. Steep gradients may prevent vegetation colonisation and again help maintain areas of open water. Different slopes will obviously also support different macroinvertebrate assemblages.

Shallow water, such as that found throughout most of Turraun, becomes rapidly in-filled with vegetation. In order to maintain open water in cutaway ponds, it is essential to create deeper areas (> 1 m deep). Aquatic Heteroptera are generally absent from completely overgrown ponds (Macan & MacFayden 1941), while open water is also important to some insects with aerial adults (e.g. Ephemeroptera and Diptera), being necessary for mating, egg deposition and emergence. Water permanence is important to water beetle assemblage (Foster *et al.* 1992). In order to maximise the diversity of groups such as Heteroptera and Coleoptera, it is important to create permanently flooded water bodies with both exposed

and densely vegetated regions and with heterogeneous substratum where possible. The ideal cutaway pond would combine an extensive shallow littoral zone with deeper basins.

Islands are a desirable feature of cutaway wetlands, not only as nesting sites for water fowl, but also to act as wave breaks. The flat exposed countryside in which these wetlands are situated allows a long fetch across which winds can gather and develop strong surface waves. Such waves could lead to bank erosion and disrupt vegetation colonisation. Natural regeneration around cutaway wetlands culminating in birch scrub will also help to dissipate some of the wind energy.

Fine sediment and sheltered conditions will promote macroinvertebrate abundance, while sediments of different textures will support different macroinvertebrate assemblages. Where possible underlying impervious substrata, such as shell marl and silty clay, should be exposed. Excavation of the pond basin should also be designed to maximise the number of types and textures of peat. Different sediment types and textures will lead to different macrophyte communities, and habitats with high macrophyte structural diversity and cover encourage high macroinvertebrate diversity and are desirable.

Account should also be taken of the quality of the water source for new wetlands. Baserich ground water influenced ponds with above neutral pH should be encouraged. Where the water is already enriched or there is a high probability that it will become enriched, through-flow must be established. Water quality will vary naturally between locations and will lead to welcome differences in macrophyte and macroinvertebrate communities between wetlands.

It is essential that cutaway ponds should not be designed as individual units, but considered in the overall context of the cutaway landscape. The number of surrounding water bodies can influence the number of species available to colonise new ponds and the rate of increase in species richness over time (Friday 1987). Creating a network of cutaway wetlands, therefore, would provide a 'wildlife corridor' allowing the spread of aquatic macrophyte and macroinvertebrate species across the midlands. Opening extant ditches and streams into new wetlands provides an instant source of macroinvertebrate colonisers. It may also be possible and advantageous to create interconnecting basins, perhaps resembling the postglacial lakes from which the bogs arose.

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Cutaway wetlands cannot be considered separately to surrounding land. Friday (1987) stated that surrounding vegetation and land use are likely to have a great effect on hydrology, water chemistry and allochthonous organic inputs. Heavily fertilised forestry or grassland must be discouraged in wetland catchments. This is especially important in light of findings by Renou *et al.* (2000), who stated that fertilisation of cutaway forestry led to an increase of phosphorus in the run off to drains. Natural regeneration is to be preferred in cutaway wetland catchments. The mosaic of natural vegetation will both encourage certain species of macroinvertebrate that require specific vegetation in the aerial phase and filter run off.

In summary, variation is the key to maximising biodiversity in cutaway wetlands; variation in terms of shoreline, slope, depth and other morphological features, along with variation in sediment type and texture and macrophyte diversity and cover. Aquatic macrophyte and macroinvertebrates have proved themselves proficient in rapidly colonising new cutaway ponds, and a natural process of colonisation and succession should be allowed in all future water bodies in order to promote biodiversity and stability. A cohesive plan should be put into place for the design of the extensive Bord na Móna cutaway, incorporating wetlands, natural regeneration sites and other cutaway uses.

It must be remembered that chance can play a large role in the macroinvertebrate communities forming in a new waterbody (Friday 1987, Williams 1993, Savage 2000) and even two adjacent cutaway wetlands, with similar age, area, morphology and sediments may have very different communities. Small water bodies are highly individual habitats; their flora and fauna usually vary widely and often unpredictably even within a small geographic area (Friday 1987). Ultimately nature itself will help to increase the biodiversity of the cutaway wetlands, generating a wonderful new ecosystem in the Irish midlands.

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# APPENDICES

# Appendix 2.4

## Macrophytes

**Detailed list of plant species recorded in and by Turraun wetland by Sylvia Reynods on 17 June 1997.** Names follow Scannell & Synnott (1987)

species	species
Agrostis stolonifera Linnaeus	Galium palustre Linnaeus
Alisma plantago –aquatica Linnaeus	Glyceria fluitans (Linnaeus) R. Br
Angelica sylvestris Linnaeus	Hippuris vulgaris Linnaeus
Betula pubescens Ehrh.	Hydrocotyle vulgaris Linnaeus
Cardamine pratensis Linnaeus	Hypericum tetrapterum Fries
Carex demissa Hornem.	Juncus acutiflorus Erh. ex Hoffm
Carex echinata Murray	Juncus effuses Linnaeus
Carex flacca Schreber	Lycopus europaeus Linnaeus
Carex lepidocarpa Tausch	Mentha aquatica Linnaeus
Carex panicea Linnaeus	Myosotis laxa Lehm.
Carex paniculata Linnaeus	Nasturtium officinale agg.
Carex nigra (Linnaeus) Reichard	Polygonum amphibium Linnaeus
Carex rostrata Stokes	Ranunculus aquatilis Linnaeus
Centaurium erythraea Rafn	Ranunculus flammula Linnaeus
Dactylorhiza incarnata (Linnaeus) Soo	Rhinanthus minor Linnaeus
Dactylorhiza maculata agg.	Salix cinerea Linnaeus
Eleocharis palustris (Linnaeus) Roemer & Schultes	Salix repens Linnaeus
Epilobium parviflorum Schreber	Sparganium erectum Linnaeus
Equisetum fluviatile Linnaeus	Triglochin palustris Linnaeus
Equisetum palustre Linnaeus	Typha latifolia Linnaeus
Erica tetralix Linnaeus	Veronica anagallis-aquatica Linnaeus
Eriophorum angustifolium Honckeny	

**Plant species recorded in and near Tumduff pond by Sylvia Reynods on 17 June 1997.** L indicates species found in or at the pond edge. Names follow Scannell & Synnott (1987)

species	species
Achillea millefolium Linnaeus	Lolium perenne Linnaeus
Agrostis stolonifera Linnaeus L	Lotus corniculatus Linnaeus
Aira caryophyllea Linnaeus	Luzula multiflora (Retz.) Lej.
Alisma plantago –aquatica Linnaeus L	Lythrum salicaria Linnaeus
Angelica sylvestris Linnaeus	Mentha aquatica Linnaeus L
Anthoxanthum odoratum Linnaeus	Molinia caerulea (Linnaeus) Moench
Arrhenatherum elatius (Linnaeus) Beauv. Ex. J.&C. Pres.	Myrica gale Linnaeus
Betula pubescens Ehrh.	Phleum pratense Linnaeus
Calluna vulgaris (Linnaeus) Hull	Plantago lanceolata Linnaeus
Cardamine pratensis Linnaeus L	Poa trivialis Linnaeus
Centaurea nigra Linnaeus	Polygala serpyllifolia J.A.C. Hose
Cerastium fontanum Baumng.	Polygonum persicaria Linnaeus
Cirsium arvense (Linnaeus) Scop.	Potamogeton berchtoldii Fieber L
Cirsium palustre (Linnaeus) Scop.	Potentilla anserine Linnaeus
Cirsium vulgare (Savi) Ten.	Potentilla erecta (Linnaeus) Rauscel
Dactylis glomerata Linnaeus	Prunella vulgaris Linnaeus
Dactylorhiza maculata agg.	Pteridium aquilinum (Linnaeus) Kuhn
Daucus carota Linnaeus	Pulicaria dysenterica (Linnaeus) Bernh
Epilobium angustifolium Linnaeus	Ranunculus acris Linnaeus
Epilobium hirsutum Linnaeus	Ranunculus bulbosus Linnaeus
Epilobium parviflorum Schreber	Aquatic Ranunculus spp. L
Equisetum arvense Linnaeus	Reseda luteola Linnaeus
Equisetum plaustre Linnaeus L	Rhinanthus minor Linnaeus
Eriophorum angustifolium Honckeny L	Rubus fruticosus agg.
Festuca rubra Linnaeus.	Rumex acetosella Linnaeus
Filipendula ulmaria (Linn.) Maxim.	Rumex acetosa Linnaeus
Galium palustre Linnaeus L	Rumex crispus Linnaeus
Galium saxatile Linnaeus	Sagina nodosa (Linnaeus) Fenzl. L
Galium verum Linnaeus	Salix cinerea Linnaeus
Glyceria fluitans (Linnaeus) R. Br. L	Senecio jacobaea Linnaeus
Heracleum sphondylium Linnaeus	Sonchus arvensis Linnaeus
Holcus lanatus Linnaeus	Sonchus asper (Linnaeus) Hill
Hydrocotyle vulgare Linnaeus L	Stellaria alsine Grimm L
Hypericum pulchrum Linnaeus	Succisa pratensis Moench
Hypochoeris radicata Linnaeus	Taraxacum officinale
Juncus acutiflorus Ehrh. ex Hoffm. L	Trifolium dubium Sibth
Juncus articulatus Linnaeus	Trifolium pratense Linnaeus
Juncus bulbosus Linnaeus	Trifolium repens Linnaeus
Juncus effusus Linnaeus	Triglochin palustris Linnaeus L
Leontodon autumnalis Linnaeus	Tussilago farfara Linnaeus
Leontodon taraxacoides (Vill.) Merat	Typha latifolia Linnaeus L
Linum catharticum Linnaeus	Ulex europaeus Linnaeus

## Appendix 4.3.1

#### **Preliminary Survey**

Aquatic macroinvertebrate and vertebrate fauna recorded during the preliminary survey of four man-made wetlands on cutaway. Blackwater Lake and Boora Lake were sampled on 18 October 1996. Lullybeg Lake and Barnaran Pond were sampled on 11 November 1996. Turraun and Tumduff wetlands are detailed in subsequent Appendices.

	taxon	Blackwater Lake	Boora Lake	Lullybeg Lake	Barnaran Pond
Annelida	Oligochaeta		*	*	*
	Hirudinea	*			
Mollusca	Potamopyrgus jenkinsi	*			
	Planorbis crista	*			
	Planorbis contortus	*			
	Pisidium spp.	*	*	*	
Chelicerata	Hydracarina			*	
Crustacea	Ostracoda	*	*	*	
	Gammarus duebeni	*	*		
	Asellus aquaticus	*		*	*
Insecta					
Ephemeroptera	Caenidae	*	*	*	
	Baetidae	*	*	*	*
Odonata	Anisoptera		*		
	Zygoptera	*	*	*	
Heteroptera	Hydrometra spp.	*			
	Notonecta spp.	*	*	*	*
	Callicorixa wollastoni	*			
	Callicorixa praeusta	*			
	Corixa panzeri	*	*		*
	Hesperocorixa castanea				*
	Sigara distincta	*	*		
	Sigara dorsalis	*	*		
	Sigara falleni		*		
	Sigara fossarum				*
	Sigara scotti		*	*	
	Sigara venusta/semistriata				*
	Trichoptera	*		*	*
Diptera	Tipulidae	*			
	Dixidae	*			
	Ceratopogonidae	*		*	*
	Chironomidae	*		*	*
Coleopotera	Haliplus spp.	*			
	Noterus clavicornis	*			
	Laccophilus minutus	*			
	Hydroporus ?nigrita				*
	Hygrotus inaequalis	*			*
	Helophorus spp.	*			*
	Enochrus ochropterus			*	
	2				
		*			
	Laccobius minutus	*		*	
	Laccobius minutus Limnebius spp	*		*	*
	Laccobius minutus Limnebius spp Curculionidae			*	*
	Laccobius minutus Limnebius spp Curculionidae Agabus larva				*
Vertebrates	Laccobius minutus Limnebius spp Curculionidae			*	*

## Appendix 4.3.2.1

#### Macroinvertebrate Species Lists for Turraun and Tumduff

List of species and Taxa captured at Turraun between October 1996 and August 1999. Coleoptera are listed in taxonomic order. Other species are listed in alphabetical order within family. M after the species name indicates marsh species that are not considered truly aquatic.

group	taxon	Turraun	Tumduff
Cnidaria	Hydra spp.	*	*
Annelida	Oligochaete	*	*
Hirudinea	Piscicola geometra (Linnaeus)	*	
	Theromyzon tessulatum (Müller)	*	*
	Glossiphonia heteroclita (Linnaeus)	*	
	Glossiphonia complanata (Linnaeus)	*	
	Helobdella stagnalis (Linnaeus)	*	
	Erpobdella octoculata (Linnaeus)	*	
Mollusca	Potamopyrgus jenkinsi (Smith)	*	*
	Lymnaea palustris (Müller)	*	*
	Lymnaea peregra (Müller)	*	*
	Lymnaea stagnalis (Linnaeus)	*	
	Planorbis contortus (Linnaeus)	*	
	Planorbis crista (Linnaeus)	*	
	Succinia/Oxyloma spp.	*	*
	Pisidium sp.	*	*
Chelicerata	Hydracarina	*	*
Crustacea	Gammarus duebeni Stock & Pinkster	*	
	Gammarus lacustris Sars	*	*
	Asellus aquaticus (Linnaeus)	*	*
	Ostracoda	*	*
Insecta	Collembola	*	*
Ephemeroptera	Cloeon simile Eaton	*	*
	Caenis luctuosa (Burmeister)	*	*
	Leptophlebia vespertina (Linnaeus)		*
Anisoptera	Family Libellulidae	*	
	Aeshna grandis (Linnaeus)	*	
	Aeshna spp.		*
	Libellula quadrimaculata Linnaeus		*
	Sympetrum striolatum/nigrescens		*
Zygoptera	Ischnura elegans (Vander Linden)	*	*
	Enallagma cyathigerum (Charpentier)	*	*
Heteroptera	Hydrometra stagnorum (Linnaeus)	*	*
	Gerris argentatus Schummel	*	
	Gerris lacustris (Linnaeus)	*	*
	Gerris odontogaster (Zetterstedt)	*	*
	Gerris thoracicus Schummel	*	
	Nepa cinerea Linnaeus	*	
	Notonecta glauca Linnaeus	*	*
	Callicorixa praeusta (Fieber)	*	*
	Corixa panzeri (Fieber)	*	*
	Corixa punctata/iberica (Illiger)/Jansson	*	
	Hesperocorixa castanea (Thomson)	*	*
	Hesperocorixa linnaei (Fieber)	*	*
	Hesperocorixa ?moesta (Fieber)	*	*
	Hesperocorixa sahlbergi (Fieber)	*	
	Arctocorisa germari (Fieber)	*	*

group	taxon	Turraun	Tumduf
	Sigara distincta (Fieber)	*	*
	Sigara dorsalis (Leach)	*	*
	Sigara falleni (Fieber)	*	*
	Sigara fossarum (Leach)	*	*
	Sigara lateralis (Leach)	*	*
	Sigara scotti (Douglas & Scott)	*	*
	Sigara semistriata (Fieber)		*
Megaloptera	Sialis spp.	*	
Trichoptera	Agrypnia obsoleta (Hagen)	*	
	Agrypnia varia (Fabricius)	*	
	Lasiocephala basalis (Kolenati)/ Lepidostoma		*
	hirtum (Fabricius)		
	Limnephilus affinis/incisus Curtis	*	*
	Limnephilus lunatus Curtis	*	*
	Limnephilus marmoratus Curtis	*	*
	Limnephilus vittatus (Fabricius)	*	*
	Athripsodes aterrimus (Stephens)	*	*
	Mystacides ?azurea (Linnaeus)		*
	Mystacides longicornis (Linnaeus)	*	*
	Oecetis ochracea (Curtis)	*	*
	Ylodes/Triaenodes spp		*
	Ecnomus tenellus (Rambur)	*	
Diptera	Tipulidae	*	*
Diptera	Chaoboridae	*	
	Ceratopogonidae	*	*
	Chironomidae	*	*
	Dixidae		
	Tabanidae	*	*
	Sciomyzidae	*	
	Stratiomyidae	*	*
Colcontoro		*	*
<u>Coleoptera</u>	Haliplus confinis Stephens	*	*
	Haliplus fluviatilis Sturm	*	
	Haliplus lineatocollis (Marsham)	*	
	Haliplus obliquus Stephens	4.	*
	Haliplus rufficollis Degeer	*	*
	Haliplus rufficollis/wehckei	*	*
	Haliplus rufficollis group	*	*
	Haliplus variegatus Sturm		
	Noterus clavicornis (Degeer)	*	
	Laccophilus minutus (Linnaeus)	*	*
	Hygrotus inaequalis (Fabricius)	*	*
	Hydroporus gyllenhalii Schiödte	*	
	Hydroporus palustris (Linnaeus)	*	
	Hydroporus palustris var. semirufus	*	
	Hydroporus pubescens (Gyllenhal)	*	
	Graptodytes pictus (Fabricius)	*	*
	Porhydrus lineatus (Fabricius)	*	*
	Agabus nebulosus (Forster)	*	*
	Ilybius fuliginosus (Fabricius)	*	
	Dytiscus marginalis Linnaeus	*	
	Dytiscus semisulcatus Müller	*	
	Gyrinus caspius Ménétriés	*	
	Gyrinus marinus Gyllenhal	*	*
	Gyrinus substriatus Stephens	*	
	Helophorus brevipalpis Bedel	*	*
	Helophorus minutus Fabricius	*	
	Hydrobius fuscipes (Linnaeus)		*
	Anacaena lutescens (Stephens)	*	
	Laccobius minutus (Linnaeus)	*	

group	taxon	Turraun	Tumduff
	Chaetarthria seminulum M (Herbst)	*	
	Octhebius minimus (Fabricius)	*	*
	Hydraena rufipes/britteni/riparia Curits/Joy/	*	
	Kugelann		
	Limnebius truncatellus (Thunberg)	*	
	Elmis aenea (Müller)	*	
	Oulimnius tuberculatus (Müller)	*	
	Donacia simplex Fabricius M	*	
	Megasternum obscurum M (Marsham)	*	*
	Curculionidae	*	*
	Coccidula rufa (Herbst) M	*	
Vertebrates	Gasterosteus aculeatus Linnaeus	*	*
	Pungitius pungitius Linnaeus	*	*

## Appendix 4.3.2.2

#### Macroinvertebrate Abundance in Turraun and Tumduff

**Total number of individuals captured in Turraun and Tumduff between January 1997 and February 1998.** During this period, 260 samples were taken from Turraun and 165 from Tumduff. In column three, Turraun figures are corrected for 165 samples. Proportional abundance is given in terms of percentage abundance.

		total ca	atch c	catch (165 S	Samples)	% abun	dance
		Turraun 7		Turraun		Turraun	Tumduff
Cnidaria	<i>Hydra</i> sp.	66	0	42	0	0.2	0.0
Annelida	Oligochaete	1905	191	1209	191	5.6	1.3
Hirudine	a Piscicola geometra	14	0	9	0	0.0	0.0
	Theromyzon tessulatum	130	43	83	43	0.4	0.3
	Glossiphonia complanata	8	0	5	0	0.0	0.0
	Glossiphonia heteroclita	1	0	1	0	0.0	0.0
	Helobdella stagnalis	3	0	2	0	0.0	0.0
	Erpobdella octoculata	1	0	1	0	0.0	0.0
Mollusca	Potamopyrgus jenkinsi	487	9	309	9	1.4	0.1
	Lymnaea palustris	47	791	30	791	0.1	5.6
	Lymnaea peregra	64	98	41	98	0.2	0.7
	Lymnaea stagnalis	2575	0	1634	0	7.6	0.0
	Lymnaea young	1	0	1	0	0.0	0.0
	Planorbis contortus	11	0	7	0	0.0	0.0
	Planorbis crista	17	0	11	0	0.1	0.0
	Planorbis spp.	1	0	1	0	0.0	0.0
	Pisidium sp.	2248	21	1427	21	6.6	0.1
Chelicerata	Hydracarina	139	284	88	284	0.4	2.0
Crustacea	Gammarus duebeni	211	0	134	0	0.6	0.0
	Gammarus lacustris	79	2	50	2	0.2	0.0
	Gammarus spp.	1944	2	1234	2	5.7	0.0
	Asellus aquaticus	263	61	167	61	0.8	0.4
	Ostracoda	222	5	141	5	0.7	0.0
Insecta	Collembola	6	0	4	0	0.0	0.0
Ephemeropter	<u>a</u> Cloeon simile	277	173	176	173	0.8	1.2
	Caenis luctuosa	1801	2416	1143	2416	5.3	17.1
	Leptophlebia vespertina	0	1	0	1	0.0	0.0
Anisopter	a Anisoptera larva	8	9	5	9	0.0	0.1
	Aeshna grandis	2	1	1	1	0.0	0.0
	Libellula quadrimaculata	0	2	0	2	0.0	0.0
	Sympetrum	0	2	0	2	0.0	0.0
Zygopter	a Family Coenagrionidae	396	183	251	183	1.2	1.3
	Ischnura elegans	146	118	93	118	0.4	0.8
	Enallagma cyathigerum	228	145	145	145	0.7	1.0
Heteropter	a Hydrometra stagnorum	11	0	7	0	0.0	0.0
	Hydrometra nymph	2	0	1	0	0.0	0.0
	Gerris argentatus	3	0	2	0	0.0	0.0
	Gerris lacustris	1	0	1	0	0.0	0.0
	Gerris odontogaster	4	0	3	0	0.0	0.0
	Gerris thoracicus	1	0	1	0	0.0	0.0
	Gerris nymph	36	0	23	0	0.1	0.0
	Nepa cinerea	2	0	1	0	0.0	0.0
	Notonecta glauca	13	1	8	1	0.0	0.0
	Notonecta nymph	15	2	10	2	0.0	0.0

	total ca		catch (165 \$		% abunda	
	Turraun T		Turraun	Tumduff	Turraun T	
Callicorixa praeusta	3	6	2	6	0.0	0.0
Corixa panzeri	103	2	65	2	0.3	0.0
Hesperocorixa castanea	0	4	0	4	0.0	0.0
Hesperocorixa linnaei	1	1	1	1	0.0	0.0
Hesperocorixa ?moesta	0	1	0	1	0.0	0.0
Arctocorisa germari	1	1	1	1	0.0	0.0
Sigara distincta	2801	302	1778	302	8.3	2.1
Sigara dorsalis	943	397	598	397	2.8	2.8
Sigara falleni	45	1	29	1	0.1	0.0
Sigara fossarum	5561	245	3529	245	16.4	1.7
Sigara lateralis	1	1	1	1	0.0	0.0
Sigara scotti	1205	164	765	164	3.6	1.2
Sigara semistriata	0	4	0	4	0.0	0.0
Corixidae nymphs	818	571	519	571	2.4	4.0
Megaloptera Sialis sp.	34	0	22	0	0.1	0.0
Trichoptera Instar I	31	17	20	17	0.1	0.1
Agrypnia obsoleta	4	0	3	0	0.0	0.0
Agrypnia varia	1	0	1	0	0.0	0.0
Agrypnia spp.	4	0	3	0	0.0	0.0
Lasiocephala basalis	0	1	0	1	0.0	0.0
Limnephilus affinis/incisus	124	128	79	128	0.4	0.9
Limnephilus lunatus	273	6	173	6	0.8	0.0
Limnephilus marmoratus	447	145	284	145	1.3	1.0
Limnephilus vittatus	1	17	1	17	0.0	0.
Limnephilus young	922	68	585	68	2.7	0.
Athripsodes aterrimus	4	7	3	7	0.0	0.0
Athripsodes sp.	9	35	6	35	0.0	0.2
Mystacides longicornis	2500	2532	1587	2532	7.4	17.9
Oecetis ochracea	43	76	27	76	0.1	0.5
Ylodes/Triaenodes		2	0	2	0.0	0.0
Leptoceridae sp.	387	363	246	363	1.1	2.6
Ecnomus tenellus	1	0	1	0	0.0	0.0
Moulting		2	0	2	0.0	0.0
Trichopteran pupa	7	6	4	6	0.0	0.0
Diptera Tipulidae	38	6	24	6	0.1	0.0
Chaoboridae	12	0	8	0	0.0	0.0
Ceratopogonidae	192	38	122	38	0.6	0.
Chironomidae	2094	4203	1329	4203	6.2	29.
Dixidae	24	0	15	0	0.1	0.0
Tabanidae	201	16	128	16	0.6	0.
Sciomyzidae	6	0	4	0	0.0	0.0
Stratiomyidae	21	2	13	2	0.1	0.0
Other larva	15	5	10	5	0.0	0.0
Dipteran pupa	22	50	14	50	0.1	0.4
Coleoptera Haliplus confinis	72	6	46	6	0.2	0.0
Haliplus fluviatilis	1	4	1	4	0.0	0.0
Haliplus lineatocollis	1	0	1	0	0.0	0.0
Haliplus obliquus	15	0	10	0	0.0	0.
Haliplus rufficollis grp.	6	5	4	5	0.0	0.
Haliplus rufficollis/wehnckei	1	1	1	1	0.0	0.
Noterus clavicornis	410	0	260	0	1.2	0.
Laccophilus minutus	7	0	4	0	0.0	0.
Hygrotus inaequalis	116	26	74	26	0.3	0.
Hydroporus gyllenhalii	1	0	1	0	0.0	0.0
Hydroporus pubescens	1	0	1	0	0.0	0.0
H. palustris	2	0	1	0	0.0	0.0
H. palustris var. semirufus	1	0	1	0	0.0	0.0

		total ca		eatch (165 S		% abun	
		Turraun T	umduff	Turraun	Tumduff	Turraun	Tumdu
	Graptodytes pictus	12	6	8	6	0.0	0.
	Porhydrus lineatus	3	1	2	1	0.0	0
	Agabus nebulosus	0	1	0	1	0.0	0
	Ilybius fuliginosus	2	0	1	0	0.0	0
	Gyrinus marinus	1	0	1	0	0.0	0
	Gyrinus substriatus	1	0	1	0	0.0	0
	Helophorus brevipalpis	37	7	23	7	0.1	C
	Helophorus minutus	20	4	13	4	0.1	C
	Helophorus spp.	17	2	11	2	0.1	C
	Hydrobius fuscipes	0	1	0	1	0.0	C
	Anacaena lutescens	3	0	2	0	0.0	C
	Laccobius bipunctatus	16	3	10	3	0.0	(
	Laccobius minutus	19	1	12	1	0.1	(
	Chaetarthria seminulum	1	0	1	0	0.0	(
	Ochthebius minimus	9	1	6	1	0.0	(
	<i>Hydraena</i> sp.	1	0	1	0	0.0	(
	Limnebius truncatellus	1	0	1	0	0.0	(
	Elmis aenea	1	0	1	0	0.0	(
	Donacia simplex	1	0	1	0	0.0	(
	Megasternum obscurum	2	0	1	0	0.0	(
	Fam. Curculionidae	18	1	11	1	0.1	(
	Coccidula rufa	2	0	1	0	0.0	(
	Haliplus larva	66	6	42	6	0.2	(
	Noterus larva	2	0	1	0	0.0	(
	Ilybius larva?	15	2	10	2	0.0	(
	Dytiscus larva	16	1	10	1	0.0	(
	Dytiscidae larva	7	7	4	7	0.0	(
	Hydrophilidae larva	6	4	4	4	0.0	(
	Laccobius larva	1	0	1	0	0.0	(
	other larva	0	1	0	1	0.0	(
Vertebrates	Gasterosteus aculeatus	558	65	354	65	1.6	(
	Pungitius pungitius	53	12	34	12	0.2	(
	Stickleback	20	2	13	2	0.1	C
total		33,833	14,155	21,471	14,155	100	10
no. of samples		260	165	165	165	260	10

# Appendix 4.3.2.3

## Rare or Occasional Taxa in Turraun and Tumduff

	taxon	Turraun	Tumduff
Cnidaria	<i>Hydra</i> sp.	*	
Hirudinea	Erpobdella octoculata	*	
	Glossiphonia complanata	*	
	Glossiphonia heteroclita	*	
	Helobdella stagnalis	*	
	Piscicola geometra	*	
Mollusca	Potamopyrgus jenkinsi		*
	Planorbis contortus	*	
	Planorbis crista	*	
Crustacea	Gammarus duebeni		*
Crustacea	Gammarus lacustris		*
	Ostracoda		*
Insecta	Collembola	*	
Ephemeroptera	Leptophlebia vespertina		*
Anisoptera	Anisoptera larva	*	
Ansoptera			*
	Aeshna spp	*	
	Aeshna grandis		*
	Libellula quadrimaculata		*
TT	Sympetrum striolatum/nigrescens	4	*
Heteroptera	Gerris argentatus	*	
	Gerris lacustris	*	
	Gerris odontogaster	*	
	Gerris thoracicus	*	
	Hydrometra stagnorum	*	
	Nepa cinerea	*	
	Notonecta glauca		*
	Arctocorisa germari	*	*
	Callicorixa praeusta	*	*
	Corixa panzeri		*
	Hesperocorixa castanea		*
	Hesperocorixa linnaei	*	*
	Hesperocorixa ?moesta	*	*
	Sigara falleni		*
	Sigara lateralis	*	*
	Sigara semistriata		*
Trichoptera	Agrypnia obsoleta	*	
	Agrypnia varia	*	
	Lasiocephala basalis /Lepidostoma hirtum		*
	Limnephilus lunatus		*
	Limnephilus vittatus	*	
	Athripsodes aterrimus	*	
	Ylodes/Triaenodes spp.		*
	Ecnomus tenellus	*	
Dintara			*
Diptera	Tipulidae	*	
	Chaoboridae	*	
	Dixidae	*	
	Sciomyzidae Stratiomyidae	*	*

**Rare taxa in Turraun and Tumduff.** A rare taxon is one that occurs in < 5% of samples.

	taxon	Turraun	Tumdut
Coleoptera	Haliplus confinis		*
	Haliplus fluviatilis	*	*
	Haliplus lineatocollis	*	
	Haliplus obliquus	*	
	Haliplus rufficollis grp.	*	*
	Laccophilus minutus	*	
	Hydroporus gyllenhalii	*	
	Hydroporus pubescens	*	
	Hydroporus palustris	*	
	Graptodytes pictus	*	*
	Porhydrus lineatus	*	*
	Agabus nebulosus		*
	Ilybius fuliginosus	*	
	Gyrinus marinus	*	
	Gyrinus substriatus	*	
	Helophorus brevipalpis		*
	Helophorus minutus		*
	Hydrobius fuscipes		*
	Anacaena lutescens	*	
	Laccobius bipunctatus		*
	Laccobius minutus		*
	Chaetarthria seminulum	*	
	Ochthebius minimus	*	*
	Hydraena rufipes/britteni/riparia	*	
	Limnebius truncatellus	*	
	Elmis aenea	*	
	Donacia simplex	*	
	Megasternum obscurum	*	
	Family Curculionidae		*
	Coccidula rufa	*	
al		53	36

## Appendix 4.3.3.7

## **Feeding Guilds**

Feeding Guilds to which taxa were assigned. Five guilds were chosen, suspension feeders, deposit feeders, scrapers, shredders and predators (after Moss 1998).

	taxon	feeding guild
Cnidaria	Hydra sp.	Predator
Annelida	Oligochaete	Deposit Feeder
Hirudinea	Erpobdella octoculata	Predator
	Glossiphonia species	Predator
	Helobdella stagnalis	Predator
	Piscicola geometra	Predator
	Theromyzon tessulatum	Predator
Mollusca	Lymnaea species	Scraper
	Planorbis species	Scraper
	Potamopyrgus jenkinsi	Scraper
	Pisidium sp.	Suspension Feeder
Chelicerata	Hydracarina	Predator
Crustacea	Gammarus species	Shredder
	Asellus aquaticus	Deposit Feeder
	Ostracoda	Suspension Feeder
Insecta		
Ephemeroptera	Cloeon simile	Scraper
	Caenis luctuosa	Deposit Feeder
	Leptophlebia vespertina	Scraper
Anisoptera	Anisoptera larvae	Predator
Zygoptera	Zygoptera larvae	Predator
Heteroptera	Gerris species	Predator
	Gerris nymph	Predator
	Hydrometra stagnorum	Predator
	Hydrometra nymph	Predator
	Nepa cinerea	Predator
	Notonecta glauca	Predator
	Notonecta nymph	Predator
	Corixidae	Omitted
Megaloptera	Sialis sp.	Predator
Trichoptera		Scraper
Diptera	Tipulidae	Predator
	Chaoboridae	Predator
	Ceratopogonidae	Scraper
	Chironomidae	Omitted
	Dixidae	Predator
	Tabanidae	Predator
	Sciomyzidae	Predator
	Stratiomyidae	Shredders
Coleoptera	Haliplus species	Scraper
	Noterus clavicornis	Predator
	Laccophilus minutus	Predator
	Hygrotus inaequalis	Predator
	Hydroporus species	Predator
	Graptodytes pictus	Predator
	Porhydrus lineatus	Predator

taxon	feeding guild	
 Agabus nebulosus	Predator	-
Ilybius fuliginosus	Predator	
Gyrinus species	Predator	
Helophorus species	Scraper	
Hydrobius fuscipes	Scraper	
Anacaena lutescens	Scraper	
Laccobius species	Deposit Feeder	
Chaetarthria seminulum	Scraper	
Ochthebius minimus	Scraper	
Hydraena rufipes/britteni/riparia	Scraper	
Limnebius truncatellus	Scraper	
Elmis aenea	Scraper	
Donacia simplex	Shredder	
Megasternum obscurum	Scraper	
Fam. Curculionidae	Shredder	
Coccidula rufa	Scraper	
Haliplus larva	Scraper	
Noterus larva	Predator	
Ilybius larva	Predator	
Dytiscidae larva	Predator	
Hydrophilidae larva	Predator	
Laccobius larva	Predator	

## Appendix 6.3.3

#### Distribution of Parasitic Larval Mites on Corixidae in Study Sites

**Distribution of parasitic larval mites on corixids in Turraun and Tumduff.** The percentage of corixids having mites attached to each location is given.

location	Turraun	Tumduff
legs	60	71
ventral side of thorax	21	29
ventral side of abdomen	18	19
hemielytra	12	3
ventral side of head	4	6
pronotum	1	0.5
wing buds of nymphs	0.5	0.5

**Distribution of mites attached to corixid limbs.** The percentage of leg parasites on each segment is given.

limb	segment	Turraun	Tumduff
hindlimb	coxae	13	14
	trochanters	8	9
	femurs	13	38
	tibiae	9	10
	tarsi	4	1
midlimb	coxae	5	2
	trochanters	7	2
	femurs	10	8
	tibiae	1	0
	tarsi	2	1
forelimb	coxae	2	0
	femurs	13	7
	tibiae	15	7

## Appendix 7.3.1

#### **Corixidae Feeding Trials**

The number of Corixidae tested for each prey item, during feeding trials. The number of test animals that fed is given in parenthesis. The number of individuals from the four main species is also given. Other species and corixid nymphs are not detailed. A&B - Algae & Biofilm, S-bA - Soft-bodied Animals, MN - Mayfly Nymphs, H-bA - Hardbodied Animals.

group	prey item	total tested	ł	S. dorsalis	S. distincta	S. fossarum	S. scotti
A&B	Phytoplankton	40	(13)		31 (7)	8 (6)	1 (0)
	Hay Infusion	18	(7)		2 (1)	16 (6)	
	Periphyton (Chara)	35	(16)	5 (2)	7 (5)	21 (7)	2 (2)
	Periphyton (Myriophyllum)	35	(3)		24 (3)	10 (0)	
S-bA	Chironomid Larvae	61	(5)	1 (0)	36 (4)	19 (0)	3 (0)
	Oligochaeta	48	(10)		31 (3)	17 (7)	
MN	Caenis luctuosa	12	(0)	1 (0)	5 (0)	6 (0)	
	Cloeon simile	21	(4)	4 (1)	6 (2)	11(1)	
H-bA	Lymnaea peregra	1	(0)			1 (0)	
	Asellus aquaticus	5	(0)	2 (0)		3 (0)	
	Crangonyx pseudogracilis	13	(0)	1 (0)	3 (0)	9 (0)	
	Zygoptera Nymph	4	(0)	2 (0)	1 (0)	1 (0)	
	Trichoptera Larvae	6	(0)	1 (0)	5 (0)		
	Coleoptera	13	(0)		12 (0)		1 (0)
	Live Daphnia	12	(3)	5(1)	3 (2)	3 (0)	
	Dead Daphnia	12	(2)	2 (0)	1 (0)	7 (1)	2 (1)
	tota	336	(63)	24 (4)	167 (27)	132 (28)	9 (3)

The number of male and female Sigara distincta and S. fossarum tested for each prey item. The number of test animals that fed is given in parenthesis.

		Sigara distincta	Si	gara fossarum	
group	prey item	3	Ŷ	3	Ŷ
A&B	Phytoplankton	15 (3)	16 (4)	5 (3)	3 (3)
	Hay Infusion	2 (1)	0 (0)	9 (5)	7 (1)
	Periphyton (Chara)	4 (4)	3 (1)	11 (2)	10 (5)
	Periphyton (Myriophyllum)	10 (3)	14 (0)	5 (0)	5 (0)
S-bA	Chironomid Larvae	23 (3)	13 (1)	4 (0)	15 (0)
	Oligochaeta	16 (3)	15 (0)	9 (5)	8 (2)
MN	Caenis luctuosa	4 (0)	1 (0)	4 (0)	2 (0)
	Cloeon simile	2 (2)	4 (0)	4 (0)	7 (1)
H-bA	Lymnaea peregra	0 (0)	0 (0)	1 (0)	0 (0)
	Asellus aquaticus	0 (0)	0 (0)	0 (0)	3 (0)
	Crangonyx pseudogracilis	2 (0)	1 (0)	6 (0)	3 (0)
	Zygoptera Nymph	0 (0)	1 (0)	1 (0)	0 (0)
	Trichoptera Larvae	2 (0)	3 (0)	0 (0)	0 (0)
	Coleoptera	7 (0)	5 (0)	0 (0)	0 (0)
	Live Daphnia	1 (1)	2 (1)	2 (0)	1 (0)
	Dead Daphnia	0 (0)	1 (0)	5 (1)	2 (0)
		Fotal 88 (20)	79 (7)	66 (16)	66 (12)

### Appendix 8.2.1

#### **Scoping for Laboratory Based Habitat Selectivity Experiments**

**Sample of Recording Sheets used in the Scoping Experiments.** The date, experiment start time, species and the experiment number were recorded on the top of the sheet. The location of the corixid in the beaker or aquarium was recorded in the column marked Loc. The duration of different behaviours was recorded in each column. The behaviours recorded were as follows: P was perching, on vegetation or the container; Rub was rubbing the hemielytra, head and abdomen with the hind legs; Rt. R was rubbing the body with the right hind leg; Lt. R was rubbing the body with the left hind leg; B was beating with the hind legs in regular motions; F was feeding and S was swimming. The column marked other was used for any behaviour other than those mentioned above. Each box represented a 15 second interval in the 30 minute sampling period. A vertical line was drawn to denote the length of time spent at each behaviour.

Date						Time					Spp						No.				
Min	Sec	Loc.	P	Rub	Rt. R	Lt. R.	В	F	S	Other	Min	Sec	Loc.	P	Rub	Rt. R	Lt. R.	В	F	S	Other
	1											31									
	2										8	32									
	3							-				33					1				
1	4											34									
	5											35									
	6								-		9	36									
	7											37									
2	8											38									
	9											39									
-	10										10										
	11											41									
3	12											42					1.4				
	13											43					1				
	14										11	44									
	15											45									
4	16											46					1				
	17											47									
	18										12	48									
	19											49									
5	20											50									
	21					-						51					-				
	22										13										
	23											53									
6												54									
	25											55									
	26										14						1				
	27											57					1.				
7												58									
	29											59									
	30										15	60									

Date						Time					Spp						No.				
Min	Sec	Loc.	P	Rub	Rt. R	Lt. R.	В	F	S	Other		Sec	Loc.	P	Rub	Rt. R	Lt. R.	В	F	S	Other
	61											91									
	62		-								23	92					-				
	63											93									
16	64											94					1				
	65											95					*				
	66				1.1.1.1.1						24				1.000				S		
1	67											97									
17												98									
	69											99									
	70			-					-		25										
	71			1								101									
18									-			102									
	73			-	1		1					103					-				-
	74			-	1						26										
	75							-				105					1				
19												106									-
	77											107									
	78										27				-						
	79			-								109									
20	-											110									
	81											111									
	82		-								28										
	83											113									
21										1	1	114					-				
	85											115					-				
	86										29	116					-				
	87											117									
22												118									
	89											119									
	90			1	1						30										

## Appendix 8.2.2

#### Scoping for Laboratory Based Habitat Selectivity Experiments

Table I gives the total length of time spent by each test individual at the nine identified behaviours. Table II details the average length of time spent at a single execution of each behaviour. Time is given in seconds. rt. rub. was rubbing with the hind right limb, lt. rub. was rubbing with the hind left limb, tot rub. was the total amount of time spent rubbing with the hind legs

Ι

date	time	species	sex	vessel	perching	rubbing	rt. rub.	lt rub.	tot rub.	beating	feeding	swim.	crawling
06-Jan-99	15:00	Sigara distincta	F	Beaker	1750	360	35	55	450	25	122	50	0
08-Jan-99	14:34	Sigara distincta	F	Beaker	1590	55	0	10	65	0	445	135	75
08-Jan-99	15:27	Sigara distincta	F	Beaker	1273	45	10	10	65	0	765	65	472
05-Jan-99	17:20	Sigara distincta	М	Tray	1635	830	70	15	915	253	10	165	0
06-Jan-99	11:31	Sigara distincta	М	Tray	1655	0	0	10	10	80	0	145	0
06-Jan-99	18:11	Sigara distincta	М	Beaker	1725	239	40	58	337	65	25	75	0
11-Jan-99	16:20	Sigara dorsalis	F	Beaker	1426	103	5	22	130	75	196	291	83
12-Jan-99	18:52	Sigara dorsalis	F	Beaker	1765	130	22	5	157	0	62	35	0
14-Jan-99	17:30	Sigara dorsalis	F	Beaker	1717	216	0	15	231	1215	355	83	0
12-Jan-99	14:46	Sigara dorsalis	М	Beaker	1800	35	15	0	50	10	20	0	0
06-Jan-99	10:17	Sigara fossarum	F	Tray	1785	3	0	0	3	3	5	15	0
06-Jan-99	16:42	Sigara fossarum	F	Beaker	1765	332	10	3	345	20	375	35	0
17-Dec-98	12:15	Sigara fossarum	М	Tray	1685	12	5	0	17	30	3	115	0
06-Jan-99	14:01	Sigara fossarum	М	Tray	1625	5	0	0	5	15	5	175	0
07-Jan-99	16:55	Sigara fossarum	М	Beaker	1770	7	0	0	7	10	35	30	0
07-Jan-99	18:47	Sigara fossarum	М	Beaker	1773	30	0	0	30	20	390	27	0
11-Jan-99	15:15	Sigara fossarum	М	Beaker	1663	118	5	20	143	167	85	132	5
14-Jan-99	09:58	Sigara fossarum	М	Beaker	1755	535	79	155	769	242	5	45	0
13-Jan-99	11:59	Sigara scotti	F	Beaker	1775	35	3	0	38	25	0	25	0
13-Jan-99	16:41	Sigara scotti	М	Beaker	1800	0	0	0	0	0	0	0	0
14-Jan-99	15:20	Sigara scotti	М	Beaker	1730	30	0	0	30	5	0	30	0

date	time	species	sex	vessel	perching	rubbing	rt. rub.	lt rub.	tot rub.	beating	feeding	swim.	crawling
06-Jan-99	15:00	Sigara distincta	F	Beaker	-	15.00	5.00	6.88	11.54	6.25	7.18	8.33	0.00
08-Jan-99	14:34	Sigara distincta	F	Beaker	-	27.50	0.00	10.00	21.67	0.00	31.79	9.00	9.38
08-Jan-99	15:27	Sigara distincta	F	Beaker		22.50	5.00	5.00	10.83	0.00	17.79	8.13	13.49
05-Jan-99	17:20	Sigara distincta	М	Tray		12.97	3.33	1.88	9.84	15.81	5.00	5.69	0.00
06-Jan-99	11:31	Sigara distincta	М	Tray		0.00	0.00	2.50	2.50	1.31	0.00	5.37	0.00
06-Jan-99	18:11	Sigara distincta	М	Beaker		8.54	2.86	3.87	5.91	3.82	3.57	15.00	0.00
11-Jan-99	16:20	Sigara dorsalis	F	Beaker		14.71	5.00	5.50	10.83	4.69	16.33	36.38	10.38
12-Jan-99	18:52	Sigara dorsalis	F	Beaker		65.00	5.50	5.00	22.43	0.00	12.40	17.50	0.00
14-Jan-99	17:30	Sigara dorsalis	F	Beaker		15.43	0.00	5.00	13.59	43.39	71.00	16.60	0.00
12-Jan-99	14:46	Sigara dorsalis	М	Beaker		11.67	7.50	0.00	10.00	5.00	5.00	0.00	0.00
06-Jan-99	10:17	Sigara fossarum	F	Tray		3.00	0.00	0.00	3.00	3.00	5.00	5.00	0.00
06-Jan-99	16:42	Sigara fossarum	F	Beaker		41.50	10.00	3.00	34.50	4.00	46.88	11.67	0.00
17-Dec-98	12:15	Sigara fossarum	М	Tray	-	6.00	5.00	0.00	5.67	3.75	3.00	8.85	0.00
06-Jan-99	14:01	Sigara fossarum	М	Tray		5.00	0.00	0.00	5.00	3.75	5.00	9.72	0.00
07-Jan-99	16:55	Sigara fossarum	М	Beaker		7.00	0.00	0.00	7.00	10.00	35.00	30.00	0.00
07-Jan-99	18:47	Sigara fossarum	М	Beaker		10.00	0.00	0.00	10.00	4.00	16.25	6.75	0.00
11-Jan-99	15:15	Sigara fossarum	М	Beaker		9.08	2.50	5.00	7.53	10.44	14.17	14.67	5.00
14-Jan-99	09:58	Sigara fossarum	М	Beaker	-	9.73	4.16	4.70	7.19	13.44	2.50	6.43	0.00
13-Jan-99	11:59	Sigara scotti	F	Beaker		8.75	3.00	0.00	7.60	6.25	0.00	12.50	0.00
13-Jan-99	16:41	Sigara scotti	М	Beaker	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14-Jan-99	15:20	Sigara scotti	М	Beaker	-	30.00	0.00	0.00	30.00	2.50	0.00	15.00	0.00

### Appendix 8.3.1

#### Laboratory Based Habitat Selectivity Experiments

**Sample of Recording Sheets used in the Habitat Selectivity Experiments.** The date, experiment start time, species and the experiment number were recorded on the top of the sheet. Time from 1 to 31 represents scans taken every minute over the 30 minute experiment. The first scan was taken at the beginning of the first minute and the last at the end of the thirtieth minute. Each column represents a different behaviour: P was perching, PR was perching with rubbing, PB was perching with beating, PF was perching with feeding, CF was crawling with feeding, S was swimming, SS was swimming to surface, SA was swimming into the aquarium wall and bottom and RS was resting on the surface film. The location of corixids (A1, B4, C6 etc.) was recorded in relevant cells, hence giving the behaviour and location of the six corixids at each scan.

1	Р	PR	PB	PF	CE	Species	aa	~ .	50	
1				PT	CF	S	SS	SA	RS	Other
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
11 12										
13										
14										
14 15										
16 17										
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22										
23										
24										
19       20       21       22       23       24       25       26       27       28       29       30       31										
26										
27										
28									*	
29							A second and a second		1	
30										
31 Other Info										

## Appendix 8.4.2

#### Habitat Usage Field Experiments

**Details of Corixidae captured in each Replicate Sample during the Habitat Usage Field Experiment.** trans. no. – transect number, M1 is *Myriophyllum* 1; M2, *Myriophyllum* 2; H1, *Hippuris* 1; H2, *Hippuris* 2. rep. no. – replicate sample number. *S. dt* - *Sigara distincta*, *S. ds* – *S. dorsalis*, *S. fs* – *S. fossarum*, *S. sc* – *S. scotti*, *C. pr* - *Callicorixa praeusta*, *H. ln* – *Hesperocorixa linnaei*, *C. pz* - *Corixa panzeri*, N – corixid nymph.

trans	rep.	depth									
no.	no.	cm	S. dt	S. ds	S. fs	S. sc	C. pr	H. ln	C. pz	N	total
M1	A1	18	2	3	0	0	0	0	0	9	14
M1	A2	19	0	7	1	0	1	0	0	27	36
<b>M</b> 1	A3	20	0	8	1	2	0	0	0	29	40
M1	A4	21	0	7	0	1	0	0	0	30	38
M1	A5	22	0	8	2	3	0	0	0	22	35
M1	B1	26	0	2	0	1	0	1	0	25	29
M1	B2	26	0	0	0	0	2	0	0	35	37
M1	B3	26	0	3	1	1	0	0	0	12	17
M1	B4	26	8	1	0	0	0	0	0	25	34
M1	B5	26	0	2	0	0	1	0	0	10	13
M1	C1	32	0	5	1	0	1	0	0	13	20
M1	C2	30	0	6	0	0	0	0	0	24	30
M1	C3	32	1	6	1	0	1	0	0	14	23
M1	C4	31	2	1	0	0	2	0	0	13	18
M1	C5	30	0	1	2	0	0	0	0	4	7
M2	D1	16	0	1	0	0	0	0	0	20	21
M2	D2	14	0	0	0	2	1	0	0	15	18
M2	D3	14	0	0	0	0	0	1	0	1	2
M2	D4	15	0	0	0	1	0	0	0	7	8
M2	D5	15	1	0	0	0	1	0	0	2	4
M2	E1	21	0	2	0	0	0	0	0	1	3
M2	E2	21	0	0	0	1	0	0	0	2	3
M2	E3	22	0	1	0	1	0	0	0	9	11
M2	E4	22	0	0	0	0	0	0	0	6	(
M2	E5	20	0	0	0	0	0	1	1	6	8
M2	F1	30	0	2	0	2	0	0	0	2	6
M2	F2	29	0	4	0	0	0	0	0	1	5
M2	F3	30	1	6	0	0	0	0	0	11	18
M2	F4	29	1	6	1	0	1	0	0	9	18
M2	F5	29	0	1	0	0	0	0	1	7	9
HI	G1	7	0	0	0	0	1	0	0	1	2
HI	G2	8.5	1	0	0	0	0	0	0	1	2
HI	G3	7	0	0	0	0	0	0	0	1	1
HI	G4	8	0	0	0	0	0	0	0	1	1
H1	G5	8.5	0	0	0	0	0	0	0	0	C
H1	HI	11.5	0	0	0	0	0	0	0	1	1
H1	H2	11.5	0	0	0	0	0	0	0	0	(
HI	H3	10	0	0	0	0	0	0	0	0	(
H1	H4	10	0	0	0	0	0	0	0	0	(
H1	H5	9.5	0	0	0	0	0	0	0	0	(
HI	II II	20	0	0	0	0	0	0	0	0	(
H1	II I2	20	0	0	0	0	0	0	0	0	(
H1	12 I3	19	0	0	0	0	0	0	0	0	
			0	0	0		0		0		0
H1	I4	20				0		0		2	2
H1	15	21	0	0	0	0	0	0	0	0	

trans	rep.	depth									
no.	no.	cm	S. dt	S. ds	S. fs	S. sc	C. pr	H. ln	C. pz	Ν	total
H2	J1	10	0	0	0	0	0	0	0	0	0
H2	J2	9.5	0	0	0	0	0	0	0	0	0
H2	J3	10	0	0	0	0	0	0	0	0	0
H2	J4	9	0	0	0	0	0	0	0	0	0
H2	J5	10	0	0	0	0	0	0	0	0	0
H2	K1	12	0	0	0	0	0	0	0	0	0
H2	K2	13	0	0	0	0	0	0	0	0	0
H2	K3	14	0	0	0	0	0	0	0	0	0
H2	K4	13	0	0	0	0	0	0	0	1	1
H2	K5	13	0	1	0	0	0	0	0	1	2
H2	L1	17	0	1	0	0	0	0	0	0	1
H2	L2	19	0	0	0	0	0	0	0	0	0
H2	L3	18	0	0	0	0	0	0	0	0	0
H2	L4	18	0	0	0	0	0	0	0	0	0
H2	L5	19	0	0	0	0	0	0	0	0	0

The average catch per replicate sample at each depth sampled in *Myriophyllum*. Depth is given in millimetres. d is the distance from shore in metres.

depth	d	S. dorsalis	S. distincta	S. fossarum	S. scotti	C. praeusta	Nymph	Total
M1				11111				
200	3.0	6.6	0.4	0.8	1.2	0.2	23.4	32.6
260	4.5	1.6	1.6	0.2	0.4	0.6	21.4	26.0
300	9.0	3.8	0.6	0.8	0	0.8	13.6	19.6
M2								
150	1.5	0.2	0.2	0.0	0.6	0.4	9.0	10.6
210	3.0	0.6	0	0	0.4	0	4.8	6.2
300	5.0	3.8	0.4	0.2	0.4	0.2	6	11.2