Chapter 5: Work Package 3 (b): Micro distribution of brown trout and eels in relation to diurnal oxygen variation.

5.1 Overview of chapter

This chapter deals specifically with an investigation of the movement of adult brown trout and eels in response to diurnal variation in dissolved oxygen. An intensive tracking survey began in the summer 2002 and was repeated in 2003 on three rivers, a "clean-water" site (the Derreen), a site with extensive growths of *Ranunculus* (the Aggard River), and a moderately eutrophic system (the Rye Water) with an excessive amount of instream plant growth, in particular *Cladophora* sp.

5.2 Introduction

The brown trout and the European eel are important elements in the fish communities found in many freshwater systems in Ireland. Like aquatic systems elsewhere in Europe, many of the rivers and lakes in Ireland have undergone cultural eutrophication (Reynolds, 1998). The main effects of eutrophication are dissolved oxygen sags at dawn caused by the proliferation of algae and macrophyte growth, siltation, increased biomass and concurrent reduction in the diversity of sensitive species (Environment Agency, 2000a).

Dissolved oxygen is essential and in some cases even the limiting factor, for maintaining aquatic life, its depletion in water is probably the most frequent general result of certain forms of water pollution (Alabaster and Lloyd, 1980). Oxygen content in freshwater systems varies with temperature, salinity, turbulence, and atmospheric pressure and most importantly with the photosynthetic activity of algae and plants. High dissolved oxygen concentrations (supersaturation) during the day are often associated with deoxygenation ("oxygen sag") at night, when respiration processes exceed photosynthesis (Flanagan, 1990). Early morning dissolved oxygen concentrations can be naturally low but the magnitude of this diurnal variation will be greatest where both eutrophication and organic pollution occur and it is indicative of less than satisfactory conditions (Flanagan, 1990). Supersaturation of dissolved oxygen can arise during bright, hot, calm weather in the presence of abundant plant or algal growth which can generate oxygen by photosynthesis at a high rate (Environment Agency, 2000b). Photosynthesis is more vigorous during strong sunlight, therefore the diurnal effect is more pronounced in sunny conditions than during cloudy weather.

Many factors can cause or contribute to the deoxygenation of a riverine system. They can be divided into two main categories – bacterial action (organic loading and pollution from sewage, agricultural wastes and industrial pollutants) and weather-related causes (Environment Agency, 2000b).

In a pristine environment one would expect dissolved oxygen levels just below 10mg/l O_2 at typical river temperatures or 100% saturation (Mc Garrigle, 2001). However, within any river reach there may be pockets of high and low oxygen due to localised biological processes (Williams *et al*., 2000).

Fish obtain the oxygen they need from that dissolved in the surrounding water, absorbing it through their gills. Sensitivity to low dissolved oxygen concentration differs between fish species, between the various life stages (e.g. egg, larvae and adults) and between the different life processes (e.g. feeding, growth etc.) (Alabaster and Lloyd, 1980). Salmonids require clean, well-oxygenated water for all stages in their life history, from developing embryos to spawning adults (Hendry *et al*., 2003). Saturation values of 70% and upwards are generally acceptable, while values consistently below this will have serious implications for fish life, salmonids being first affected (Lennox and Toner, 1980). Salmonid fish will begin to be affected as dissolved oxygen levels drop to 50%, whereas cyprinids are affected at levels around 30% (Flanagan, 1990), below these levels mortality may occur, depending on the duration of such conditions and the acclimatisation period.

Temperature is a factor of great importance when there is a shortage of oxygen. Increased temperatures also affect the solubility of oxygen. For example, water at $5^{o}C$ can hold a maximum of 12mg/l (100% saturation) of oxygen, whereas water at $20^{o}C$ can hold a maximum of only 9.1mg/l (100% saturation). Consequently less oxygen is available to organisms at higher water temperatures (Environmental Agency, 2000b).

In the warm summer of 1995 the number of fish kills in Ireland rose due to the combination of adverse effects of eutrophication and low flows (Mc Garrigle, 1998; Champ, 2003). Such fish kills have increased the awareness of the impacts of nutrient loading to riverine systems and have prompted more research into the problem. Eutrophic conditions may also raise the pH of the water due to the removal of CO_2 during photosynthesis. This can create other implications, for example a raised pH can significantly increase the percentage of un-ionised ammonia, which is potentially toxic to aquatic biota (Lee and Jones, 1991). Elevated pH can also affect gill function (Harper, 1990).

The use of fish communities as indicators of water quality is becoming more common and is now required by the Water Framework Directive. Life histories are generally well known and because fish are often the high order consumers they can reflect the effect of environmental stress on the entire aquatic community (Berkman and Rabeni, 1986). Research to date has concentrated on the impact of eutrophication on the composition of fish communities, indicating a change from populations dominated by salmonid species in clean river systems to an increase in more tolerant coarse fish (Lee and Jones, 1991). Little work has been carried out on the actual response of fish to fluctuations in dissolved oxygen in eutrophic conditions. Fish are mobile and can move away from areas of environmental stress. Radio telemetry is the best-known method of following them during a critical period, to examine how they react to changes in environmental conditions and provide a better understanding of fish movement (Gowan, 1994).

Researchers from University College Dublin (UCD) and the National University of Ireland Galway (NUIG) in collaboration with the Central Fisheries Board initiated this study in summer 2002 on three rivers, one on the west coast (the Aggard - NUIG) and two on the east coast (the Rye Water and the Derreen - UCD). However, because 2002 was the wettest year on record at a number of stations in the south and east (Met Eireann, 2002) it was necessary to repeat the study in summer 2003. Temperatures during August 2003 were 2°C higher than normal and the period between the 4th and the 8th of the month was particularly hot when daytime air temperatures rose above 25^{o}C in many places and remained above 15^{o}C at night. It was also the driest August since 1976 (Met Eireann, 2003), however, water levels did not reach the lows experienced during the summer of 1995 due to the preceding months of May, June and July being relatively wet. The NUIG element of the work package involved the examination of abiotic variaton on diel activity patterns on both the European eel and the brown trout during a six-day period in June 2003. The UCD element examined the movement of adult brown trout specifically in response to diurnal variation in dissolved oxygen over a five-week period in 2002, which was then repeated in 2003.

5.2.1 Aims

These studies were designed to advance understanding of the movement of two common riverine fish species in relation to diel variation in a range of variables including dissolved oxygen, through radiotelemetry. There is increasing interest in the potential of biotelemetry as a means of measuring fish behaviour, and the study was also designed to examine its utility as a tool to identify quickly early-warning signals of oxygen stress in macrophyte-dominated river systems. The hypothesis was that if nocturnal oxygen stress occurred fish would modify their behaviour by moving to areas in the river where oxygen was at satisfactory levels for the species.

5.3. Methods

5.3.1. Study sites

Three rivers were chosen for the study, a clean-water site (the Derreen River), a site with extensive growths of *Ranunculus sp*. (the Aggard River), and a moderately eutrophic system (the Rye Water) with an excessive amount of instream plant growth, particularly *Cladophora* sp. Table 5.1 lists the characteristics of each site.

The Derreen River is a tributary of the Slaney and rises in the Wicklow Mountains at an altitude of 650m where it flows across blanket bog down to the fertile valleys of North Wexford. The loss of much of the boglands through drainage has resulted in episodic flooding (Reynolds, 1998). The Derreen has a catchment area of 35.12 km^2 and flows through a low intensive agricultural area where the emphasis is on sheep and cattle grazing for most of 38.5 km course before joining the Little Slaney River 5km south of Tullow. The water quality is good (Q4), however, it is prone to occasional incidences of pollution. During the study period the diurnal dissolved oxygen regime deviated little from 100% saturation, which characterises a 'healthy stream' (McGarrigle, 2001). *Ranunculus* sp. dominates the instream vegetation and provides excellent cover for salmonids. Although overhanging riparian vegetation is scarce, there are some clusters of willow trees and brambles, which provide excellent cover for brown trout.

The Rye Water is the largest tributary of the River Liffey, rising in north central Kildare at an altitude of 75.3m. It has a catchment area of 193.54 km^{-2}. It follows an east-southeast course for 24.8km before it meets the main Liffey in the town of Leixlip. Towards its lower reaches it flows through a small lake in Carton Estate upstream of the study site. The catchment is predominately agricultural with several medium-sized towns within the commuter belt of Dublin. The Rye Water has been impacted by various sources of organic effluent for over 20 years. Some of the point sources have been alleviated but others, together with diffuse sources continue to cause problems. Biological quality has deteriorated over the last ten years due to an increase in nutrient inputs from diffuse sources (mainly agricultural) and point sources (Anon, 2003). The Rye Water is currently eutrophic (Q3) and during the summer months the substrate is often totally covered by a blanket of filamentous algae. The site chosen has a good growth of bank-side vegetation which provides excellent cover for brown trout.

The Aggard Stream is a tributary of the Dunkellin River located in Co. Galway. Due to its underlying geology (Carboniferous limestone) and the predominately agricultural nature of the surrounding catchment, the stream is enriched with plant nutrients and supports dense stands of in-channel macrophytes, dominated by *Ranunculus* spp.

Table 5.1: The main characteristics of each site.

	Derreen site	**Rye Water site**	**Aggard site**
Q value	4	3	4
Fish species present	Salmon, brown trout, eel, stoneloach, lamprey	Salmon, brown trout, eel, minnow, 3-spined stickleback, stoneloach, lamprey, pike	Salmon, brown trout, eels, 3-spined stickleback and pike
Mean MRP (mg/l P)	0.018	0.04	0.007
Mean TON (mg/l N)	1.276	0.976	2.104
Mean depth (cm)	0.38 (± 0.02)	0.30 (± 0.02)	0.28 (± 0.11)
Max depth (m)	1.11	0.96	
Width (m)	6.67 (± 0.23)	10.0 (± 0.01)	4.5 (± 0.32)
Velocity (m/s)	0.01 – 1.03	0.01 - 0.61	
Substrate type	Boulder (5%), cobble (55%), gravel (30%), sand (5%), mud/silt (5%).	Boulder (5%), cobble (40%), gravel (40%), sand (5%), mud/silt (10%).	
Geology	Granite, Felsite and other intrusive rocks rich in silica	Middle carboniferous limestone	Carboniferous limestone
Habitat types	riffle (20%), glide (60%), pool (20%)	riffle (30%), glide (60%), pool (10%)	

5.3.2 Fish tagging

Adult eels (freshwater-phase (yellow)) and brown trout were electric fished from each site and anaesthetised until they reached stage II of anaesthesia (Walsh & Pease, 2002). Length and weight measurements were taken for each fish. Each fish was externally tagged with a small VHF radiotag secured by sterile monofilament thread 3/0 (non-absorbable suture) inserted through the dorsal musculature (Beaumont *et al*., 1996). Table 5.2 lists the species, type of tag, anaesthetic used etc. on each river. Once secured the tagged area was coated in malachite green to reduce potential fungal infection. The fish were held in net cages in the river to recover for three hours and then released back into the stretch as near as possible to where they were caught. Tracking on the Rye Water did not commence for a week until fish had recovered from the tagging procedure. Three fish were lost to predation on the Rye Water during the initial week in 2003, the tags were retrieved and additional fish were tagged within the same size range.

Table 5.2: Details of species type, number and equipment used on each river during the project (June and August 2003)

	Derreen	Rye Water	Aggard
Species tagged	Brown trout	Brown trout	Brown trout and eels
No fish tagged	10	13	3 and 3
TL_{range} (mm)			320-353
FL_{range} (mm)	192-250	205-249	230-250
Anaesthetic used	Phenoxyethanol	Phenoxyethanol	Clove oil
VHF Tag model	Biotrack Ltd., Model SS2	Biotrack Ltd., Model SS2	Holihill Ltd, Model BD2
Tag type (size)	<2% fish mass	<2% fish mass	<1.2% fish mass
Type of tracking	Dawn and dusk and 24 hour)	Dawn and dusk and 24 hour)	24 hour
No days tracked	12	11	6

5.3.3 Telemetry

Dawn and day tracking (UCD)

Tracking, using a Mariner M57 receiver with a portable three-element Yagi antenna, took place at each site on consecutive days, to maintain the validity of data, over a five week period in July and August 2002 and 2003. Tracking was confined to the dawn (4am to 7am) and day period (1pm to 4pm) when oxygen concentrations were expected to be at their lowest and highest, respectively.

Daily reach length was recorded from two fixes, one at dawn and one during the day period for each fish to examine if movements were related to the variation in oxygen. Home ranges were recorded from fixes taken throughout the study period.

Twenty four hour tracking (NUIG)

The location of each individual was recorded approximately hourly for five days (23-28/6/2003) using a Lotek SRX-400 receiver combined with a 3 element Yagi antenna. Positions were recorded to ± 0.5 m using a Trimble GeoXT differential GPS.

5.3.4 Abiotic conditions

The traditional approach to assessing water quality in a river/lake is to conduct an expensive and often labour intensive water sampling survey. The results from this kind of survey do not give an accurate picture of water quality performance in real time. Therefore, chemical analysis has its limitation because it is an intermittent process, samples may miss an event, or the wrong pollutant may be tested for. A new approach was adopted for this project based on remote monitoring. The Office of Public Works designed and constructed a prototype *in situ* housing for an YSI multimeter (Model 6920) as part of a co-cooperative study with the CFB (no cost to the project). The housing was bolted to a bridge and was accessed from the top of the bridge rather than from the river. Two housings were installed, one on the Rye Water in 2002 (12/07/02 until 09/08/02) and another on the Derreen in 2003. Trials were carried out during June 2002 on the Rye Water and this housing was relocated 3km downstream in July 2003 due to inadequate water depths at the initial site. The second housing was placed on the Derreen River in early August 2003. The multiprobe datalogger was programmed to record diurnal variations in oxygen and temperature every fifteen minutes during the study period. During the period of the tracking in 2002 oxygen, conductivity and pH readings were also taken in three habitat types, namely riffle, glides and pools along each study area (Aherne, 2002). Daily water samples were taken throughout the tracking period on the Rye Water and Derreen rivers and returned to the Central Fisheries Board for analysis. Total phosphorus, molybdate reactive phosphorus and total oxidised nitrogen were recorded. *In situ* measurements were also made for pH, conductivity and temperature (as described above). Habitat characteristics such as depth and cover were also recorded at each location.

Environmental conditions (dissolved oxygen and temperature) were monitored hourly on the Aggard stream at a series of fixed positions between 23-25/6/03 using a multiparameter meter, and for the remainder of the study every 15 minutes using two portable automatic dataloggers (Hydrolab Inc). Fluctuations in discharge were recorded hourly by noting water level relative to a temporary staff gauge. Ambient light levels were recorded hourly by fixed-point digital photographs (Kodak DX4330: greyscale JPEG at 1080 x 720 resolution). Approximate light levels were estimated by calculating mean greyscale value per image (UTHSCSA ImageTool v.3).

5.3.5 Data analysis

Rye Water and Derreen

Fish location data for the Derreen and Rye Water were exported to GIS (ArcView 3.3 and movements were analysed using a specialist Arc View animal movement extension (Hooge and Eichenlaub, 1997). Diel movement of fish was examined by using "24 hour tracking" and on a daily basis by using 'daily reach length'. Movement over the entire project was used to establish 'home range'. The Ranges V program developed by Kenward and Hodder (1996) was also used to estimate home ranges for each fish using cluster polygons. A home range may be defined as the area that an animal normally moves in (White & Garrott, 1990). Probability levels were set at 95%.

Further statistical analyses were conducted using SPSS 11 (analysis of linear data) and Oriana 2.0 (analysis of circular data). Pearson's correlation was used to examine the relationship between dissolved oxygen, % saturation and temperature. The Mann-Whitney U test was used to assess differences between the home range and also diurnal activity between the Rye water and Derreen sites. Partial correlation was used to examine the relationship between daily reach length and dissolved oxygen and temperature. Diurnal dissolved oxygen ranges were calculated for days when tracking was carried out and activity under extremes was examined using Mann-Whitney U tests. (i.e. when dissolved oxygen ranges went above the 75^{th} percentile).

Aggard river

Fish activity data from the Aggard river were pooled within species due to low sample sizes. Patterns in abiotic variation were examined in the Aggard river by plotting DO, temperature and light values over time (both untransformed and angular-transformed). The existence of diel cycles in these data and fish activity was examined using circular-linear correlations and Rayleigh distribution tests (Zar, 1999). The potential association between fish activity and measures of abiotic variation (light, DO & temperature) were examined using circular-linear correlations. Due to significant diel variation in each of the measured abiotic variables, data were grouped relative to their magnitude as percentiles: e.g. data recorded when DO concentrations were less than the 25th percentile value were coded as low, those recorded between the 25 and 75th percentile were coded as normal, and those recorded at concentrations greater than the 75th percentile were coded as high. An identical approach was used for light and temperature for both trout and eel activity. Descriptive circular statistics (mean vector – the arithmetic average time in the diel cycle of a particular behaviour, and mean vector length – a measure of dispersion around the mean) were calculated to examine the distribution of fish activity throughout the diel cycle. Watson's U^2 tests (Batschelet, 1981) were used to examine whether the timing of increased fish activity (activity $\geq$ 5th percentile) could be related to periods of low dissolved oxygen (values $\leq$ 25th percentile) or elevated temperature (values ≥ 75th percentile). Kolmogorov-Smirnov tests were used to compare macrophyte coverage in the areas/habitats used by tagged fish relative to that available in the general habitat.

5.4 Results

Results are separated into abiotic factors, 24 hour tracking, daily reach length and home range.

5.4.1 Abiotic factors

Dissolved oxygen concentrations showed a consistent cycle of supersaturation during the day followed by reduced concentrations at night on all rivers in 2003 (Figs. 5.1 to 5.3). The difference in oxygen concentration between the dawn and day was found to be statistically significant in the Rye Water and the Derreen rivers ($P<0.001$). Temporal variation in oxygen was highest in the eutrophic Rye Water (4.38mg l^{-1}, 47.6%-18.75mg l^{-1}, 166.2% DO) in comparison to relatively low variation in the Derreen (8.02mg l^{-1}, 84%-11.46mg l^{-1}, 110% DO), the control site (Figs. 5.1 and 5.2). Critical levels (for salmonids ≤50% DO saturation) were recorded on 5 consecutive mornings (extending for 7 to 8 hours) on the Rye Water during August 2003 (from 7/8/03 to 12/8/03) when water temperatures reached 20-21^{o}C. Dissolved oxygen concentrations also showed a consistent cycle of supersaturation on the Aggard stream during the day (max. conc. = 11.7 mgl^{-1}, 116 % saturation) followed by reduced concentrations at night (min. concentration = 7 mgl^{-1}, 65.9 % saturation) (Fig. 5.3). Dissolved oxygen concentrations were positively correlated with temperature ($r = 0.47$, $P < 0.001$).

Rayleigh Z scores showed significant deviations from a uniform distribution, showing low DO concentrations (≤ 25th percentile) and high temperatures (≥ 75th percentile) were recorded in quite distinct periods within the diel cycle on the Aggard stream (Fig. 5.4 and 5.5). Low DO levels were typically recorded in the early morning (mean vector = 04:26), whilst high water temperatures were typically recorded in late evening (mean vector = 20:35).

Temperature variation in both years was slightly greater on the Derreen River than the Rye. The Rye Water was generally warmer than the Derreen with little variation in temperature (Figs. 5.1 and 5.2), which may be attributable to the passage of the river through a small lake in Carton Estate upstream of the survey site.

Detailed temporal and spatial variability in dissolved oxygen concentration on the Rye and the Derreen was examined by Aherne (2002). Three habitat types were identified as pool, riffle and glide and oxygen measurements were taken along a transect in each habitat type. A nested ANOVA showed no significant difference in oxygen levels between habitats at both sites (Rye Water, P=0.416, F=1.088, df=2; Derreen, P=0.203, F=18.193, df=2,), however lower oxygen levels were generally found along the margins of the Rye Water in the dawn period. The oxygen profiles indicated that although there was slight variation in oxygen concentration within and between habitat (riffle, pool and glide), the variation was not statistically significant.

Discharge was constant on the Aggard stream throughout the study (± 1 cm variation in level. Circular-linear correlations showed that DO, temperature and light were all significantly correlated with time, e.g. they underwent a significant diel cycle (time v DO, r = 0.947, n = 100, P < 0.0001; time v temperature, r = 0.88, n = 99, P < 0.0001; time v light, r = 0.899, n = 100, P < 0.0001).

5.4.2 Diel movement of trout

24 hour tracking on the Rye Water and Derreen rivers 2002 and 2003

Diel movement was examined on both rivers to determine the average activity of trout every hour. On the Rye Water in 2002, there was a peak in activity in the morning between 7:00 and 8:00 and then between 11:00 and 12:00 (Fig.5.6). These peaks in activity may reflect feeding forays. In 2003 feeding forays were more pronounced with a large peak between 21:00 and 23:00.

In the Derreen River peaks in activity were more obvious in the 2002 data set, between 4:00 and 5:00 in the morning and then later between 20:00 and 21:00 and a further peak between 1:00 and 2:00 (Fig. 5.7). In 2003, the trout in the Derreen appeared to have made a number of small-scale movements throughout the day with the largest peaks occurring between 4:00 and 5:00 and later between 18:00 and 19:00. Diel movement in 2002 was not significantly different between the two sites, however there was a statistically significant difference between rivers in 2003 (Mann-Whitney U; p= 0.003, z=-2.975, n=45).

Daily reach length on the Rye Water and Derreen rivers 2002 and 2003

Mean daily reach length of trout on the Rye Water (distance recorded between the fix obtained at dawn and that taken during the day) was generally <10m on the Rye in 2002 (Fig 5.8) with two exceptions, fishes E1 and F1 which moved 62m and 66m, respectively. This was not the case in 2003 when only four fish moved an average 10m per day, four others moved between 10 and 34m daily and the remaining two trout, L1 (56m) and R1 (114m), made substantially larger daily movements than the other fish. *(These values must be used as a guide only as it makes no assumptions about where the fish may have moved between fixes).*

Mean daily reach length on the Derreen was generally shorter than the Rye Water with all fish moving less than 12m in 2002 and less than 19m in 2003 (Fig. 5.9). In 2003, the majority of trout moved <14m with only one fish (C2) making larger daily movements. Analysis indicated that the daily reach length travelled by each fish on the Rye and the Derreen were significantly different in 2002 (t-test; p= 0.002, t=3.095, df=182) but not in 2003.

Home Range

Home Range was determined for fish in the Derreen and Rye Water (Table 5.3). In 2002, four trout in the Rye Water had a home range (cluster polygon) greater than 70m^2 whereas nine trout tagged in 2003 had a home range greater than this value. The median value of home range (cluster polygons: fish with >38 fixes) for all trout in 2003 was 295m^2 which is four times as big as the median value in 2002 (68.5m^2) (Table 5.3).

Home ranges used (cluster polygons) were similar between years on the Derreen where the median home range in 2002 was 86m^2 and 104m^2 in 2003 (Table 5.4). These values are more similar to that found on the Rye in 2002. A Mann-Whitney U test was used to compare median values of home range (cluster polygon) using more than 38 fixes. Trout on the Rye and Derreen used similar home ranges in 2002 (Mann-Whitney U: p=0.789, z=-0.267, n=14) but they were significantly different in 2003 (Mann-Whitney U: p=0.046, z=-1.995, n=16).

Table 5.3: General information about tagged brown trout on the Rye Water, Summer 2002 and 2003.

Trout code	N	Length (cm)	Weight (g)	Cluster polygon (m^2)	Condition factor before tagging	Condition factor after tagging
			Rye 2002			
A1	62	24.8	210	45	1.38	-
B1	12	21.9	149	54.5	1.42	-
D1	62	29.9	315	144	1.18	0.94
E1	61	27.9	298	1843	1.37	-
F1	16	29.5	310	391	1.21	-
G1	47	31.3	410	68.5	1.34	1.14
H1	62	27.2	250	39	1.24	1.04
I1	8	25.1	196	2752	1.24	-
			Rye 2003			
K1	40	21.5	145	788	1.46	-
L1	43	23.9	190	380.5	1.39	1.13
M1	38	23.7	200	268.5	1.5	-
N1	44	24.9	200	321.5	1.3	-
P1	39	19.4	120	26	1.64	-
Q1	46	20.5	130	189.5	1.51	1.05
R1	38	20.5	120	1912	1.39	-
S1	44	20.5	130	115.5	1.51	-

V1	31	20.9	123	37.5	1.35	-
W1	14	21.4	110	113	1.12	-
U1	6	21.5	128	105.5	1.29	-

Note: N= number of fixes C1, J1, O1 and T1 have not been included due to early mortality

Table 5.4: General information about tagged brown trout on the Derreen, summer 2002 and 2003.

Trout code	N	Length (cm)	Weight (g)	Cluster polygon (m^2)	Condition factor before tagging	Condition factor after tagging
			Derreen 2002			
K2	53	23.7	160	**541**	1.20	1.11
L2	54	24.1	165	**45**	1.18	-
M2	54	24.9	165	**44**	1.07	1.09
N2	54	21.9	120	**403**	1.14	1.03
O2	54	20	95	**51.5**	1.19	1.1
P2	54	20.7	100	**86**	1.13	1.1
Q2	51	21.9	135	**139.5**	1.29	1.31
R2	54	25.3	195	**146.5**	1.20	-
S2	23	23.1	135	**80**	1.1	1.12
T2	54	23.3	145	**56**	1.14	1.09
			Derreen 2003			
A2	64	23.1	150	**186.5**	1.22	1.01
B2	64	25	180	**103**	1.15	-
C2	63	20.1	115	**300**	1.42	-
D2	64	20.5	110	**68.5**	1.28	0.93
E2	63	19.2	95	**98**	1.34	0.88
F2	29	21.6	180	**779**	1.79	-
G2	62	20	110	**104**	1.38	0.88
H2	48	21	130	**93.5**	1.40	0.98
I2	27	21	125	**49.5**	1.35	-
J2	64	20.2	110	**170.5**	1.33	0.89

Note: N= number of fixes

Relationship between Trout Movement and Environmental Conditions

The relationship between daily reach length, dissolved oxygen and temperature was examined on each river in each year using partial correlation. Trout movement was not correlated with dissolved oxygen or temperature. Even under extreme conditions when the dissolved oxygen variation was at its highest, daily reach movement was not statistically significantly different in 2002 or 2003 from normal conditions.

In one of the hottest weeks in August 2003 (Fig 5.1), oxygen levels on the Rye Water fell to their lowest levels (<5mg l^{-1}) on five nights (7th, 8th, 10th, 11th and 12th). During this week of extremely low oxygen sags, tracking took place on the 6th, 8th, 12th and 14th of August but unfortunately these efforts often located fish when oxygen conditions had returned to normal. However, tracking on the 12th and 14th did occur during severe oxygen fluctuations. On the 12th of August, oxygen concentrations were below 6mg l^{-1} O_2 between 02.16 and 10.01hours and fell further between 08.16 and 09.01 hours to levels below 5mg l^{-1} O_2, the minimum value was 4.93mg $l^{-1}O_2$. The dawn tracking began at 04.30 hours and continued until all the fish had been located at 05.30. The day track was carried out between 16.45 and 19.00 hours. One of the fish (U1) was found dead and three other fish (L1, R1 and S1) moved distances (218m, 352m, 21m respectively) that could be considered larger than normal. However, fishes K1, M1, Q1, W1 and V1 did not demonstrate abnormal movement and fish N1 could not be located at dawn. It is possible that fishes L1, R1 and N1 make up the mobile component which will be discussed later. On the 14th of August, although conditions were less severe than on previous nights, the oxygen fell below 6mg l^{-1} O_2 between 07.31 and 10.16 hours with a minimum value of 5.54mg l^{-1} O_2 occurring at 10.16. Tracking began at 04.00 and continued until 01.30 the next morning. During the critical period in the morning all fish made some movements, < 10m between 07.00 and 10.30 with L1 moving the furthest (15m). However, these movements were not out of character. Later that evening fish R1 started to drop downstream after 20.16 hours and had moved 392m by 00.15 hours. Sunset occurred on this date at 19.57 hours. Fish K1 also started moving downstream and covered 182m between 20.29 and 01.05 hours. Other fish moving to a lesser extent included P1, Q1, S1, L1 and V1. Fish M1 and N1 held their position that night. It is difficult to tell whether fish were stressed that morning, as trout activity suggested that most trout appeared to be feeding normally by the evening

The water depth available to trout was statistically different on the Rye Water between 2002 and 2003 (P<0.0001) with deeper water available in 2002. This may have had an impact on the depth used by trout in each year. Depth use was statistically different with fish choosing deeper water in 2002 than in 2003, however, this may also be attributed to the fact that a number of bigger fish were tagged in 2002 and these individuals would be expected to preferentially choose deeper water. Pool and glide habitat accounted for 67% of habitat types on the Rye Water in both years with a higher percentage of slow flowing water on the Rye in 2003 (0%) than 2002 (4%) due to the warmer weather. Depth use and availability was similar on the Derreen between years even though 2002 was considered a wetter year. In this river pool and glide habitat accounted for 63% of habitat types available to fish in 2002 and 73% in 2003. The Derreen River is “spatey” in nature and high water levels often return to normal within hours.

The same depths were available (2002 P=0.189, 2003 P=0.057) to trout in both rivers in 2002 and 2003. However, it is interesting to note that trout choose similiar depths on both rivers in 2002 (P=0.636) but not in 2003 (P=0.000). In 2003, the trout on the Derreen preferred depths from 30-80cm whereas the fish on the Rye were present in a shallower range from 30-50cm.

The percentage habitat types available were similar on both rivers in 2003 with glide accounting for 40% on the Rye as opposed to 48% on the Derreen and pool accounted for 27% on the Rye and 24% on the Derreen. Although the two rivers have similar habitats the Derreen has a larger area with deeper water >60cm whereas the Rye water has a greater amount available between 50-60cm and this may explain why trout were using shallower areas in the Rye Water in 2003. River velocities varied significantly on both rivers over the two years ($P<0.05$).

Flow data were only available for the Rye water. There was a weak positive correlation between daily reach movement (m) and daily flow (m^3/s) on the Rye Water in 2002 with some fish moving larger distances between dawn and day on days with higher flow (Spearman rank-order correlation, $r_s = 0.237$, $p= 0.035$, $n=79$). This was not the case in 2003 as there was no relationship between daily reach length and flow (Spearman rank-order correlation $r_s = 0.037$, $p= 0.810$, $n=45$).

Trout used a combination of substrate, trees, reeds and roots for cover. However, an interesting observation was made on the Rye Water where the trout were located in stands of *Phragmities* sp. along the river bank. They were often located as far as 1m into these reeds in areas that would normally be unsuitable for trout.

24 hour tracking on the Aggard stream

Eel

Each eel showed similar behaviour – typically locating themselves in structurally complex refugia (e.g. amongst the branches of a submerged tree, or within macrophyte beds) and then making consistent small-scale movements within a localised area (Figure 5.10 & Table 5.5). Unfortunately, either due to tag failure or predation the signal from Eel 3 was lost during the first day's fieldwork. Attempts to locate the signal approximately one kilometre upstream, and downstream of the study stretch were unsuccessful, suggesting that the tagged fish had not simply moved out of range of the receiver.

Table 5.5: Table summarising successive movements made by eels and trout during the study

	Successive distance (m) moved				
Fish	**Mean**	**95 % CI**	**Range**	**Total distance moved**	**n**
Eel 1	3	0.9	28	190	69
Eel 2	3	0.8	22	252	71
Eel 3	3	1.1	4	27	9

All eels combined	3	0.6	28	469	149

Normal eel activity (levels between 25th and 75th percentile) was not distributed equally throughout the diel cycle (Rayleigh Z = 4.9, P < 0.007 (Figure 5.10a), but was weakly concentrated in the early hours of the morning (mean vector = 01:11; mean vector length = 0.25).

Periods of increased eel activity (≥ 75th percentile, Fig. 5.10b) were not coincidental with periods of low dissolved oxygen (Watson's U^2 = 0.422, d.f. = 29, 45, P < 0.001), or elevated water temperature (Watson's U^2 = 0.64, d.f. = 29, 45, P < 0.001).

Trout

On average, the tagged trout were more active, moving more often and further than eels (Figs 5.11, Table 5.6). One individual (Trout 2) moved more than 130m between hourly readings. However, mean movements were relatively small, and it became apparent that individual trout remained within a relatively defined area over considerable periods of time.

Normal trout activity (levels between 25th and 75th percentile) was not distributed equally throughout the diel cycle (Rayleigh Z = 4.0, P < 0.018; Fig. 5.11a), but was weakly concentrated in the early morning (mean vector = 03:59; mean vector length = 0.194).

Table 5.6: Table summarising successive movements made by trout during the study

	Successive distance (m) moved				
Fish	Mean	95 % CI	Range	Total distance moved	n
Trout 1	11	4.7	137	729	68
Trout 2	6	3.4	114	390	65
Trout 3	4	1.3	37	225	60
All trout combined	7	2.1	137	1344	193

As shown above for eels, periods where trout showed increased activity (≥ 75th percentile, Fig. 5.11b) were not coincidental with periods of low dissolved oxygen (Watson's U^2 = 1.15, d.f. = 45, 71, P < 0.001), or elevated water temperature (Watson's U^2 = 0.72, d.f. = 45, 71, P < 0.001).

Habitat use

In the Aggard, trout and eels were found in areas with macrophyte densities different from those recorded in the environment (Kolmogorov-Smirnov tests: Eels KS = 1.93, *P* = 0.001; trout, KS = 1.92, *P* = 0.001). However, comparisons of habitat use by both species during periods of low or high levels of DO or temperature showed no evidence of shifts in habitat use.

5.5 Discussion

This study has demonstrated that fish inhabiting macrophyte-dominated shallow rivers can encounter marked diel fluctuations in temperature and dissolved oxygen during summer months. The Rye Water exhibited all the symptoms of an eutrophic river. The variation in dissolved oxygen between dawn and day was large with oxygen levels dropping to critical levels for salmonids (50%) for short periods of time at dawn on five consecutive days in 2003 and rising above 120% saturation during the daytime. These fluctuations are thought to place salmonids under considerable stress and increase the likelihood of mortality. The dissolved oxygen concentrations did not reach critical levels (Alabaster and Lloyd, 1980) in the Derreen River and the Aggard stream. High water temperatures were reached on the Rye Water and the Derreen on several occasions. The upper critical water temperature range for brown trout is 19-30°C (Elliott, 1981). Brown trout in the Derreen River remained in deep pools during the day, probably to avoid high summer temperatures while those on the Rye used macrophyte stands and trees for cover. Elliott (2000) found that brown trout choose lower temperature over higher oxygen concentration.

Diel movement, daily reach length and home range were examined to determine if brown trout were moving in relation to this variation in dissolved oxygen. Median diel movements (hourly) were similar between sites and ranged from 0-7m on the Rye Water and 0-8m on the Derreen. Mean diel movement by trout in the Derreen was similar between years (2002: 110.5m, 2003: 109.5m). These figures were similar to the findings of Young (1999) who recorded diel movement of 121m for adult brown trout. Mean diel movement on the Rye however was 71.2m in 2002 but substantially larger in 2003 (108m). This may be explained by the fact that there was a larger mobile component of the population during the study period in 2003. Peak activity occurred during dawn and dusk when fish were probably feeding (Crook, 2004; Elliott, 1994; Kennedy and Fitzmaurice, 1971). Peaks in activity at dawn and dusk have also been related to the drift of insects which begins near dusk and ends around dawn (Chapman and Bjornn, 1969).

Comparison of movement data is difficult because the various authors use different definitions of home range and also length of sampling section and survey period may vary. However, a number of studies can be compared to the present work. Brown trout movements

(1+ and older) on the Afon Gwyddon, South Wales were less than 15m and movements greater than 50m were rare (Harcup et *al*., 1984). These movements compare well to the Derreen results. Hesthagen (1988) reported that 85-89% of brown trout aged 2+ to 9+ were recaptured within 45m of their release point. Most of them moved less than 150m. Young (1994) who related movement to density found that 37 out of 54 brown trout home ranges were larger than 50m and also found that trout greater than 340mm moved more than smaller fish. Gowan *et al.* (1994) dismiss the theory that resident stream salmonids have restricted movement and suggest that salmonids exhibit large movement even during summer feeding periods and this is a potentially common and normal phenomenon.

On the Rye in 2002, two fish moved further than other fish and in 2003 there were four such fish. Why these movements occurred is unclear, they could have resulted from oxygen variation but statistical analysis failed to link movement with dissolved oxygen or temperature. However, it is also possible that there was a mobile component in the population and the remaining trout composed the sedentary fish as outlined by Hestagen (1988). Daily movement on the Derreen between dawn and day, was considerably lower than the Rye Water. Oxygen levels on the Derreen were consistently adequate so perhaps environmental conditions are less stressful to trout in this system. Daily reach movement between rivers in 2002 was significantly different but this may be explained by the difference in range of fish sizes used. Fish length ranged from 21.3cm to 31.9cm on the Rye as opposed to 20cm to 25.3cm on the Derreen. Many authors have found that larger brown trout have larger home ranges than smaller fish (Young, 1994). The daily reach length used by the fish in 2003 were not significantly different re-enforcing the idea that they did not move in association with diel dissolved oxygen variation.

From the literature it is not possible to clarify the size of a normal home range, however in this survey home ranges were similar to ranges found by Ovidio and Phillippart (2000). Median home ranges on the Derreen were similar in both years and broadly comparable to the Rye water in 2002. It is postulated that fish on the Rye water were subjected to greater environmental pressures with higher temperatures and wider oxygen amplitudes in 2003 which may have contributed to the larger home ranges. Home ranges in the summer of 2002 were not significantly different between sites, the oxygen amplitude was not as severe and oxygen rarely fell below 60% saturation on the eutrophic stretch. Some individual fish in the Rye water remained stationary in marginal reed beds for extended periods. During extreme conditions they may conserve their energy by sitting in the reeds.

Movements on the Rye Water in 2003 appear to be different to those recorded in 2002 and those recorded on the Derreen. However, no statistical association was made between movement and oxygen variation or temperature even under extreme conditions. Some fish remained stationary in marginal reedbeds at times of severe stress. There is evidence to suggest that fish may acclimatise to low dissolved oxygen and high temperatures (Doudoroff and Shumway, 1970; Alabaster and Lloyd, 1980). If dissolved oxygen or temperature change gradually over time and remain at a critical level for a short period of time before returning to normal then fish can tolerate these stresses up to a certain lethal limit. The fish may experience a variety of physiological effects that may culminate in death if conditions remain unsuitable for a prolonged period (Davies, 1975, Doudoroff and Shumway, 1970, Alabaster and Lloyd, 1980).

Both eels and brown trout on the Aggard stream were more active during the early morning, but there was no evidence that either species encountered temperature or DO conditions that led to behavioural shifts or modified habitat use. However, the amount of variation recorded could well be expected to influence habitat choice in both species. Movements of eels in the Aggard stream were relatively limited, in marked contrast with studies conducted in a larger Irish river (McGovern & McCarthy, 1992), but those of trout were within the scope described by other workers (Young, 1999). There is a comprehensive literature describing how even subtle variation in abiotic conditions can influence the behaviour of fishes (Godin, 1997) and it was unexpected that there would be no obvious influence on fish movement. Although this was a relatively small-scale study, it seems apparent that both brown trout and European eels are able to withstand marked fluctuations in their abiotic environment.

Trout in this study may have used a behavioural strategy which involved the use of macrophyte stands for refuge. Plant biomass was highest during the summer months on the Rye Water. During July and August, the substrate was almost totally covered by *Cladophora* sp. and large bands of *Phragmities* sp. lined the bank throughout the study area. These reeds not only provide food in the form of macroinvertebrates but they provide refuge from predators. Trout were located as far as 1m into these reeds even though the habitat often appeared to be of questionable suitability for trout. The surrounding water often appeared very murky and the substrate was mainly a combination of mud and silt. The reeds would provide a refuge from the flow for lethargic fish. The reeds may have enabled them to move to the surface where they could gasp for air while reducing their chance of being spotted by predators. Aquatic surface respiration has been reported for a number of fish species (Miranda *et al*., 2000) and juvenile trout have been observed gulping air at the surface in elevated temperatures (Champ, T., *pers comm*). Research carried out by Miranda *et al*. (2000) found that densities of fish (Centrarchids, which included bluegill, redear sunfish, largemouth bass, warmouth and crappies) in plant stands did not vary between dawn and dusk suggesting that fish did not move from the vegetation when conditions became adverse. They also suggested that fish might use the stands as a corridor to travel until more suitable oxygenated pockets were located. Trout on the Rye had two possible behavioural strategies; either to emigrate to a more suitable riverine areas or make do with existing microhabitats which provided tolerable conditions where they could remain until water quality improved.

In the summer of 2003 higher than normal temperatures resulted in extensive weed growth and caused extended periods of low dissolved oxygen at dawn in the Rye Water. During the same period there was also heavy mortality of trout in the Rye Water. This was higher than that recorded during the previous year and higher than that recorded on the Derreen River. It is thought that this substantial increase in mortality was due to morbidity brought on by low dissolved oxygen levels, which would have made the fish more susceptible to predation/scavenging.

Ten fish were tagged in the Derreen in 2003 and eight of these fish survived to the end of the field study. Ten fish were originally tagged in the Rye Water also in 2003 using the same tagging and handling technique, but three fish were lost to predation early in the survey these tags were retrieved and a further three fish were tagged. A total of 13 tagged fish were tagged on the Rye Water but only 6 survived to the end of the study. It was speculated that four of the trout were eaten by mink (*Mustella vison*) (tag was retrieved in a scat and a backbone of fish was found in the river). The American mink is an opportunistic predator, which preys on mammals, crayfish and fish. It is mainly active around dusk and throughout the night. Mink are not as skilled at catching fish as otters so it is thought that the fish in the Rye Water may have been stressed and therefore easier to catch. During the warm week in August when oxygen levels were below 5 mg l^{-1} O_2 and temperatures were extremely high (>19 °C) two fish that had been tagged the day before the oxygen levels fell, were found dead. One of which displayed signs of asphyxiation (flared gills) (Leo Foyle, University College Dublin, *pers. comm.*) and the other was found in a mink scat. Another fish, found dead in the reeds, appeared to have a puncture hole resembling that made by a heron (*Ardea cinerea*). It is thought that the fish were affected by low oxygen (lethargic) and so were unable to avoid predation. Predators are also present in the Derreen river, however, only one fish was killed during summer 2003. This may suggest that fish in the Rye Water were stressed and more vulnerable to predation. Maximum long–sustainable swimming speeds are affected by low oxygen. However, little research has been carried out on the effect on short swimming bursts which are necessary to avoid prey. It is thought, however, that if feeding activity is restricted by low oxygen levels then fish would probably conserve their energy by reducing the number of swimming bursts (Doudoroff and Shumway, 1970).

Although the condition factor of the fish after tagging was generally near to unity indicating good condition, one cannot ignore the fact that the addition of an external tag may affect the normal behaviour of the fish. Feeding behaviour and movement of the fish may be affected by the addition in weight. Crypsis, or resemblance with the background is very important to salmonids (Tikkanen *et al.*, 2000) so the colouration of the tag (black), which cannot change along with their body colour, may make the fish more obvious to predation especially if the fish is already stressed due to oxygen sags. The method of tag attachment described above has since been improved by Crook (2004). He describes a method of raising the tag attachment by using silicone mounds so that less of the tag is in contact with the fish, which minimizes dermal irritation thus reducing the stress caused to the fish

5.6 Conclusions

The Rye Water experienced adverse environmental conditions associated with eutrophication in the form of pronounced oxygen sags at dawn and super saturation during the day. Daily oxygen variation was larger in 2003 than in 2002 and this resulted in extreme conditions that may have caused stress to the trout populations. However, the lethal limit for brown trout was never reached. Movement in the Derreen was similar to that recorded by other authors. Fish movement was not correlated with dissolved oxygen and temperature but home ranges were larger on the Rye Water in 2003 than in 2002. Mortality in the Rye Water in 2003 was higher than that recorded in 2002 and higher than in the Derreen River (the control stretch). It is likely that this was caused by oxygen level falling below 5 mg l^{-1} which stressed the fish and made them more susceptible to predation in the Rye Water. Trout and eels in the Aggard stream showed no evidence of increased mobility when exposed to the environmental variables experienced in the current study. More research is needed in this area to establish whether trout move at oxygen levels below 4 mg l^{-1} or seek refuge in slack water, where they remain stationary, at what oxygen concentration in the field a fish kill might occur and to evaluate the effects of sub-lethal stress.