Cranfield University

Stephen Hughes

The restoration of an urban still water fishery: monitoring for success at Tom Thumb Lake

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Supervisor: Dr Andrew Gill

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ABSTRACT

Tom Thumb Lake is a former gravel pit and carp fishery situated in East London. In 2005 the Lake was restored as an accessible, self-sustaining fishery. The objectives of this study were to outline a monitoring plan to assess the success of the restoration, this included: monitoring water quality in relation to the requirements of fish, monitoring the macroinvertebrate communities in areas of the lake that will be newly vegetated, an angler survey to assess basic demographics (such as age, sex, ethnicity) and whether or not the priority groups identified by the Environment Agency were using the Lake. In addition, a basic topographic survey was conducted.

Basic water quality parameters (temperature, pH, DO, N and P) were monitored at Impact sites (those to be vegetated) and Reference sites (an area of the Lake already well vegetated), macroinvertebrate samples were also taken at these locations. The water quality requirements of fish were based on Incipient Lethal Levels (ILL) taken from fish physiology publications. The survey was completed and handed out to anglers but numbers returned were not sufficient for inclusion in this report.

The topographic survey identified a depth range of 0-2.4m, with shallow areas predominantly close to known gravel bars in the centre of the lake. Based on the monitoring data collected, water quality was generally well within the limits researched from literature, although temperature and pH were occasionally close to the upper limits. Macroinvertebrate samples showed some differences, particularly in total abundance, between the Impact and Reference sites.

An outline set of monitoring guidelines were constructed for future managers of the Lake to follow, which should enable them to reliably gauge the success of the project. Recommendations for refining the ILL method and potential uses for other lakes were made.

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LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ANOVA – Analysis of variance

DO – Dissolved oxygen

EA – Environment Agency

LBBD – London Borough of Barking and Dagenham

LILL – Lower incipient lethal level

MBACI – Multiple-Before-After-Control-Impact

UILL – Upper incipient lethal level

1 INTRODUCTION

1.1 Tom Thumb Lake

Eastbrookend Country Park is situated in the Dagenham area of East London and covers an area of 197.6 acres of reclaimed agricultural land. Prior to the park opening in 1995, the area was used for gravel extraction during the construction of nearby Dagenham and also as a dump for rubble during the Second World War (LBBD, no date). The reclamation of the land as a country park involved large scale earthworks, capping with clay and topsoil and the planting of 50 000 small trees; the park is now managed by the Ranger Service of the London Borough of Barking and Dagenham (LBBD). The park has five lakes, all of which are by-products of earlier gravel extraction between the 1930s and 1960s (LBBD, 2006).

Tom Thumb Lake is 0.7 hectares in size and is known to have an undulating bed of gravel bars and hollows. Figure 1 shows the layout of Tom Thumb with numerous angling swims along the north-western and southern edges; the eastern edge is heavily vegetated with riparian vegetation and marginal macrophyte species. The western corner of the lake also has some vegetation cover and is currently designated a “No Fishing Area”. Footpaths run along the lake edges except along the eastern side where the stand of riparian vegetation prevents easy access to the banks.

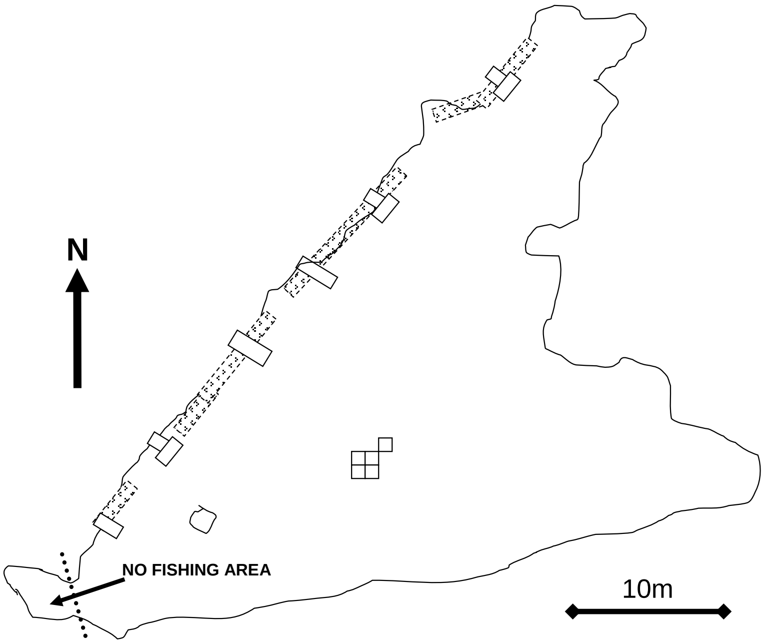

Figure 1 Plan view of Tom Thumb lake showing angling swims (solid boxes) and wildfowl exclusion areas (dashed boxes) along the north-western bank

Since the establishment of the country park, Tom Thumb has been managed by Bardag Angling Society on a day ticket basis under licence from the LBBD. The lake was originally stocked with large numbers of carp ranging from 5-25lb in weight, although there was a marked absence in fish at the lower size and age ranges. The lake is home to a large number of wildfowl, including moorhens and Canadian geese which readily graze on the marginal vegetation, particularly young growth (see Weisner *et al*, 1997). The resultant lack of cover has lead to a problem of Cormorant predation on smaller fish; these birds are known to reduce the biomass of angling species such as roach, bream or perch by up to 75% with the first two years of life cycle being particularly vulnerable (Britton *et al*, 2002). The lake is also known to suffer from algal blooms and periods of severely low dissolved oxygen (DO); in 2003 large numbers of fish were removed due to poor DO levels (LBBD, 2006). In addition to the water quality and ecological problems, the lake suffered from very poor physical access for disabled people and incidences of anti-social behaviour believed to be a result of younger anglers becoming bored or frustrated.

Because of the above problems, it was decided in 2005 to restore Tom Thumb as a self-sustaining, fully accessible fishery intended to act as an example of responsible management and as a pilot for further projects in the Borough. Much of the work has now been completed, with funding from both the Environment Agency (EA) and LBBD. The lake was drained to a low water level and most of the original carp stock removed and those remaining taken out by line. Accessible pathways, ramps and renovated angling platforms were installed although plans for a new car park were abandoned due to concerns from the adjacent landowners (Neil Winter, pers. comm., 2008). The lake was re-filled with water pumped from nearby Eastbrookend Lake and is now awaiting final re-stocking and the planting of marginal vegetation. Construction of mesh exclusion areas for macrophytes went ahead at the lowered water level and these were subsequently flooded rendering them useless; these will be raised again by planting contractors in line with the re-established water level.

The fish stocking will include the species and relative abundances outlined in Table 1 and the planting will follow the agreed aquatic planting plan (see appendix A). After stocking, the lake will continue to be managed as a day ticket fishery (cost £4 per day) by Bardag Angling Society. They will begin to actively encourage younger, disabled and first-time anglers by holding regular junior matches and coaching sessions. The size and species of fish, along with ticket pricing should encourage newer anglers as will the proposed free “have a go” coaching sessions.

This report gives a review of the restoration so far and provides a framework for future managers of the lake to reliably assess the success of the project, recognising both ecological and socio-economic factors.

1.2 Aims and Objectives

The aims of this study were to devise a robust monitoring plan that would allow future managers of Tom Thumb Lake to assess whether or not the lake is achieving the target of being “*a self-sustaining, ecologically balanced*” fishery (LBBD, 2006) and is accessible to new anglers and those in priority groups (young, disabled and ethnic minorities). This included:

- establishing guidelines for monitoring basic water quality
- providing a framework of acceptable water quality thresholds which fishery managers can use to assess the general “health” of the fishery in relation to the requirements of fish species
- monitoring the initial response of anglers to the restoration through a simple questionnaire
- conducting an initial round of monitoring to provide a “baseline” of fishery status prior to and immediately after the final stocking and re-planting

By furnishing lake managers with an appropriate monitoring plan, the success of the project can be reliably assessed and coupled with angler survey data can be used to provide ecological, economic and social justification for future urban lake restoration projects. The concept of water quality thresholds allow future lake managers to place monitoring data in context with the requirements of fish and assist them in identifying potential problems and the need for possible management action.

2 LITERATURE REVIEW

2.1 Introduction to ecological restoration

Human society relies on the natural environment to provide it with essential life-support and economically vital ecosystem services (Costanza *et al*, 1997). For millennia, humans have acted as stewards and protectors of the environment but this attitude has changed, particularly in the latter half of the 20^{th} century. Rapid urban expansion, industrialisation and agricultural intensification have caused considerable environmental damage which is having subsequent effects on human health and development (*e.g.* United Nations Environment Programme, 2007). This damage has been particularly widespread in Northern and Western Europe leading to a number of adverse ecological impacts including (Madgwick and Jones, 2002):

- Reduction in habitat and species diversity
- Fragmentation of habitats increasing vulnerability of isolated species
- Reduction in ability of ecosystems to provide economically important services

Recognition of these impacts is now widespread, particularly in Europe, leading to an acknowledged need for both restoration and protection as part of wider environmental management strategies. This is particularly important in the UK where natural landscapes have been almost completely replaced by human-influenced “cultural” landscapes. Early European conservation efforts focused on the protection of the few remaining isolated areas of natural value; in many cases these small sites represented all that remained of certain natural ecosystems. However, this approach often failed to conserve biodiversity and so the focus began to shift towards the importance of restoring and maintaining ecological functioning as a means of conservation; this lead to the advent of ecological restoration as an independent scientific discipline in the 1980s (Young *et al*, 2005).

There are many definitions of ecological restoration ranging from the conceptual "*re-establishment of a harmonious relationship between human society and natural systems*" (Cairns, 1994) to the more technical "*the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed*" (Society for Ecological Restoration, 2004). Some practitioners and definitions state that restoration must aim to recover natural or "reference" conditions. However, it must be recognised that restoration operates within numerous constraints, both ecological and socio-economic and it is often impossible or not politically viable to "*turn back the clock*" towards a completely natural system (Madgwick and Jones, 2002). Ehrenfeld (2000) recognised 4 distinct approaches that can be taken towards restoration:

- Restoration for an individual species, usually of conservation importance
- Restoration at a community or ecosystem level, recognising larger-scale processes
- Restoration at landscape scale
- Restoration for specific ecosystem services (*e.g.* nutrient cycling in wetlands)

Each of these approaches has associated weaknesses; firstly, focused species specific restoration can often have detrimental effects on other species or ecosystems. Secondly, the term "ecosystem" is very difficult to define, making the setting of project objectives problematic. Ehrenfeld (2000) also states that practitioners of restoration must be realistic with themselves and the public about what can be achieved. However, even when restoration attempts are made they are often abandoned when the results are unexpected or hard to explain (*e.g*. Zockler, 2000) or because there is insufficient long-term commitment to funding. Madgwick and Jones (2002) state that many restoration projects are only funded for one to three years when successful habitat restoration can take much longer causing Europe to be "*littered with short-term, failed projects*". Despite the numerous obstacles and constraints placed upon restoration, there are an abundance of successful projects. For example, see Hertzman and Larsson (1997) and Snazell (1997) which illustrate well the range of scales, costs and techniques encompassed by restoration ecology and also that restoration can be concerned with repairing damaged areas or creating entirely new ones.

2.2 Gauging success of restoration projects

Chapman and Underwood (2000) state that much money is wasted on restoration projects that are "*poorly designed and seldom evaluated*". This is despite the recognition by many restoration practitioners that the setting of goals is the most important part of restoration (Ehrenfeld, 2000). However, these goals must be specific and well defined as many restorationists have paid "*less attention to developing working definitions of restoration goals that would permit precise measurement to the extent to which goals are being achieved*" (Westman, 1991). When goals are defined, they are often so broad or ambiguous that they are difficult to measure reliably. An appropriate goal should take into account human values through stakeholder participation, be readily measured (ideally multiple parameters with low levels of intercorrelation) and recognise that the achievement of natural conditions is frequently difficult or impossible. Indeed, Westman (1991) states that the term "ecosystem substitution" would be a more accurate term for describing the process of replacing one human-modified ecosystem with another. Prior to this thinking many restoration projects were deemed successful because they simply "*looked right*" and were therefore assumed to be functioning correctly (Grayson *et al*, 1999 and Connell and Sousa, 1983). Without readily measurable goals, the achievement of success is open to debate. In addition, Grayson *et al* (1999) state that reliably gauging success is important to prevent the wasting of resources, prevent potential detrimental damage to other species and also to learn lessons for future restoration projects. Downes *et al* (2003) describe learning lessons and the sharing of information as the "*institutional memory*" of restoration ecology.

After sufficiently well defined goals are set, a monitoring plan to measure the parameters must be devised and implemented. Often the goal of restoration is to restore a site to a "reference" condition but the pre-project monitoring of control and impact sites necessary to reliably prove success is often absent (Glasson, 1994). Chapman and Underwood (2000) states that parameters used to measure successful restoration must change over time until they converge towards reference conditions and after this both reference and restored conditions must follow the same trajectory. Also, the extent of post-project monitoring should be sufficient to ensure that an ecosystem is self-sustaining; Connell and Sousa (1983) suggest that this occurs after a population has completely turned over once. Alternatively, Cairns (1991) defined this as when "*structural and functional attributes continue in the absence of whatever subsidies may have been necessary during the initial restoration efforts*". However, the time-scale to achieve ecosystem stability can be tens of years and beyond political feasibility. In such cases, Westman (1991) suggests that monitoring can be designed to assess whether short-term changes at a location are on the correct trajectory towards the desired end-point.

In addition to an adequate timeframe, a monitoring plan should include appropriate parameters at locations representative of the site as a whole. Cairns *et al* (1993) state that parameters should be cost-effective, readily measurable and cause minimal disruption; they also suggest the use of standard techniques wherever possible to make data comparison between projects much simpler. Kondolf and Micheli (1995) stress the importance of monitoring socio-economic parameters, particularly when projects are funded by public bodies. The parameters and frequency of monitoring should be rigorous and flexible enough to cope with natural variations. Monitoring is of paramount importance if the science of restoration ecology is to be developed and refined, as such Holl and Howarth (2000) suggest that future legislation should stipulate a mandatory budgetary requirement for monitoring all restoration projects. A recent workshop held by the River Restoration Centre found differing opinions from practitioners in the amount of project budget they feel should be spent on monitoring, with answers in the range of 5-40% (RRC, 2006). In fact, this conference found that monitoring budgets should vary (in percentage terms) depending on the scale and risk of the project. This means that small projects with newer (riskier) techniques would have a large percentage monitoring budget.

In addition, restorationists must recognise the dynamic, changing nature of all ecosystems and any monitoring plan must be designed to assess natural variability and be flexible when faced with unexpected changes (Clarke, 1986). The variable nature of natural ecosystems was well described by Elton (1930) who questioned the existence of stable ecological states saying "*the balance of nature does not exist and perhaps has never existed*". Perhaps then, monitoring should look for persistent ecosystems within well defined boundaries rather than the classic idea of a stable system (Connell and Sousa, 1983).

The stated objective for restoring Tom Thumb Lake as a "*self-sustaining, ecologically balanced fishery*" that is accessible to new anglers from priority groups (LBBD, 2006) agrees with the findings of the above review of literature. The goal is realistic and practical to monitor by assessing whether the lake meets the requirements of the fish within it and the anglers who use it, thus recognising both ecological and socio-economic factors.

2.3 Lake restoration: challenges and solutions

Much of lake restoration effort has focussed on smaller, shallower water bodies as these are considered to be more sensitive than larger, deep lakes to problems such as drainage and eutrophication (Jeppesen and Sammalkorpi, 2002). This is largely due to the smaller volume of water being much more influenced by pollutant inputs from the catchment but also the effects of nutrient release, particularly phosphate, from the sediment. Early European legislation governing water quality, such as the Urban Waste Water Treatment Directive (91/271/EEC) has been successful in reducing nutrient inputs from sewage and industry. However, some lakes have responded well to reduced nutrient loading (*e.g.* Jeppesen et al, 2002) whereas others have been more resistant; this is likely due to release of phosphorous from sediments which can persist for 20-40 years in some lakes (Jeppesen and Sammalkorpi, 2002). Fish, particularly planktivorous and benthivorous species, can also be a cause for resistance to restoration by reducing the numbers of herbivorous zooplankton that would otherwise control algal plankton populations through grazing. Benthivorous fish can encourage high nutrient levels by physical disturbance of the sediment and by disrupting benthic animals that would otherwise stabilise and oxidise the sediment (*e.g.* Andersson *et al*, 1978). Clearly, lakes with problems such as these pose a serious challenge to restoration beyond simply reducing nutrient inputs. This has lead to an increased focus on modifying in-lake processes and biota as a replacement or supplement to the management of catchment inputs. Techniques range from the physico-chemical such as the dredging of sediment and oxygen injections, to water level alterations and the manipulation of fish and macrophyte communities.

Joseph Shapiro pioneered a method known as biomanipulation which involves the removal or reduction of planktivorous species and the stocking or encouragement of piscivorous species (*e.g.* Shapiro and Wright, 1984). This process helps reduce predation pressure on large zooplankton which in turn increases the grazing pressure on phytoplankton to create a "*clearwater*" state instead of the previous turbid, eutrophic state. A review by Drenner and Hambright (1999) found that this approach was most successful in smaller, shallower (<3m depth) lakes. A range of techniques can be used for fish removal, such as electro-fishing, netting, disturbance of spawning areas or the increased stocking of piscivorous species. Perrow *et al* (1998) suggest a flexible approach using which ever technique(s) are appropriate for the specific lake.

In addition to fish community structure, the role of macrophytes is increasingly being acknowledged as an important force in lake nutrient dynamics. Studies such as that of Blindow *et al* (2000) found that areas with high densities of submerged macrophytes act as daytime refugia for zooplankton, reducing the predation pressure placed upon them and allowing them to more effectively graze on phytoplankton during the night. Lauridsen and Buenk (1996) found this horizontal migration to macrophyte refugia to be very important in shallow lakes were vertical migration is restricted. In addition to providing refugia for grazing zooplankton, macrophytes can have more direct benefits for water quality through uptake of nutrients that would otherwise be used by phytoplankton, encouraging deposition of sediment and metal compounds and reducing sediment disturbance by wind (Srivastava *et al*, 2008). However, the establishment or re-colonisation by macrophytes, particularly littoral zone species such as *Phragmites* can be dramatically slowed or even prevented by the grazing pressure from wildfowl. This grazing was found to be highest during early growth phases in sheltered areas where waterfowl tend to be more numerous (Weisner *et al*, 1997) but that the simple erection of mesh exclusion zones can significantly improve macrophyte growth rates by reducing grazing pressure (e.g. Søndergaard et al, 1996).

Lake ecology is an increasingly important field, particularly with the advent of the Water Framework Directive (2000/60/EC) requiring all water bodies to achieve “*good ecological status*”. This has lead to initiatives such as ECOFRAME (Moss *et al*, 2003) which classifies shallow lakes based on their physical and ecological characteristics and provides a set of target ranges for achieving a certain status category (*e.g.* Poor or High). Although the above approaches have been successful in the short-term, many projects suffer a relapse after several years likely due to continued high nutrient inputs or poor continued recruitment of piscivores. A review conducted by Søndergaard *et al* (2007) found that most biomanipulation projects see a continual improvement in nutrient levels up until around 10 years when they begin to relapse and increase, the most likely reason being internal loading from sediments. These relapses can be prevented by refining methods, combining catchment management, physico-chemical and biological techniques and by on-going supplementary management of restored lakes (Jeppesen and Sammalkorpi, 2002).

The restoration of Tom Thumb Lake could be seen as a mixture of the above approaches to lake restoration using a range of appropriate techniques (Perrow *et al*, 1998). Firstly, removal of the carp dominated fish community and replacing it with a more sustainable community of planktivorous and piscivorous fish could be seen as a simple biomanipulation. This is being carried out alongside the planting of new marginal vegetation, which if successful will provide refuge areas for fish and zooplankton which should have positive secondary impacts on water quality. Monitoring the success of the Tom Thumb restoration should give an indication of the success of these techniques when used in conjunction.

2.4 The specifics of urban lake fisheries

The Environment Agency (2006) estimate that approximately 250 000 urban ponds have degraded resulting in the loss of angling opportunities in urban areas. The main problems are eutrophication, siltation and loss of fish habitat which in turn drastically reduces their recreational value (Hickley *et al*, 2004). Also, urban lakes are unusual in that they are often subjected to continued anthropogenic disturbance even after restoration. This disturbance often takes the form of intensive recreational use or the continued input of polluted or nutrient rich runoff (Gilbert, 1989).

A common problem in urban lake fisheries arises from the fish stocking density and species make-up which is often manipulated by angling groups to provide higher catch rates. North (2002) divided recreational fisheries into three categories: natural, improved and intensive. Stocking densities in the fisheries studied ranged from very low for natural systems (10 fish per hectare) to very intensive systems (up to 126200 per hectare) which is a biomass far in exceedance of those published for highly eutrophic waters and higher even than the Environment Agency's farming units. Within the UK, roach (*Rutilus rutilus*) dominate with a presence in 83% of stillwater fisheries and carp (*Cyprinus carpio*), bream (*Abramis brama*) , perch (*Perca fluviatilis*) and tench (*Tinca tinca*) present in approximately 55%; carp were the most dominant species in highly intensive systems with a presence in 60% of sites (North, 2002). This level of intense stocking goes against the spirit of the Food and Agriculture Organisation's Code of Conduct for Responsible Fisheries (1995) but Cowx (2002) states that many recreational fisheries continue to place large catches above other social and environmental benefits.

The effects of poor fish community structure or the complete dominance by a few species have well documented effects on lake dynamics. As mentioned previously, large benthivorous fish can disturb the sediment causing internal phosphorous release and planktivorous fish can place pressure on zooplankton which would otherwise control algal blooms. Aside from the effects on water quality, populations dominated by many large, adult fish can place pressures on natural spawning by destruction or unavailability of spawning areas and direct predation on fry. Cowx (2002) describes this as a "*recruitment bottleneck*" which is often bypassed by repeated stocking of fish at great cost to fishery managers and this does nothing to encourage natural recruitment. If the Tom Thumb fishery is to be self-sustaining, any barriers to natural recruitment must be overcome and all fish species provided with the necessary resources and habitat for their entire life cycle.

Hickley *et al* (2004) give an excellent overview of the rehabilitation of urban lake fisheries in England and Wales. They cite the many problems faced by urban fisheries, in particular that they are often neglected by planners and subjected to the many pressures of pollution and multiple human uses. However, urban fisheries can provide other benefits beyond those of their rural counterparts; for example, reducing environmental costs associated with travel and reducing pressure on less degraded rural fisheries. In addition, populated urban areas provide a potentially large number of new “recruits” to angling, particularly those who are less able to travel to rural areas, namely the young, the disabled and the elderly. Both urban and rural anglers have similar desired outcomes, although a study in Germany found urban anglers to be slightly more catch-orientated (Arlinghaus and Mehner, 2003).

Hickley *et al* (2004) found that in general urban fisheries are shallow lakes with hard margins, silted beds and a lack of habitat. This coupled with high biomasses of benthivorous fish, phytoplankton and wildfowl as well as polluted or nutrient enriched surface runoff mean that urban stillwaters are in a poor state to perform as successful fisheries. In addition to these abiotic and biotic factors, vandalism and inappropriate use further exacerbate the problem. However, Hickley *et al* (2004) state that most of these situations are recoverable but clearly, any restoration must recognise the importance of both social and environmental factors. In particular, given the generally high population density around urban fisheries, the potential for numerous competing demands on water body use must be recognised making stakeholder consultation a vital aspect of any restoration project. Again, the restoration at Tom Thumb has recognised both the environmental pressures placed on the lake as well as the important socio-economic factors.

2.5 Recreational fishing in the UK

Recreational fishing, angling, is the most popular participant sport in the UK attracting approximately 4 million anglers over 12 years old in 2005 (EA, 2006). The sport generates an estimated £2.75 billion in revenue annually and supports 20 000 related jobs. In addition to these economic benefits, anglers make up an important interest group for environmental issues having often been described as “*the eyes and ears of the water environment*” (*e.g.* Angling Unity, no date). Also, projects have shown that angling is good for self-esteem and can be an effective way of tackling anti-social behaviour and youth crime whilst raising the awareness of young people to environmental issues (EA, 2006). The Get Hooked on Fishing Project is now a national scheme that works with children identified by local agencies as being at risk from crime or anti-social behaviour and engaging them with supervised angling opportunities. The project has proven results in reducing levels of truancy and offending and appears to be extremely cost effective; an annual investment of £340 per participant can save costs of up to £150 000 for every custodial sentence avoided (EA, 2004a).

However, Environment Agency statistics on angling participation and public perception suggest that certain sectors of society are under-represented amongst anglers. Males accounted for 75% of all anglers, with the 15-24 year age range being the most numerous. 94% of total anglers are white with only 3% from Asian backgrounds and 0% from Afro-Caribbean backgrounds; also interest in angling amongst disabled people is high but there are issues of physical access which may discourage them (Simpson and Mawle, 2005 and EA, 2006). The Environment Agency's 2005 report Public Attitudes towards Angling also found that there were approximately 4.4 million potential anglers in the UK divided into two equal groups: lapsed anglers (those who had fished before but had not done so in the last 2 years) and new anglers (those who have never fished before but have expressed an interest). The primary reason that both groups did not currently fish was "*not having someone to go with*" although "*having someone to show them how to fish*" was also very important amongst new anglers. This report also found that respondents in large urban areas such as London were generally less positive about angling possibly due to there being less opportunities and locations to fish (Simpson and Mawle, 2005).

There are clear and numerous benefits to further increasing angling participation, which data suggests is fluctuating but with no overall trend (EA, 2004a). Due to this, the Environment Agency has developed a long-term strategy to increase participation, particularly amongst the priority groups of young people (12-16 years), the elderly (60+ years) and disabled people (EA, 2006). This strategy, known as Angling 2015: Fishing for the future, is part of a larger EA project to promote water based recreation in general (EA, 2006) and aims to:

- promote the benefits of angling through 2000 extra angling coaches
- encourage new and returning anglers with the goal of increasing licence sales to young and disabled anglers by 20%
- create new fisheries and better manage existing ones aiming for stable or improving fish populations

Existing studies by the Environment Agency, for example those in the Lee Valley and on the River Colne (EA, 2004b and EA, 2005) demonstrate that anglers differ in their habits, expectations and opinions. For example, Lee anglers tended not to target a certain species and placed services and infrastructure (for example, accessible paths and litter bins) above quality of fishing issues. Colne anglers differed in that they were more likely to target a certain species, most commonly carp, and placed quality of fishing issues (such as water quality and fish habitat) more highly than their counterparts at the Lee. However, these studies have one striking similarity, the dominance of males aged 25 to 44. These studies further highlight the reasoning behind the Angling 2015 strategy and the importance of encouraging a broader range of people into the sport.

Given Tom Thumb's proximity to a major urban area, it is an ideal project to form part of the Angling 2015 strategy. Residential areas close to the lake will provide a large number of potential new recruits to angling, helping to achieve the EA's stated goal of increasing participation. The accessible platforms, relatively low ticket price and planned coaching sessions should particularly encourage anglers from those groups identified as priority targets by the EA. Additionally, the stated objective of creating a self-sustaining system at Tom

Thumb (LBBD, 2006) agrees well with EA's goal of encouraging sustainable fisheries management.

2.6 General requirements of fish species at Tom Thumb Lake

A fundamental aspect of a self-sustaining coarse fishery is that the water body in question meets the requirements of those species within it. This includes the necessary standard of water quality, availability of appropriate habitats for feeding, refuge and spawning and an adequate supply of resources, particularly food (Perrow *et al*, 2003). As such, these requirements will be detailed for those coarse species proposed to be stocked in Tom Thumb Lake and an assessment of whether or not these criteria are met will be conducted later in this report. It is vitally important that the requirements are met for all stages of the species life cycle, from spawning to adulthood. Table 1 lists the proposed species and stocking densities for Tom Thumb Lake.

Table 1 Summary of species, sizes and weights re-stocked into Tom Thumb Lake during summer 2008

Species	**Size**	**Total weight**	**Date stocked**
Scardinius erythrophthalmus	10-25cm	50kg	early July 2008
Carassius carassius	10-25cm	50kg	
Tinca tinca	10-25cm	35kg	
	1.5-3kg	9-36kg (6-12 individuals)	late July 2008
Rutilus rutilus		50kg	to be stocked autumn 2008
Perca fluviatilis		10-20kg	

Table 2 gives a summary of the general water quality requirements of all five fish species that were stocked in Tom Thumb. In addition, the table gives a brief indication of the various habitat requirements as well as preferred prey species and their UK spawning periods. This table shows that the stocked species have a variety of life cycles, preferred habitats and prey species and the management of Tom Thumb must cater to all these needs if the fishery is to be self-sustaining.

Table 2 Summary of the water quality and food species requirements of the stocked fish at Tom Thumb; data taken from FishBase (2008)

Species	General water quality	Preferred habitat
Tinca tinca	tolerant of low DO	sediment dweller
Perca fluviatilis		close to obstacles and abundant aquatic vegetation
Rutilus rutilus	can thrive in polluted waters	open water
Carassius carassius	tolerant of very low DO, low temperature and organic pollution	shallow ponds rich in vegetation
Scardinius erythrophthalmus	Similar to other cyprinids *e.g. Rutilus rutilus*	benthopelagic
Species	**Prey species**	**Spawning period**
Tinca tinca	Juveniles: benthic macroinvertebrates, occasionally algae Adults: benthic macroinvertebrates	May-September
Perca fluviatilis	Juveniles: zooplankton, macroinvertebrates, fish fry Adults: macroinvertebrates, other fish species (*e.g.* roach)	April-May
Rutilus rutilus	macroinvertebrates, crustacaens, molluscs, aquatic plants	May-June
Carassius carassius	plants, insect larvae and plankton	May-June
Scardinius erythrophthalmus	benthic/pelagic macroinvertebrate, insects, aquatic plants	May-July

2.7 Environmental factors and fish

Fry (1971) classified environmental factors based upon their effects on fish into the following categories:

- Lethal (known as Incipient Lethal Levels, ILLs) beyond which fish have resistance for an Effective Time (ET) after which they die
- Controlling factors govern the metabolic rate *e.g.* temperature
- Limiting factors limit the metabolic rate below that allowed by controlling factors, for example, oxygen availability may limit respiration below the level allow by food availability and temperature
- Masking factors modify the effect of other factors

Temperature can act as a lethal factor depending on the tolerance of the species and the acclimation rate, longer acclimation times allow fish to survive larger temperature ranges (Beitinger and Bennett, 2000). However, temperature changes in natural water bodies are usually slow enough for fish to avoid lethal levels and as such temperature often acts as a controlling factor, affecting metabolic rates and growth. Despite this, unusually warm summers or cold winters have been known to elevate temperatures to lethal levels, particularly when fish have no means of escaping to more tolerable temperatures (Wootton, 1998). However, the direct lethality of temperature is made complex due its close relationship with the saturation capacity of dissolved oxygen (Mortimer, 1956).

Dissolved oxygen is perhaps a more frequent lethal factor for fish, particularly in ice covered lakes or during exceptionally hot summers when the oxygen saturation capacity of water is reduced (Mortimer, 1956). Vulnerability also varies between life stages, as larvae are less able to avoid lethal conditions. Often oxygen acts a limiting factor, its limited supply serving to reduce the metabolic rate of that allowed at a specific temperature; again this limiting effect depends on the metabolic rate of specific species (Wootton, 1998).

Other parameters such as salinity seldom achieve lethal levels but the effects of salinity on osmotic processes may be important when this parameter fluctuates. Ammonia is highly toxic to fish but because of its high solubility it seldom reaches lethal levels; however, the proportion of un-ionised ammonia increases with pH which is a problem particularly in intensively stocked fisheries (Smart, 1981). pH itself rarely reaches lethal levels for fish but secondary effects, such as the mobilisation of metals must be recognised. Indeed, to describe individual effects of all specific parameters is over simplistic and the considerable interactions between them must be acknowledged (Wootton, 1998).

By placing water quality monitoring data in the context of these environmental factors, lake managers can assess the potential for detrimental effects on fish in Tom Thumb, ranging from poor growth and recruitment up to possible fish kill events. Trends in data towards Incipient Lethal Levels (ILLs) may allow lake managers to identify and rectify potential problems before they have a more serious impact on the fishery.

3 METHODOLOGY

3.1 Topographic survey

This survey was conducted using a FishFinder echo sounder mounted on a 3 metre inflatable boat. Landmarks along the bank or in the lake itself (for example, large trees, islands or signs) that would be identifiable on a map were chosen as the start and end points for each transect. The boat was then driven in a straight line between the landmarks at the maximum speed possible and depth readings noted from the FishFinder every 10 seconds. These transects were then plotted on a map and the distance calculated from scale; this enabled approximate speed and distance between each point depth measurement to be calculated. A total of seven transects were completed with the aim to capture as much spatial variation in depth as practical given time constraints.

3.2 Sampling point determination

The sampling locations for invertebrates and water quality were broken down into Impact and Reference locations shown in figure 2. The Impact sampling points were those areas along the north-western bank where new angling swims and waterfowl exclusion areas were constructed. The points were chosen by numbering the exclusion areas from 1-6 and generating random numbers within this range. The lengths of the chosen exclusion areas were measured and the sampling point placed at the centre. There were 4 Impact sampling locations.

Selection of sampling locations for Reference sites differed in that there were no discrete exclusion areas in which to sample. In this case, it was decided to approximate the length of the Eastern vegetated bank at 50 metres and generate random numbers up to this limit. The sampling point was then deemed to be the 4 locations at the random number of metres starting from the northern end of the bank, although some slight alterations were made where access to the water was difficult or potentially dangerous. This made for a total of 8 sampling points; this number was chosen for logistical reasons, particularly for invertebrate sampling when any more samples would have been difficult to transport back to the laboratory.

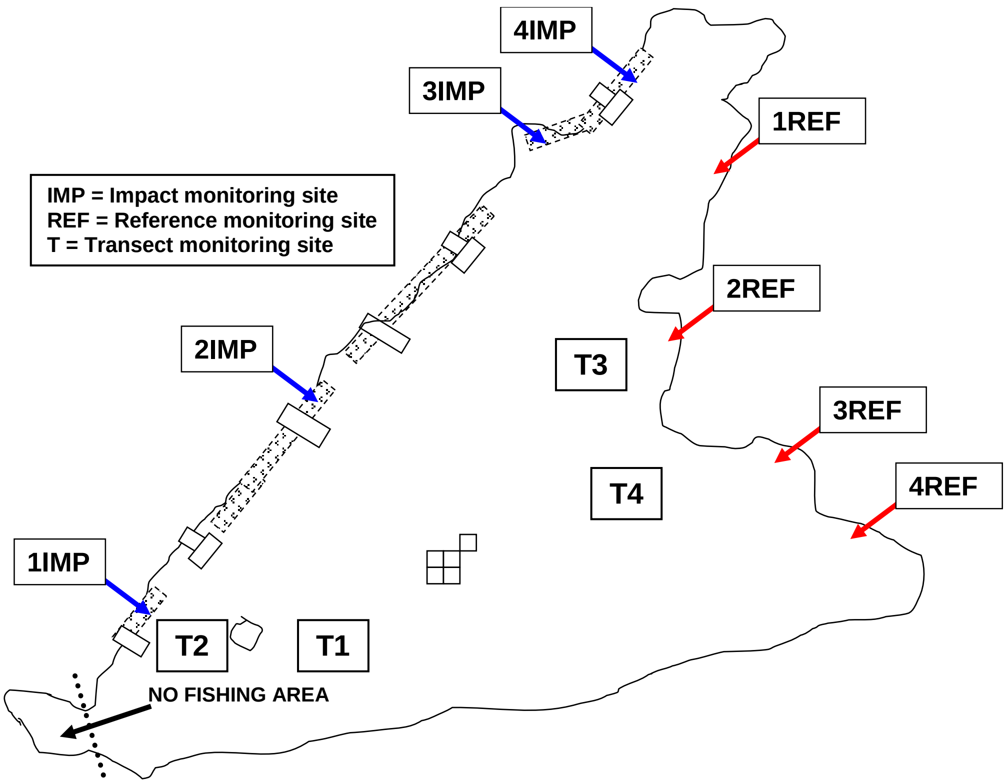

Figure 2 Plan of Tom Thumb lake showing the 4 Impact and 4 Reference sampling locations for water quality and macroinvertebrates. Also shown are Transect monitoring sites sampled during the topography survey. Solid rectangles on north-western bank are angling platforms, dashed lines are waterfowl exclusion areas

The rationale behind selecting the north-western exclusion areas as Impact sites was that these points will be directly affected by the planting of new aquatic vegetation and monitoring here will attempt to quantify the changes caused both in water quality and macroinvertebrate populations. This is based upon the fundamental assumption that planting and protection from wildfowl grazing will allow similar vegetation stands to establish as those on the eastern bank. A further assumption is that with the establishment of macrophyte stands, an increasing abundance and diversity of macroinvertebrates will naturally colonise these areas. These new areas will provide refuge for invertebrates and have secondary benefits to water quality by increasing the grazing pressure on phytoplankton (*e.g*. Blindow *et al*, 2000). The Eastern bank was chosen as the location for Reference sites because this area is already well vegetated; the predicted lack of significant change in vegetation over time at these points allows them to act as reliable indicators of natural, background variation. The selection of Reference and Impact locations is in accordance with the Multiple-Before-After-Control-Impact (MBACI) monitoring protocol (Downes *et al*, 2003). In this case, the Before period is considered to be prior to the restocking of the lake and the planting of new aquatic vegetation in the wildfowl exclusion areas. The After period can be considered to be during and after the final planting and stocking is completed; the use of multiples sites for each Impact and Reference category allows statistics to be performed to assess natural variability within these categories as well as between them (Downes *et al*, 2003). In addition to these repeated sites, a number of locations were monitored during the topography survey to give an idea of water quality away from the lake margins; these points are show as T1-T4 in figure 2.

3.3 Sampling procedure

3.3.1 Water quality

Water quality was monitored at the eight point locations mentioned above on a fortnightly basis for 10 weeks from May to July. Basic water quality parameters including temperature, pH and dissolved oxygen were measured at all points using a multi-meter probe. In addition to this, nitrate concentration was measured *in situ* using a nitrate probe and 50ml samples taken back to the laboratory for total phosphorous (TP) analysis using an autoflow analyser. Notes were taken for each sampling point on each monitoring round to record any changing circumstances which may affect the results. Depth was measured at each location and the readings/samples taken at 30% of total depth from the surface. Figure 2 shows the locations of sampling points. Bottled samples were taken following the British Standards Institution guidelines (BSI, 2008). Samples and readings were taken at a consistent 30% of total depth as some water quality parameters, particularly temperature, are known to demonstrate gradients with depth (*e.g.* Brönmark and Hansson, 2005).

Additionally, all effort was made to record readings and take samples at the same time every monitoring day; this was important as many water quality parameters are known to demonstrate strong diurnal variations (Brönmark and Hansson, 2005). However, it was not always possible to sample at the same time so this potential source of variation in recorded values must be acknowledged. Water quality sampling in open water during the topography survey was conducted in the same fashion *i.e*. using a multiprobe and nitrate meter, although no samples were taken for total P analysis.

Each parameter, except for total phosphorous, was measured through *in situ* field probes and the results noted. For total phosphorous, the samples were taken back to the laboratory and filtered prior to being placed in the autoflow analyser. This filtering was justified as this study was concerned with the amount of phosphorous available to organisms within the water column which can potentially act as a key nutrient in the eutrophication process (*e.g.* Moss, 1988). However, in oxygenated waters phosphorous readily forms precipitates that are unavailable to phytoplankton, therefore, removing these particles should not significantly affect the concentration of available phosphorous in the water column (Brönmark and Hansson, 2005). However, it is important to note that changes in the oxygen or redox conditions within the lake can lead to phosphorous release from precipitates, particularly when oxygen conditions are poor.

3.3.2 Macroinvertebrates

Macroinvertebrate samples were taken from the 8 Impact and Reference locations mentioned in Sampling Point Determination (section 3.2). A standard 2m sweep was conducted for one metre either side of the determined location. The technique involved a 1mm net which was used to sweep the water and disturb the top layers of sediment along a measured 2 metre course and back over again. The contents of the net were transferred to labelled buckets, taken back to the laboratory where they were then preserved in 95% methanol for future identification. Identification was conducted by sorting through each sample for 45 minutes and removing any invertebrates found. The invertebrates were then transferred to petri dishes where they were identified under microscope following identification keys in Croft (1986) and numbers of individuals counted. Each species found were identified to at least family level although some were identified to higher taxonomic resolution. Each sample was sorted for 45 minutes to ensure consistency of effort. The waste invertebrates in methanol were then safely disposed of by laboratory technicians.

This process was repeated twice, one in early June and the second in late July. All taxa were counted during the first repeat, except *Cladocera* which were recorded as “numerous” for all samples taken. However, during the second repeat, an estimate of the abundance of *Cladocera* was taken by dividing the sorting tray into equal quarters, counting the abundance in one quarter and multiplying this by four. This was done so measures of relative abundance could be measured between the sites. This was viewed as important because *Cladocera* are a key fish prey species and also because of the grazing pressures they place on phytoplankton (*e.g.* Timms and Moss, 1984).

3.4 Determining the water quality tolerances of coarse fish species

Appendix B lists the range of tolerances for each fish species for a number of key water quality parameters: temperature, pH, DO, nitrate and phosphorous concentration. These tolerance ranges were established by searching relevant journals including: *Fish Physiology*, *Journal of Fish Biology* and *Environmental Biology of Fish*. Using these sources, it was possible to get upper and lower Incipient Lethal Levels for most of the fish species for temperature, pH and dissolved oxygen. In addition, upper limits were set for nutrients (nitrate and phosphate) in line with the Environment Agency’s General Quality Assessment Grade 3 (Moderate) levels (EA, no date). For those fish species where such studies were absent or difficult to find, similar species were used or the search criteria widened to a higher taxonomic level. For example, data on the DO tolerances of *Scardinius erythrophthalmus* were difficult to find in the literature so it was decided to use the same values as those for *Rutilus rutilis*, another Cyprinid species.

These tolerance ranges are shown in appendix B along with the literature source they were obtained from. It was decided to divide the tolerance ranges into two distinct periods. The winter period runs from October to March and has a broader range as during this period it was assumed sufficient for fish merely to survive and grow before spawning the next year. As such, these tolerance ranges were taken from the literature as those beyond which adult fish would begin to show signs of stress, injury and ultimately death (*i.e.* their Incipient Lethal Levels). However, fish are known to have numerous optimal ranges within which they can thrive, grow and reproduce. These niches may differ, for example, the optimal temperature range for reproduction is often much smaller than that within which fish can survive (Elliott, 1981). As such, a narrower range of tolerances was adopted for the key summer months (April to September) during which the fish spawn (see table 2). Outside these narrower ranges, adult fish will be able to survive and perhaps grow but any reproduction will be drastically reduced or even prevented entirely. This may be due to factors limiting processes such as ovarian development, as is the case with *Tinca tinca* at low temperatures (Breton *et al*, 1980) or because the factor is lethal to early life stages of the species, for example, low pH and *Perca fluviatilis* eggs (Rask, 1983). Winter limits are all UILLs or LILLS whereas summer limits are a mixture of ILLs, controlling and limiting factors (Fry, 1971).

Based on the assumption that a self-sustaining fishery requires all species within it to naturally thrive, the broadest range of tolerances were chosen within which all five species could survive or reproduce, depending on whether the period was winter or summer. This assumption of reproduction and survival within certain tolerances does not apply to the concentrations of nitrate and phosphate. Threshold values were displayed for these parameters merely as a framework within which lake managers can set their monitoring data and then assess the significance of any changes.

However, the concept of a single line threshold beyond which fish may cease to reproduce or even die may mislead lake managers into thinking they must act immediately after a parameter exceeds this limit. As such, it was decided to create a tolerance band around these threshold values, using 95% confidence limits from all data collected for a certain parameter. For example, the 95% confidence limits were calculated for pH by applying equation (1) to all pH values measured at all sites over the entire monitoring period. Therefore, these 95% confidence limits act as a proxy measure of variation in a certain parameter in Tom Thumb over that specific time period. This was deemed appropriate because any time a parameter enters within these tolerance bands without exceeding the extreme values will be likely due to natural variation. However, if a parameter is within these tolerance bands for extended periods then this can serve to alert lake managers to the potential for impacts on fish populations and the lake in general. These confidence limits should be re-calculated whenever new monitoring data becomes available, particularly when transferring between summer and winter periods as levels of variation are likely to alter significantly between seasons. Ideally, these confidence limits should be based on both the variability in the experimental assessment of fish tolerances and that of water quality. However, the former data were not available and so water quality variability alone was used a compromise solution.

$$\textbf{95\% confidence} = 1.96 * [SD(\chi)/\sqrt{n}] \qquad (1)$$

where SD(χ)=standard deviation of a specific water quality parameter across all sites and dates, and n is the total number of monitored values for a specific parameter across all sites and dates

Figure 3 shows a conceptual diagram of the threshold band approach with Optimal (green) areas within which fish can readily survive and reproduce, Aware (yellow) areas within which fish populations are likely to thrive but which may be an indicator of potential problems with fish or the wider lake system and Concern (red) areas within which a significant number of fish deaths or poor/absent reproduction are very likely to occur. Extended periods within the yellow (Aware) area should result in increased general visual surveillance of the system and a heightened awareness by managers for potential problems. Extended periods within the red (Concern) areas are likely to indicate significant problems with water quality that are likely to have a direct impact on fish populations and should trigger additional monitoring to identify the problem and any appropriate remedial action. Note that the optimal band for survival during winter is much broader than the optimal summer band for reproduction. It must be noted that the relationship and gradient between the winter and summer values is a simple linear extrapolation in the absence of any other data on this transition.

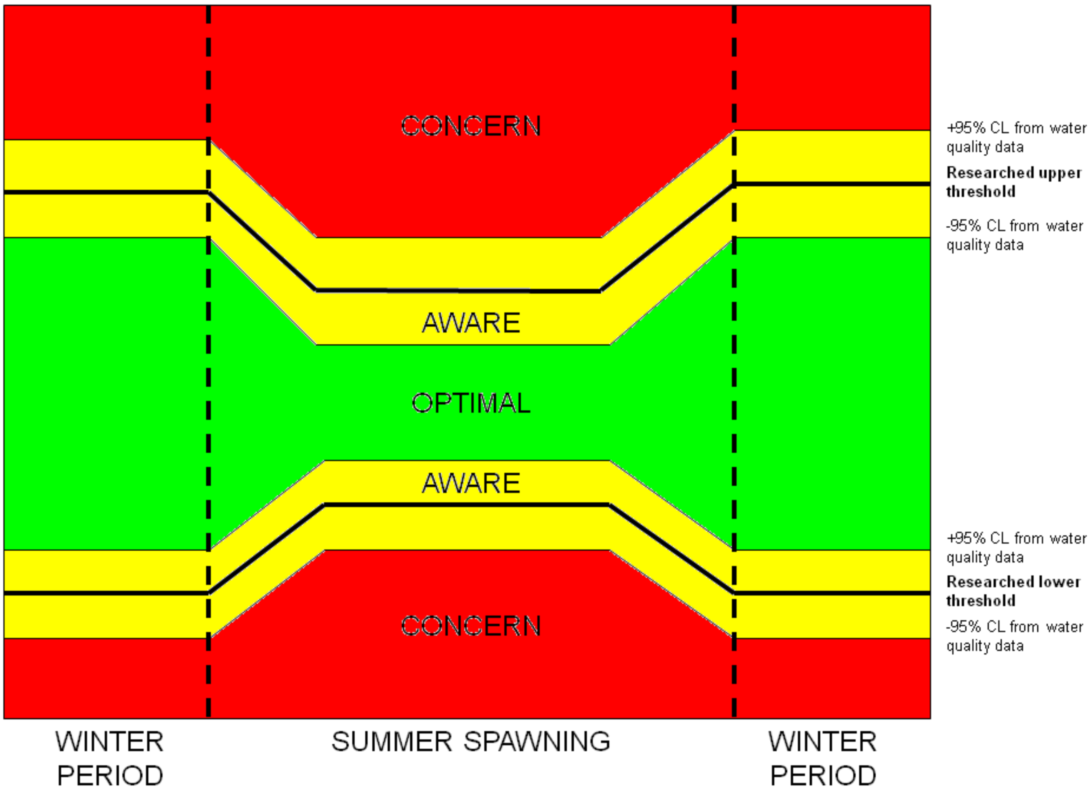

Figure 3 Conceptual diagram of the threshold band system for monitoring water quality in relation to the requirements of coarse fish species in Tom Thumb Lake. Dashed lines separate the Winter and Summer periods. Fishery managers should aim to maintain water quality within the green (Optimal) area, forays into the yellow (Aware) areas highlight potential problems and any occurrences in the red (Concern) areas mean water quality is outside its threshold (usually lethal) level for fish and action must be taken

3.5 Angler surveys

A simple questionnaire (figure 4) was devised and copies handed to the Ranger staff at Eastbrookend Country Park. These were offered to all anglers when purchasing day tickets. The questionnaire was designed to be as quick and easy to complete as possible with clear, unambiguous questions. Also, ensuring questionnaires were anonymous and the use of the Cranfield University, EA and LBBD logos helped to ensure those completing them that their answers would be dealt with appropriately and confidentially. The questionnaire was designed with reference to the guidance in Denscombe (no date). Section One asked anglers their reasons for fishing at Tom Thumb and their opinions of the restoration. Additionally, respondents were asked if they would attend a free coaching session, this question was intended to assess the potential demand for such sessions which the Environment Agency intend to use to encourage new anglers (EA, 2006). Section Two was intended to be a basic survey of angler demographics including: age, sex, ethnicity and registered disabled status. These data should be of use to the Environment Agency in assessing the number of anglers from certain groups, particularly the priority young, disabled and ethnic minority groups (EA, 2006) and may give an indication of whether or not the restoration has been successful in encouraging these groups to fish at Tom Thumb. Section Three attempted to assess the proportion of new and returning anglers at Tom Thumb after the restoration by asking how many times they have visited within the past two years. In addition, a basic survey of angler economics was included asking respondents for the distance travelled and approximate total spend for that specific trip. This last section was expected to be an important indicator of the restoration yielding positive economic results which could be an important factor in securing approval and funding for similar projects in the future (Carter, pers. comm., 2008).

A questionnaire was chosen over a structured interview survey because the number of anglers present at the site during monitoring was generally low (1-3 people) and this would have required multiple trips to the lake outside of the normal monitoring schedule in order to get a reasonable number of respondents. As such, it was more practical to construct the simple questionnaire which enabled LBBD staff to distribute them as they sold the day tickets. This significantly reduced the travel and time requirements of the survey.

Reference number:

Tom Thumb angling survey

We would be very grateful if you could complete the following simple questionnaire by circling the appropriate answer(s). The questionnaire consists of three short sections on both sides of this sheet.

Section One

Would you consider attending a free "have a go" angling coaching session?	Yes	No
Why did you choose to fish Tom Thumb today? (you may circle multiple answers)	Access	Location
	Surroundings	Permit cost
	Facilities	Quality of fishing
	Other (please state)__________	

____

____

What are your opinions of Tom Thumb after the restoration?

Section Two

Sex:	Male	Female	
Age:	Under 12	12-20	21-30
31-40	41-50	51-60	60+
Ethnicity:	White British	White Irish	White other
Black African	Black Caribbean	Black other	Asian Indian
Asian other	Mixed	Other	Rather not say
Are you registered disabled?	Yes	No	Rather not say

Section Three

Is this your first visit to Tom Thumb lake?	Yes	No	
If you answered No to the above, how many times have you visited in the last 2 years?	1-2	3-4	
	5-6	6+	
How many miles did you travel to Tom Thumb today?	0-2	3-4	5-6
	7-9	10-15	15+
How much have you spent on today's trip (inc. travel, bait, tackle and permits etc.?)	£4-10	£11-20	£21-30
	£31-40	£41-50	£51+

Thank you for your time.

This survey is being carried out by Cranfield University in partnership with the Environment Agency and the London Borough of Barking and Dagenham. The survey is designed to assess the usage of Tom Thumb lake by anglers since the restoration project was completed. All questionnaires are strictly anonymous. Your feedback will help to further improve Tom Thumb lake now and in the future.

Cranfield University — Environment Agency — The London Borough of Barking & Dagenham

Figure 4 Angler survey designed for Tom Thumb Lake

Questions with numerical category answers (*e.g.* distance travelled or spend per trip) were generally divided into categories of equal value to allow more reliable comparison between categories (Denscombe, no date). The values of groups for distance travelled were skewed towards low distances (0-10 miles) based on the assumption that the lake will attract those groups who may find it difficult to travel long distances (*i.e.* the young and disabled). The categories and value range for spend per trip was assigned with reference to the ticket price of £4, therefore the lowest category was £0-10 as it would be unlikely for an angler to spend a smaller amount including the ticket purchase. The upper limit was set at £51+ based on Hickley (1996) which stated the average spend per trip for coarse fishing was £21, however this amount is likely to be slightly more in 2008 due to the effects of inflation. Using the Bank of England target inflation rate of 2% (Bank of England, 2008), £21 in 1995 would have risen to £27.17 in 2008 which is approximately central in the £0-51+ total range of spend per trip categories.

4 RESULTS AND ANALYSIS

4.1 Topographic survey

Figure 5 shows a map plotted with approximate routes for all seven transects taken. As mentioned previously, distances were estimated from the map scale and average speed of each transect calculated. Calculating speed for each individual transect was important because the effects of wind and reduced power from the electric boat motor batteries became increasingly apparent. A reduction in speed meant less distance was covered per 10 second interval; using a constant average speed for all transects would have yielded incorrect distances and a misleading picture of the depth profile. Although a total of seven transects were taken, only the depth profiles one and seven are presented here for the sake of brevity; the remaining depth profiles are shown in appendix C. Mean depth from all transects taken was 1.4m with a total depth range of 0-2.6m.

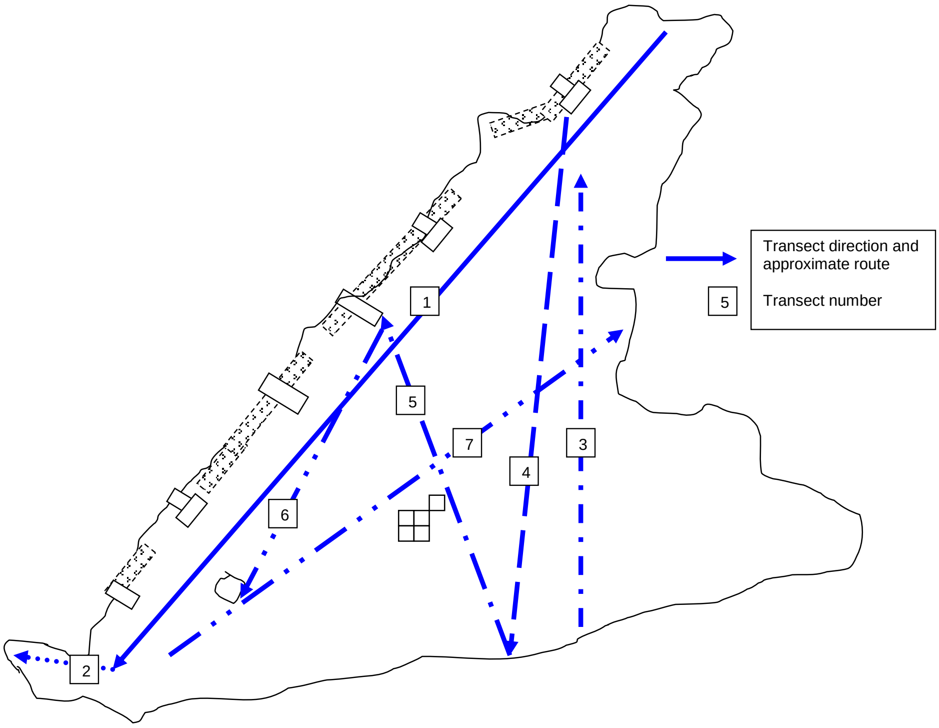

Figure 5 Map of depth transects taken on Tom Thumb Lake, direction of arrow is direction taken by the boat, number in square is the transect number (see appendix C)

Figure 6 shows distance-depth plots for transects one and seven; these show large variation in depth ranging from 0 to 2.6m. Shallow areas correspond generally with the known gravel bars in the central part of the lake but also close to the vegetated eastern bank near to the Reference site locations. Depth undulates more along transect seven as the gravel bars and hollows are more pronounced in this part of the lake. Transect one was slightly north of the gravel bar area so depth here fluctuates less and the lake is more uniformly deep.

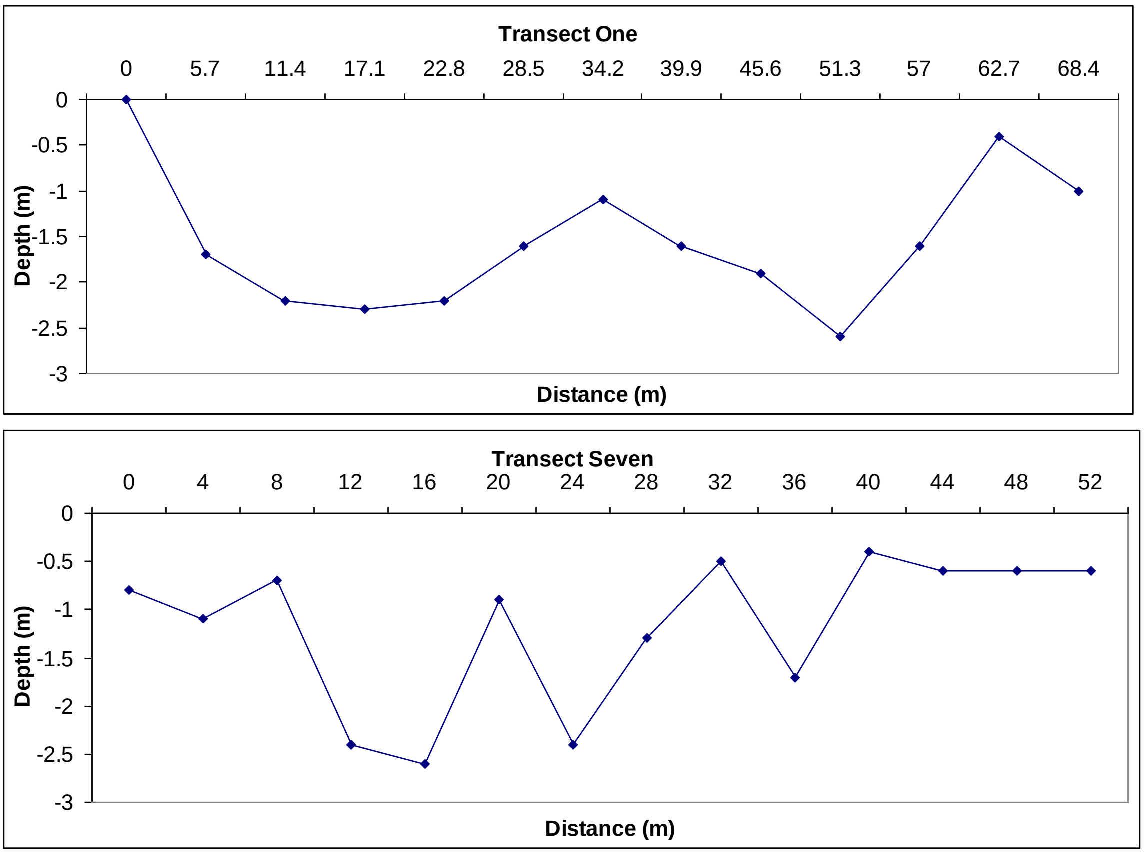

Figure 6 Depth transects one and seven taken from Tom Thumb Lake

4.2 Fish species water quality thresholds

Figure 7 below shows five water quality threshold plots obtained from published data on fish physiology (appendix B). The temperature plot shows all species are able to survive very low temperatures (around 2ºC) in winter. The physiological lower limit rises to 12ºC which relates to the minimum temperature above which spawning occurs during the summer. The error bands calculated from 95% confidence limits (see Section 3.4) show very little natural variation (±0.82ºC) within Tom Thumb over the time period of monitoring. The plot of dissolved oxygen has only a lower limit which again is reasonably low (5% saturation) in winter but rises in summer when spawning occurs. However, this plot shows more variation (±8.43) creating a much broader yellow (Aware) area than for temperature. Note that most of the tolerance ranges from literature give values in mg/l (see Appendix B); these were subsequently converted to % saturation values based on Mortimer (1956). The lower pH limit was again defined from literature showing a narrower range during spawning. No studies could be found on the upper limit for pH so this is set in reference to the ECOFRAME guidance for Ecotype 15 of moderate quality which was the closest match for Tom Thumb. This classification is based on size, catchment characteristics and climate (Moss *et al*, 2003). Again, pH shows very little variation around the threshold defined in the literature.

Nitrate and phosphate plots are also shown, not as an indicator of potential effects on fish populations but to act as a framework within which future lake managers can set their monitoring data. Here, some variation is demonstrated around the nitrate threshold creating a medium thickness (Aware) tolerance band which may highlight potential future problems with nutrient enrichment. The very low occurrence of phosphorous in the collected samples due to levels consistently being below the detection limit mean that this threshold currently has no associated tolerance band.

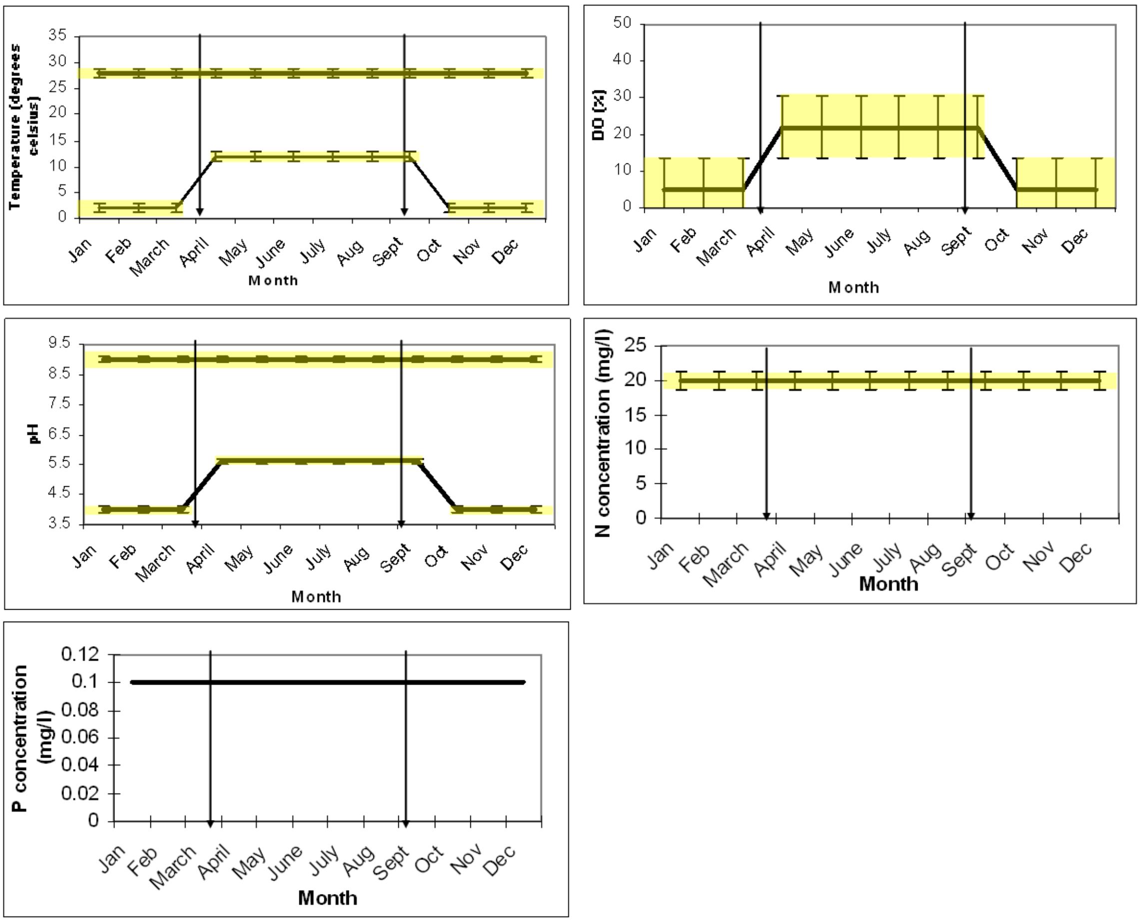

Figure 7 Guideline water quality thresholds for 5 water quality parameters in relation to the requirements of fish species within Tom Thumb Lake. Arrows distinguish between the winter survival period and the summer reproduction period. Thick lines are upper/lower threshold limits researched from literature. Error bars are 95% confidence limits around the threshold value obtained from monitored data. See conceptual diagram (figure 3) and section 3.4 for explanation on the use of these plots. Note that the phosphate plot has no confidence limits as this parameter was consistently below the detection limit of equipment

4.3 Water quality

Figure 8 shows the key water quality parameters plotted for the period May-July within the summer tolerance ranges shown above (Section 4.2). The data are shown as average plots of all four Impact sites on the left and all four Reference sites on the right with their associated 95% confidence limits generated from all four sites for that particular parameter on that specific date.

Temperature shows a general upward trend over the summer at both Impact and Reference sites; variation is low within the Impact category and slightly higher on occasions within the Reference category. pH appears to show some changes during the monitoring period but these stay within the tolerance bands. Dissolved oxygen appears to show a fluctuating but very slight increase across the monitoring period although this is more pronounced in the Impact category. The 95% confidence limits vary in magnitude between sampling dates but are generally greater for the Reference category. Nitrate levels appear to show similarly large levels of variation within site categories and over time with no real trend discernible.

ANOVA statistical comparisons between the site categories across all 5 monitoring dates showed the differences between Impact and Reference sites to be insignificant for all parameters: temperature ($F_{(1,28)}$=0.017, p=0.901), pH ($F_{(1,28)}$ =1.653, p=0.246), DO ($F_{(1,28)}$=0.540, p=0.490) and nitrate ($F_{(1,28)}$=0.033, p=0.861).

Total phosphorous analysis resulted in levels consistently below the detection limit of the equipment (0.1mgP/l) for all but 3 samples collected from Impact sites on 15/06/2008 which were 2.5, 0.4 and 0.1mg/l. As such, a plot of phosphate concentration is not presented in this section as average values would be consistently well below the EA GQA level.

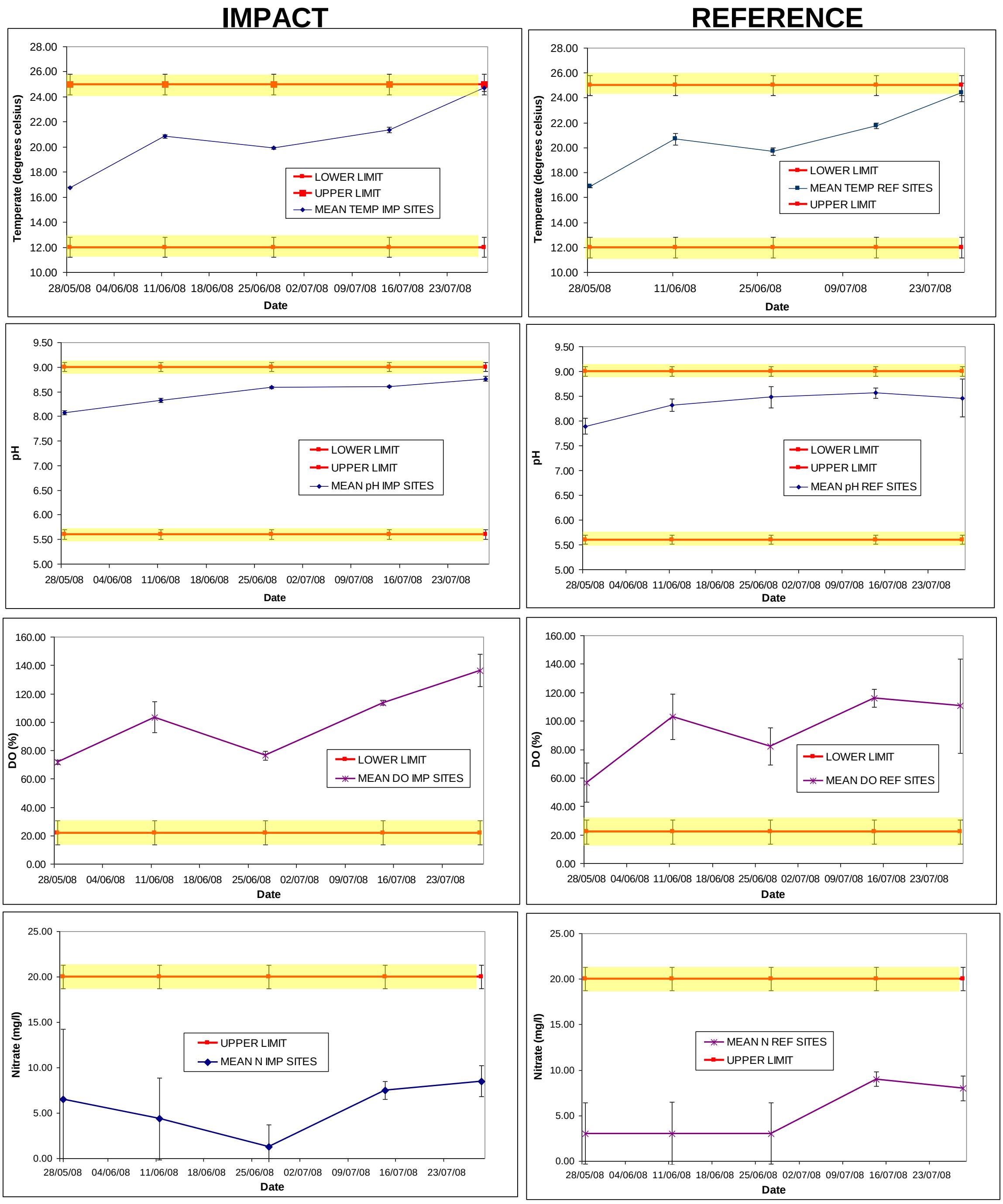

Figure 8 Plots of the baseline water quality data collected at Tom Thumb lake over the summer of 2008. Impact sites are on the left and Reference sites on the right. Bold red lines are the upper and lower summer tolerance ranges taken from the data in figure 7 above with the yellow areas indicating tolerance bands based on 95% confidence limits calculated from all data for that parameter. The water quality lines are means from all four Impact or Reference sites with the associated 95% confidence limits. Note that 0.1 values on the nitrate plots (bottom) are in fact trace values from the nitrate meter and do not necessarily represent a concentration of 0.1 mg/l

Table 3 below shows the water quality monitoring data taken during the topography survey on 14/07/2008 at the locations (T1-T4) in figure 2. These data show that water quality here is broadly very similar to that measured at the lake margins on the same day, although temperature does appear to be slightly cooler (~ 1ºC) in open water.

Table 3 Water quality data taken in open water during the topography survey (14/07/2008)

Location	Temperature (ºC)	pH	DO (%)	N (mg/l)
T1	20.92	8.40	111.00	8
T2	20.18	8.57	108.30	8
T3	21.04	8.53	110.50	6
T4	21.33	8.60	113.60	8

4.4 Macroinvertebrates

A series of biodiversity statistics were performed on the collected species presence and abundance data. For this study the alpha biodiversity indices Shannon-Wiener (H) and Berger-Parker Dominance (d) were performed for all sites, in addition to the basic species richness and total abundance data shown in Table 4.

ANOVA performed for all alpha indices across both site categories and dates found the difference between site categories to be significant for species richness ($F_{(1,7)}$=6.845, p=0.04) and total abundance ($F_{(1,7)}$=78.377, p<0.001) but not for Berger-Parker (d) or Shannon-Wiener (H). However, the effects of other taxa could have been masked by the large dominance of *Cladocera* in the second repeat. As such, it was decided to split the data into separate dates and calculate ANOVA statistics for each. This split found the difference in total abundance between site categories was only significant for the second repeat ($F_{(1,7)}$=94.527, p<0.001). Also, there was a significant difference in Shannon-Wiener H in the first repeat ($F_{(1,7)}$=10.052, p=0.034) and this was almost significant in the second repeat ($F_{(1,7)}$=3.938, p=0.094).

Table 4 Summary of alpha biodiversity statistics performed on invertebrate samples collected from Tom Thumb Lake. Note that the 11/06/2008 data has only 3 Impact sites and that *Cladocera* abundances were only estimated for samples collected on 28/07/2008

11/06/08				
Site	Number of species (n)	Total individuals	Shannon-Wiener (H)	Berger-Parker (d)
INV1REF	10	49	1.75	0.31
INV2REF	7	25	1.45	0.48
INV3REF	7	27	1.40	0.44
INV4REF	8	24	1.46	0.50
INV1IMP	6	25	1.29	0.48
INV3IMP	6	47	0.86	0.77
INV4IMP	4	7	0.96	0.57
MEANREF	8.00	31.25	1.52	0.43
MEANIMP	5.33	26.33	1.04	0.61
28/07/08				
Site	Number of species (n)	Total individuals	Shannon-Wiener (H)	Berger-Parker (d)
INV1REF	10	474	0.96	0.59
INV2REF	9	503	0.71	0.83
INV3REF	10	544	0.59	0.88
INV4REF	10	575	0.82	0.80
INV1IMP	6	117	0.91	0.68
INV2IMP	8	165	0.98	0.73
INV3IMP	11	182	1.53	0.44
INV4IMP	6	27	0.97	0.74
MEANREF	9.75	524.00	0.77	0.78
MEANIMP	7.75	122.75	1.10	0.65

The change in significance for total abundance when separated by dates suggested *Cladocera* did have an effect. Therefore, further ANOVA was performed for total abundance in the second repeat with *Cladocera* estimates removed. This analysis found the difference between Impact and Reference abundances (without *Cladocera*) to be insignificant for the first repeat ($F_{(1,7)}$=0.169, p=0.698) and the second repeat ($F_{(1,7)}$=3.610, p=0.106). It must be noted that ANOVA for species richness was not affected by the inclusion of *Cladocera* estimates as this measure is concerned only with presence of species, of which *Cladocera* was noted for both repeats (see Appendix D).

In addition to the above alpha diversity indices, dendrograms were constructed using Community Analysis Package software (Pisces Conservation Ltd). These dendrograms were based on Bray-Curtis similarity (Magurran, 2003) and are shown in figure 9. The uppermost dendrogram shows some clustering for

Reference sites in both repeats and Impact sites in the second repeat. This dendrogram is broadly split by the date with repeat 1 at the top and repeat 2 at the bottom. There are a number of anomalous results, firstly W1AIMP and W1AREF cluster despite being at opposite ends of the bank. Also, W1DIMP and W2DIMP cluster and do not follow the general split by date.

This broad split in the data by date is most likely due to the inclusion of *Cladocera* abundances in the second repeat; as such it was decided to create a second dendrogram without these estimates (see bottom of figure 9). This time the date split is absent although some common clusters remain (highlighted by the red circles). Between both dendrograms W1CIMP appears to cluster closer to the Reference sites than other Impact sites. Other similarities are maintained, including clustering of Reference sites and similarities between W1AIMP and W1AREF as well as W1DIMP and W2DIMP. Also note the slightly smaller scale of the horizontal axis on the lower dendrogram, suggesting removal of *Cladocera* increases similarity. The possible reasons for these clusters are examined in a later section of this report.

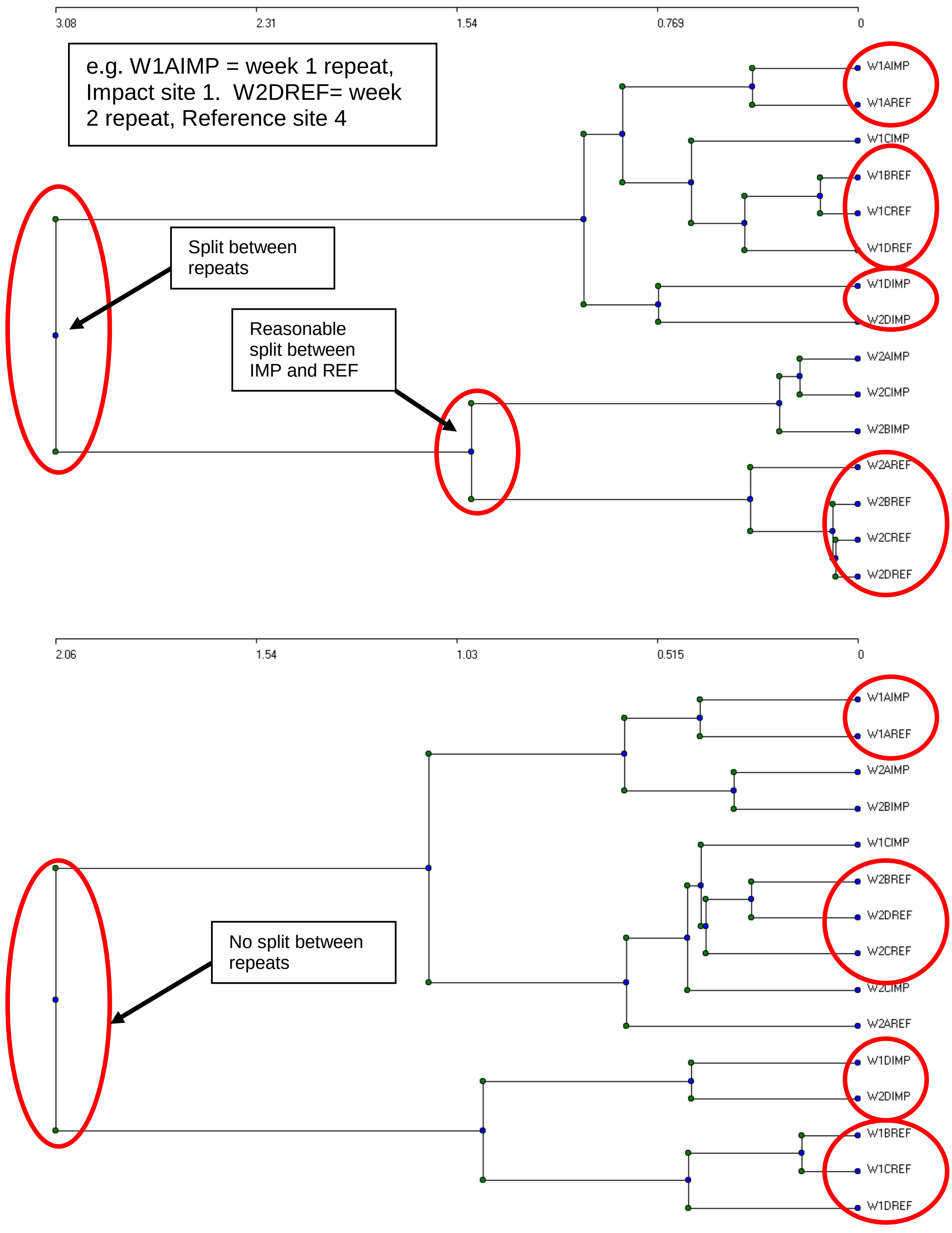

Figure 9 Wards agglomerative clustering dendrograms based on Bray-Curtis similarity index. Top plot includes *Cladocera* estimates and lower plot does not. Red ovals highlight similar clusters between the two dendrograms. Note the slightly different scales between the horizontal axes

4.5 Angler surveys

Unfortunately, due to a delay in the re-opening of the lake to anglers, data from completed questionnaires was not received in time for inclusion in this report. As such, this section briefly outlines how these data would have been analysed and placed in the context of other angler surveys.

Data would have been entered into Microsoft Excel and simple pie charts constructed of the angler demographic data, giving a visual breakdown of the age, sex and ethnicity of anglers at Tom Thumb. Similar pie charts could be constructed from data using existing EA surveys (*e.g.* EA, 2004b and 2005) allowing for visual comparisons between specific fisheries and within the national context set in the Public Attitudes survey (Simpson and Mawle, 2005). Bar or pie charts would also be constructed from the economic measures data and similar comparisons made as for demographics.

5 DISCUSSION

5.1 Potential effects of depth on the fishery

The depth transects show that the lake varies greatly from deep, steep sided banks up to 2.6m deep to shallow, gravel bars and silted marginal areas at around 0.5m deep. However, even in the deepest areas the effects of wind are likely to be sufficient to ensure the entire water column is mixed. Studies show that the propensity of a lake to become stratified depends on wind speed, temperature and total depth (*e.g.* Gorham and Boyce, 1989). However, given the relatively shallow depth of Tom Thumb and the general lack of wind cover along the banks likelihood of thermal stratification is low. A lake with consistent mixing of the entire water column is known as a holomictic lake with multiple (polymictic) mixing events occurring throughout the year (Brönmark and Hansson, 2005). This consistent contact of well oxygenated, mixed water with the sediment surface is important, particularly with the generally high pH in Tom Thumb (see figure 7) which would cause increased release of phosphate from sediments in poorly oxygenated waters (*e.g*. Boström et al, 1982). This release of phosphate can have secondary effects on water quality. The relatively shallow depth of Tom Thumb mean it is unlikely that large variations in temperature due to depth will occur but factors such as shading by vegetation could influence temperature (Moss, 1988).

5.2 Water quality May-July 2008

This section focuses on differences in water quality between the Impact and Reference categories and the implications for lake managers. Additionally, comments are made on trends over time and the likely implications on the fishery. ANOVA statistical analyses (see Results section 4.3) showed there to be no significant difference between the two site categories for all measured water quality parameters. This suggests that water quality in Tom Thumb Lake is homogenous and that localised water quality is not largely affected by the presence of vegetation or the associated macroinvertebrates. This is an important finding for managing the lake; Chapman and Underwood (2000) state that a successful restoration must see Impact sites converging towards Reference conditions. However, given the similarity between site categories, a successful restoration must see this similarity maintained and any trajectory of change in water quality must be mirrored by both Reference and Impact sites. Additionally, it can be assumed that because water quality is similar between site categories, this can not be used to explain the differences found in macroinvertebrate communities.

The general increase in temperature is expected over the summer and is mirrored in both categories. At the end of July, temperature just enters the yellow tolerance band but stays below the researched UILL. However, these temperatures are likely to drop below the tolerance band as autumn approaches. Also, these temperatures represent a worse case scenario, being taken from 30% depth in the shallow lake margins. Cooler waters are likely to be available elsewhere in the lake, and fish are known to move to such areas to regulate their body temperature, a process known as behavioural thermoregulation (Brönmark and Hansson, 2005). However, as mentioned earlier high temperatures may be an issue for very early life stages of fish which are less able to avoid such conditions through changes in behaviour (Wootton, 1998). The similar trend between both categories suggests a homogenous temperature profile across the lake.

pH shows a similar trend over time between the two categories although the small increase may not represent a significant change and may be due to differences in sampling time or equipment calibration. However, both plots show pH almost entering the yellow tolerance band which should alert lake managers to potential impacts on fish. Managers should also be aware of the potential secondary effects of high pH, including an increase in un-ionised ammonia concentration, which can be toxic to fish (Smart, 1981). The similar steady changes across both site categories suggest Tom Thumb does not suffer from the large, rapid pH variations associated with phytoplankton blooms (*e.g.* Brunson *et al*, 1994).

The fluctuating nature of DO across all sampled sites and dates may be related to a number of factors, including:

- Sampling at different times of day; DO is know to demonstrate large diurnal variations (Brönmark and Hansson, 2005)
- The effects of changing temperature; increasing temperature means water can hold less oxygen at saturation meaning an equivalent concentration of oxygen at a low temperature will be closer to saturation (100%) at a higher temperature (Mortimer, 1956)
- Increased rates of photosynthesis during the day in summer and subsequent release of oxygen by plants (Brönmark and Hansson, 2005)

Dissolved oxygen again showed no significant difference between site categories or any discernible trend over time, with levels consistently maintained above the lower threshold. The lack of difference between site categories suggest the effects of varying vegetation densities and the associated photosynthesis and respiration are not sufficient to significantly alter DO levels. These DO levels are a positive result for lake managers as poor oxygen conditions have been a past issue at Tom Thumb and such events are known to be a common cause of fish kills, particularly in the warm summer months (Wootton, 1998).

Nitrate showed significant variation across all sites and dates with no real trend discernible. Possible reasons for this could include defecation by wildfowl, which was particularly noticeable along certain sections of the Impact bank. A study by Stoianov *et al* (2000) found the mean daily input of nitrate per Canada goose in a London lake to be 1.5g. Localised congregations of wildfowl could lead to a spatial variation in nitrate concentration between sites. Also, internal sources of nitrate can be significant, with recycling of urea and ammonia in the water column accounting for a large proportion of the total supply to phytoplankton (*e.g.* Présing *et al*, 2001). Despite this variation, nitrate levels were consistently well below the EA GQA Grade 3 level but the potential combined effect with high pH must be recognised (Smart, 1981).

Total phosphorous analysis consistently returned values below the detection limit of equipment. This is a positive result for lake managers suggesting that consistently high levels of phosphorous do not occur in Tom Thumb. However, algal blooms have been an issue in the past (LBBD, 2006) and so ongoing monitoring is advised to identify any short-term peaks in phosphorous concentration. However, the consistent occurrence of concentrations below the detection level suggests a different analysis method may be appropriate, for example, autoclave digestion would allow the analysis of unfiltered water samples.

Sampling during the topography survey was conducted to give a very basic indication of water quality away from the lake margins. These data show water quality to be broadly similar across all parts of the lake, although no robust conclusions can be drawn from this isolated dataset. Temperature appeared slightly lower in open water but this is most likely due to sampling at different times of day; the topography survey was conducted in the morning whereas the normal Impact and Reference monitoring was conducted in mid to late afternoon.

These data suggest Tom Thumb does not suffer from any of the major issues faced by shallow lakes that were identified in the literature review, namely low DO, high nutrient levels and large pH fluctuations due to phytoplankton blooms. However, it would have been useful to conduct monitoring before the lake was drained and carp removed to fully assess any changes in water quality due to this part of the restoration. Even though site categories appear to be similar in terms of water quality, further improvement may still be possible. For example, macrophyte stands are known to have direct benefits for water quality by utilising nutrients that would otherwise be used by phytoplankton. Also, vegetated areas encourage deposition of metal particles and help to reduce sediment disturbance from wind action (Srivastava *et al*, 2008). General water quality, and particularly nutrient levels are known to improve after a restoration of this type but lake managers must be aware of potential relapses to a turbid or eutrophic state due to poor fish recruitment or internal nutrient loading (Søndergaard *et al*, 2007).

5.3 Is the water quality sufficient to maintain the fishery?

By plotting the water quality time series against the tolerance ranges for fish within Tom Thumb it was possible to get a basic indication of whether water quality during the monitoring period was likely to be sufficient for a self-sustaining fishery. These plots (figure 8) show that despite increases and trends in some parameters, namely temperature and pH, none exceed threshold values and only one parameter (temperature) enters the yellow tolerance band. Even those parameters that do approach tolerance levels do so only for short periods and in line with expected natural variations (*e.g.* increasing temperature over the summer months). Therefore, based on these data the water quality should be of a sufficient standard for fish to naturally reproduce and thrive within Tom Thumb.

These monitoring data are a useful indicator of the suitability of Tom Thumb to act as a self-sustaining fishery. If such a standard of water quality is maintained throughout the year, Tom Thumb Lake should suffer no poor recruitment of fish due to water quality constraints. To ensure this occurs, monitoring should continue throughout the year in order to identify any potential changes in water quality that could impact on fish. The threshold limits should allow managers to identify potential trends towards threshold levels and decide if any appropriate action must be taken before they are reached. This should help lake managers to prevent catastrophic events such as fish kills by acting earlier. In addition, the use of 95% confidence limits as tolerance bands provide a “buffer” around the threshold limits based on a parameters observed variability. This buffer should prevent lake managers making knee-jerk management decisions when quality sporadically exceeds threshold levels. However, if a parameter is consistently plotted outside the tolerance band then this should alert managers to change outside of normal variability and signal potential impacts on the fishery.

5.4 Will planting improve macroinvertebrate populations?

This section discusses the macroinvertebrate community data to ascertain any differences or trends, particularly between the site categories. The results show that when all taxa, including *Cladocera*, are analysed there is a difference between Reference and Impact sites in terms of abundance and species richness. However, this difference is not as apparent for abundance when *Cladocera* estimates are removed for comparative purposes, suggesting their large dominance may be masking the effects of other species. The raw data in Appendix D show that *Cladocera* are considerably more numerous (and dominant) in Reference sites and this may be the main reason for any difference found between site categories. This is confirmed by the significant difference in abundance in the second repeat but not the first. Further confirmation was given by removing *Cladocera* estimates from ANOVA calculations, which rendered the difference between site categories insignificant for both repeats. The effect of *Cladocera* estimates on Shannon-Wiener (H) is less clear although further sampling may help to establish any relationship. These results show that *Cladocera* play a large role in macroinvertebrate community structure; therefore it was correct to include them in the analyses. With hindsight, *Cladocera* estimates for both repeats would have been useful in establishing more direct links between site categories across time. The heavy dominance of *Cladocera* on macroinvertebrate communities, particularly in vegetated Reference sites agree with existing studies that state *Cladocera* use marginal vegetation to avoid predators during the day (Timms and Moss, 1984).

The dendrograms again confirm the large effect that inclusion of *Cladocera* had on similarity (see the split between dates in top dendrogram, figure 9).

However, these dendrograms also highlight some expected clusters and some notable anomalous results. The split between W2IMP and W2REF sites is more pronounced when *Cladocera* are included, due to their much higher abundances in Reference sites (see Appendix D). Even though the difference between categories is lessened when *Cladocera* are removed, Reference sites still appear to cluster for both repeats suggesting other taxa are similar between these sites. The raw data suggest taxa such as *Corixidae, Chironomidae, Physidae* and *Gammaridae* are responsible for this. Another notable result is the consistent clustering of W1DIMP and W2DIMP regardless of whether or not *Cladocera* are included. This site, 4IMP (see figure 2) had the lowest abundance and species richness across both repeats (see Appendix D). W1AIMP and W1AREF also cluster regardless of *Cladocera* inclusion; the raw data suggest that similarities in *Lymnaeidae* and *Corixidae* could account for this. W1CIMP consistently clusters close to Reference sites instead of other Impact sites; table 4 and the raw data show that this site (3IMP, see figure 2) has the highest richness and abundance in the Impact category for both repeats.

These data appear to illustrate some differences in species richness and abundance between site categories, particularly when *Cladocera* are included. If exclusion areas are successful in allowing vegetation establishment along the Impact bank (Søndergaard *et al*, 1996) then macroinvertebrate communities are expected to progress to a similar state as those along the Reference bank. Chapman and Underwood (2000) state that this convergence of impacted sites towards Reference conditions is a requirement of successful restoration and that after time any difference between site category macroinvertebrate communities should reduce. This means that over time the availability of prey for planktivorous fish will increase and macrophytes will provide refugia for zooplankton during the day, allowing them to act as a more effective grazing control on phytoplankton (Blindow *et al*, 2000).

Given that water quality has been established to be broadly similar across the whole lake, this reason can not be used to explain the differences seen in macroinvertebrate communities within and between site categories. Therefore, it must be assumed that other structuring forces, such as the presence of suitable habitat (*e.g.* Richardson and Jackon, 2003) and fish predation pressure (*e.g.* Perrow *et al*, 2003) play a key role in defining these communities. This is a positive result for lake managers because it shows that water quality is not acting as a limiting factor in the development of macroinvertebrate communities. Therefore, increasing habitat availability through planting and reducing predation pressure through the availability of refugia will allow macroinvertebrate communities in the lake as a whole to improve. These improved communities should provide numerous benefits for water quality as mentioned earlier and help the fishery to become self-sustaining.

5.5 The initial response of anglers to the restoration

The delay in receiving data means that no conclusions can be drawn on the angler response in this report. However, it is recommended that this survey continue and the data be collated in a simple fashion as mentioned previously (see section 4.5). Hopefully, analysis of these data will show sufficient numbers of anglers attending the site to generate revenue and also show new anglers and those from priority groups using Tom Thumb Lake. If the data does demonstrate these aspects, in addition to a general positive response towards the restoration, then this survey may prove useful in providing justification for similar projects in the future (Carter, pers. comm., 2008).

5.6 Limitations and constraints

5.6.1 Water quality

Although monitoring during summer 2008 showed Tom Thumb to have generally good water quality within the threshold limits these data do have limitations that lake managers must recognise. Perhaps most importantly, this monitoring only gives an indication of water quality during the summer. Large fluctuations in parameters can occur as the seasons progress and these may have an impact on fish populations (*e.g.* Brönmark and Hansson, 2005).

5.6.2 Tolerance plots

The tolerance plots should prove a useful tool for managers of Tom Thumb, allowing them to visually assess the significance and likely impact of changes in water quality on fish populations. However, these plots have several assumptions and limitations that must be acknowledged before conclusions can be drawn. Firstly, most of the tolerance values found in literature are from idealised, experimental laboratory studies which may not accurately reflect such tolerances in natural systems. Secondly, many of the studies vary in the experimental technique which could affect the final values. In particular, the Incipient Lethal Levels (ILLs) for temperature are based on a range of acclimation rates which are known to affect the ultimate lethal level significantly (*e.g.* Beitinger and Bennett, 2000). Thirdly, lake managers must recognise that these indicators of basic water quality will not reflect all aspects of Tom Thumb system. Other organisms or processes within lakes are also dependent on water quality and these may have different tolerance ranges to those of fish. For example, *Gammarus*, a freshwater shrimp found in Tom Thumb (see Appendix D), will be lost from a system when pH drops below 5.5 whilst other macroinvertebrates and fish species remain (Brönmark and Hansson, 2005). If water quality does not meet the needs of these other aspects of the system, this could have indirect effects on fish populations by reducing prey species or habitat availability. As such, these tolerance ranges should only be used in the context of wider knowledge of fishery health and performance (perhaps purely from visual or anecdotal cues) especially when these water quality parameters are spending extended periods at or close to threshold levels.

Also, these single plots do not portray the range of tolerances that different species demonstrate. For example, the Crucian carp (*Carassius carassius*) is known to survive entirely anoxic environments for extended periods and will remain where other less hardy species are absent (Doudoroff and Shumway, 1970). However, for a self-sustaining fishery it is necessary that all species are able to survive and reproduce, as such a precautionary narrow range of tolerances has been adopted where this will be possible.

Individual plots of Incipient Lethal Levels do not portray the various optimal ranges each parameter has within the ILLs. For example, just because a parameter is within the ILLs does not necessarily mean that parameter is at an optimal level; feeding or growth rates are known to reduce with temperature well before the LILL (Wootton, 1998) which could significantly reduce fishery performance without causing it to collapse. Also, these plots do not portray the controlling and limiting effects that each parameter can have in addition to their lethality (Fry, 1971). Finally, individual plots do not portray the many and complex interactions between the various factors and their potential combined effects (Wootton, 1998).

5.6.3 Macroinvertebrates

The analysis of macroinvertebrate communities proved useful in demonstrating the relative differences between sites and categories and also the important role that *Cladocera* play. However, the methodologies of collection and analysis have a number of limitations that must be acknowledged. Firstly, the use of a 1mm net will have allowed smaller (but no less important) organisms to escape collection. Also, those organisms able to attach strongly to surfaces, such as leeches, will be under-represented whilst those that move around freely will be over-represented (Moss, 1988). Secondly, it was not practically possible to preserve the samples immediately upon collection; this had to be done on arrival at the laboratory meaning the invertebrates were alive in the buckets for approximately two hours. Therefore, it was possible that predation occurred within the buckets which could have affected final species and abundance counts. Finally, sorting of samples for a pre-defined 45 minutes was important so all samples could be completed within a reasonable time frame. However, it is possible that some individuals or species were missed during the 45 minutes, particularly for those samples that were turbid or contained a large amount of vegetation or debris. Also, it must be noted that *Cladocera* were extremely abundant, especially in Reference samples, making it difficult to accurately assess their abundances. Finally, it would have been useful to estimate *Cladocera* abundances for both repeat dates, allowing more direct assessments of change over time.

6 RECOMMENDATIONS

6.1 The need for continued monitoring

Adequate post-project monitoring is vital to ensure that a restored ecosystem has become self-sustaining or is at least on the correct trajectory towards this goal (Connell and Sousa, 1983 and Westman, 1991). However, many projects have seen this monitoring cease once they simply "*look right*" leaving the ecosystem open to relapse back to the degraded state (Grayson *et al*, 1999). A robust monitoring regime would allow managers of Tom Thumb to identify potential problems or relapses much earlier and enact any appropriate measures in an attempt to prevent them. In addition, a robust assessment of the success of the Tom Thumb restoration may be useful in justifying expenditure on future projects. Also, any weaknesses or failures can be learnt from and avoided in future projects adding to the "*institutional memory*" of restoration ecology (Downes *et al*, 2003). As such, this section provides a framework for ongoing monitoring of the status of the Tom Thumb fishery, including which parameters to monitor, when, where and how to monitor them and indicative costs for such monitoring.

Figure 10 shows the suggested monitoring guidelines for future lake managers at Tom Thumb. The previous section on the water quality requirements of coarse fish species identified temperature, pH and dissolved oxygen as the three main parameters that can have a significant impact on fish populations. Because of the importance of these parameters and the relative ease of measurement through *in situ* probes, it is recommended that monitoring at all of the Impact and Reference locations continues. By continuing bank side monitoring only the additional costs, labour requirements and safety considerations of boat use are saved. However, it is recognised that the temporal resolution of fortnightly monitoring may be burdensome for future lake managers and so it is recommended that monitoring take place on a monthly basis for six months over summer (April to September) which has been identified as the key spawning period for those fish in Tom Thumb (see table 2) and also likely to be the time at which angling activity is highest. When monitoring on a monthly basis, all efforts should be made to monitor on the same day at the same time (for example, 11am on the 15th of the month) to ensure data consistency and allow more reliable comparisons over time. This is important as many water quality parameters, such as DO, are known to demonstrate strong diurnal variation (Brönmark and Hansson, 2005). Selection of the same Reference and Impact sites used in this study will allow direct comparison of data over time in line with established MBACI protocols (see Downes *et al*, 2003). By continuing to monitor Impact sites, changes in water quality over time can be assessed as new vegetation stands become established on this bank. Reference sites will continue to act as measures of natural variation.

This guidance also suggests optional monthly monitoring of water quality over the winter period (October to March) which would help to identify any deterioration in water quality between spawnings which may impact on fish recruitment into the subsequent year. Also, optional monitoring of macroinvertebrates once per summer would help lake managers to assess the state of these communities, in particular those of the Impact sites and whether or not these communities are changing in structure to become more like the existing vegetated sites along the Reference bank. This extra monitoring is suggested as an option based on time and budget availability to build a more comprehensive picture of lake status but is less important than the core monitoring during the summer spawning period. The use of simple biodiversity indices (see Magurran, 2003) will allow managers to assess and compare changes in macroinvertebrate populations over space and between years. However, it is recognised that macroinvertebrate sampling is generally more logistically difficult than measuring water quality and requires space, time and expertise for the identification of species. As such, continued annual monitoring of this by LBBD staff may not be possible, and the costs of specialist consultant monitoring prohibitive. Guidance on sampling techniques is given in figure 10 but because this monitoring is optional, only very basic guidance on analysis of this data is given in figure 11.

The guidance is intended to be simple and easy to follow, as such it contains locations, timings and simple techniques, enabling different people to follow it whilst still collecting data in a consistent manner. Equipment and labour requirements were based on the general time taken and equipment needed during collection of the 2008 data. The suggested minimum four year period is based upon data from FishBase (2008) which states all species in Tom Thumb have an approximate turnover time of 1.4-4.4 years, except *Scardinius erythrophthalmus* which has a turnover of 4.5-14 years. Therefore, the 4 year monitoring recommendation is a compromise between ensuring all species have turned over and the associated costs. This is in line with Connell and Sousa (1983) who suggested that a system is self-sustaining after one natural turnover of population and Westman (1991) who stated that monitoring can assess whether short-term changes are on the correct trajectory towards the desired end-point. Continued monitoring after turnover would be useful in building a longer-term picture of Tom Thumb's status but this would have additional costs and so is only suggested as an option.

In addition to *in situ* monitoring of water quality, it is recommended that samples be taken for nitrate and phosphate analysis in the laboratory. These samples should be taken at the same locations mentioned above for temperature, pH and DO. By monitoring for these nutrients, managers will be able to assess whether the risk of eutrophication and algal blooms are increasing and enable them to enact any necessary preventative measures. Phosphate monitoring may be particularly important in the long-term as internal loading of this nutrient is thought to be responsible for a large number of lake restoration relapses (Søndergaard *et al*, 2007). As such, nutrient levels should be assessed against the previous year's data with the goal of maintaining or improving on current levels within the framework of the EA's GQA scheme. It is acknowledged that commercial laboratory analysis of water samples for nutrient levels may be costly and so a reduced number of samples may be necessary. It is recommended to have at least one round of nutrient sampling in the summer months when the risk of algal blooms and eutrophication are generally highest (Moss, 1988); winter monitoring of nutrients would be not be as important but could form part of the optional plan.

After quality data have been collected, they can be entered into an Excel spreadsheet to assess them against the water limits provided in Appendix B and the plots shown in figure 7. The managers can then use this framework to assess the status of the fishery and decide if any further action is required. The second section (figure 11) gives lake managers guidance on how to interpret the resultant water quality plots. Again, the guidance is written in a simple manner that should be easy to follow, allowing lake managers to draw conclusions and take appropriate action dependent on which section of the tolerance plots the water quality data fall in.

Values used in constructing the indicative costing table (figure 11) were taken from commercial retailers of specialist sampling equipment such as Alana Ecology (http://www.alanaecology.com/), cost of labour was estimated at £15 per hour and the cost of laboratory water analysis is the commercial rate charged by Cranfield Soils Laboratory (£8 per sample). This table shows that the recommended monitoring plan has a total estimated cost of £1491.25; this is around 1% of total project budget at £130 000 (RRC, 2006). This small monitoring budget (in percentage terms) agrees with the findings at the RRC conference (2006) because the Tom Thumb restoration is a relatively high budget project using established techniques. Figure 11 shows that the bulk of cost is accounted for by initial equipment outlay but this could be significantly reduced if this equipment is already available or if these costs are spread across other lake monitoring plans. The extra costs of optional monitoring are accounted for entirely by labour and sample analysis but even with these options, monitoring costs would still only account for a small percentage (around 2%) of total project budget.

TOM THUMB LAKE MONITORING GUIDELINES

Annual monitoring

Parameter	**Location**	**Timing**	**Technique**
Temperature	All IMP and REF sites (see map)	Monthly April to September, same time and day (*e.g.* 11am on the 15th of every month)	Use water quality probe, insert to 30% depth from surface, allow 1 minute for probe to stabilise and note values[1]
pH			
DO			
Nitrate	All IMP and REF sites		Calibrate nitrate meter with blank strip, wet strip and place in meter, wait 1 minute and note value[2]
Phosphate	All IMP and REF sites	Two samples over same period as above, take at same time as other samples	Following BS guidelines (BS ISO 5667-6:2005), fill 60ml sample bottle at 30% depth, refrigerate and send to laboratory for total P analysis

[1] Option to use either standard water quality probes or a combined multi-probe

[2] Option to also send nitrate samples to laboratory for analysis

Optional winter monitoring and for macroinvertebrates

Parameter	**Location**	**Timing**	**Technique**
Basic water quality (as Summer)	Repeat as for Summer monitoring during Winter months (October to March)		
Macroinvertebrates	All IMP and REF sites	One sample during April to September taken at same time as other samples	Using a 1mm net, sweep one metre either side of monitoring location and back over. Transfer sample to bucket, preserve with 95% ethanol and send to laboratory for identification

Equipment requirements (per monitoring round):

- Water quality meter with temperature, pH and DO probes
- Nitrate meter with test strips (optional, or send to laboratory)
- Two 60ml sample bottles per year for phosphorous samples
- 1mm net, 8 buckets and 95% ethanol for macroinvertebrate sampling (optional)

Labour requirements

- Approximately 2 hours per round for basic water quality monitoring
- Additional 2 hours for macroinvertebrate sampling (optional)

Recommended time frame:

- annual monitoring for a minimum four year period

Key:

- IMP = Impact sampling location
- REF = Reference sampling location

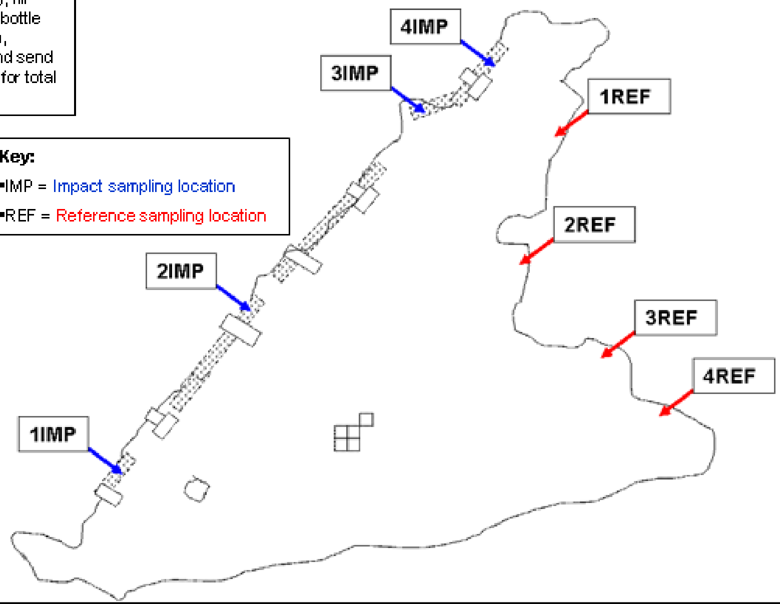

Figure 10 Proposed guidelines on monitoring of Tom Thumb Lake

TOM THUMB LAKE MONITORING ANALYSIS GUIDELINES AND INDICATIVE COSTING

Guidance on analysis of water quality

1. Input water quality data into Microsoft Excel and calculate mean and 95% confidence limits for each parameter across the whole Impact or Reference category for that specific date
2. Plot time series graphs of these mean and variance data relative to the summer threshold levels taken from the literature
3. If Winter data collected, substitute the Summer threshold values for Winter values
4. It is recommended that 95% confidence limits be re-calculated for newly collected data particularly when plotting Winter values as levels of variation are likely to change between seasons

Guidance on interpreting water quality data

1. Values plotted within the green zone are likely to be due to natural trends or variation and should not be of concern to lake managers
2. Values plotted within but not exceeding the yellow tolerance bands are approaching threshold levels but may still be doing so due to natural trends or variation. However, lake managers should be aware of potential problems and increase general visual surveillance of the lake
3. Values plotted in exceedance of the outer tolerance bands are beyond recommended levels for fish and are likely to indicate trends and potential significant impacts NOT due to natural variation. Lake managers should contemplate further monitoring to identify the cause and the likelihood of management action to prevent or repair damage to fish populations

N.B. Lake managers should be aware of any general trends in the data even if they do not enter or exceed threshold levels. Managers should also note that these thresholds only relate to the direct requirements of fish species and do not indicate the water quality in reference to the requirements of other organisms within the lake which may have indirect effects on fish populations

Analysis of macroinvertebrate data

Any macroinvertebrate samples taken should be sent to specialist laboratory for analysis to at least Family taxonomic level. Simple biodiversity measures can then be applied to this species/abundance data following guidance in standard texts. Suggested measures include: Shannon-Weiner (H), Berger-Parker dominance (D) which asses diversity at one point location. Sorensen's and Bray-Curtis similarity indices can be calculated to assess levels of similarity or difference between two or more sites or change over time. For guidance see Magurran (2003)

Indicative costing of monitoring

Initial equipment outlay	
Item	Cost (£)
Hand net	46.95
pH and temp meter	79.95
DO meter	483.95
60ml sampling container (pack of 100)	5.90
Gloves, other consumables	26.50
Total £	643.25
Labour costs	
Labour (2hrs @ £15 per hour per monitoring round)	30.00
Total labour per year £	180.00
Lab analysis costs	
Nitrate (2 per year @ £8 per sample)	16.00
Phosphorous (2 per year @ £8 per sample)	16.00
Total analysis per year £	32.00
TOTAL ANNUAL COST £	426.42
(assume 6 rounds of monitoring, 2 lab analyses, and	
split cost of equipment over 4 year period)	
TOTAL CORE COST FOR 4 YEAR PLAN £	**1491.25**
Optional monitoring	
Labour (2hrs @ £15 per hour per monitoring round)	30
Nitrate (2 per year)	16
Phosphorous (2 per year)	16
optional cost for 4 year plan £	976
(assume 6 rounds of monitoring and 2 lab analyses	
per year over 4 year period)	
TOTAL CORE AND OPTIONAL COST FOR 4 YEAR PLAN £	**2467.25**

Figure 11 Proposed guidelines on the analysis of monitoring data and indicative costing for core and optional monitoring requirements

6.2 Further work

A second monitoring plan of similar intensity to that already conducted is recommended after 3 to 5 years. This can be done to assess the general status of the fishery after fish, macroinvertebrate and macrophyte communities have had time to establish; generally considered to be after populations have had the chance to naturally turnover at least once (Connell and Sousa, 1983). By conducting a second, intensive survey, the relative success of the project in the medium to long-term can be assessed, when compared to this initial survey and the intervening yearly monitoring. In addition to this survey, a summary of issues faced by the fishery, any failings or successes of the project and any lessons learnt should be acknowledged and shared with the wider restoration ecology community. This is particularly important as the Tom Thumb restoration was intended to act as a pilot for future projects helping the EA to achieve its goals of promoting sustainable fisheries (LBBD, 2006 and EA, 2006).

In addition to the repeat of intensive summer monitoring, it would also be useful to conduct an electrofishing or net survey of fish population structure. Doing this will allow lake managers to directly assess the age structure of fish populations and evaluate whether or not the restoration has been successful in encouraging natural recruitment. Large numbers of fry or young fish would likely indicate successful recruitment. Conversely, populations heavily dominated by older, large individuals would indicate recruitment is poor or absent, described by North (2002) as a "*recruitment bottleneck*". Directly assessing fish populations would be more useful for evaluating the ecological success of the restoration than using proxy measures, such as water quality or macroinvertebrate sampling.

It is also suggested that continued surveying of anglers at Tom Thumb take place. This would be useful in assessing whether the initial response to the restoration was maintained in the medium to long-term. Also, an extended survey could assess the effectiveness of the “have a go” sessions and accessible platforms in recruiting new anglers, particularly those from priority groups. Such data would be a useful justification for the EA, LBBD and other public bodies for capital expenditure on similar projects (Carter, pers. comm., 2008).

Based on this further work and the intervening monitoring, success can be judged if:

- water quality is consistently within the threshold limits specified allowing fish to naturally recruit
- macroinvertebrate communities in Impact sites have converged towards Reference levels
- vegetation in Impact sites has been protected from wildfowl grazing allowing considerable macrophyte stands to have developed
- fish surveys show a good range of ages, sizes and species within the fishery indicating high levels of natural recruitment
- surveys of anglers demonstrate sufficient numbers using the lake to generate revenue
- angler demographics demonstrate new anglers and those from priority groups are using the lake

6.2.1 Applications for other lakes

The concept of water quality threshold limits for fish communities could be adapted to other water bodies, altering tolerance levels based on the requirements of species present. For example, a solely carp-based fishery would have much broader thresholds than that of Tom Thumb. By constructing these threshold limits for other fisheries, comparisons can be made between their performance and capacity to be self-sustaining. Broadening the literature search to include more UK coarse fish species would allow fishery managers to pick and choose the appropriate species and construct bespoke thresholds for each water body.

A preliminary review of literature found this multi-species lake specific approach to water quality thresholds to be a new idea. Similar approaches were found for intensive aquaculture systems (*e.g.* Tucker, 1991) but these differ in that they are usually concerned with one species in a more readily controlled environment. Additionally, the EU Freshwater Fish Directive (78/569/EEC) stipulates water quality targets for fisheries broadly separated into Salmonid and Cyprinid categories and not based on species specific requirements. Tailoring water quality thresholds to specific water bodies would allow appropriate targets to be set, relative only to those species concerned.

6.3 Refining the threshold approach

Further research of published fish tolerances to water quality parameters could be conducted to refine the threshold band approach to include the various optimal ranges for growth, feeding and reproduction within Incipient Lethal Levels (Wootton, 1998). This research could also attempt to account for the controlling and limiting effects that water quality can have on fish and their potential combined effects (Fry, 1971). By refining the system thus, lake managers may be able to not only ensure the fishery is capable of being self-sustaining but also to optimise water quality to within narrower ranges to maximise fishery performance. Also, further research into the water quality requirements of other lake organisms (namely vegetation and macroinvertebrates) could be conducted to ensure that water quality meets the needs of all aspects of the lake system, not just the fish.

6.4 The possible effects of climate change

Jeppesen *et al* (2007) present a review of the likely impacts of climate change on shallow lakes. They propose a number of alternative states under a warmer climate but in general water quality will decrease. This could be due to enhanced phytoplankton growth, reduced capacity of macrophytes to maintain clear water, an increase in smaller omnivorous fish feeding on zooplankton and an increased growing season for phytoplankton. Because of these reasons, they state that climate change must be considered by all lake managers when setting future targets, particularly with reference to critical nutrient loads.

7 CONCLUSIONS

The Tom Thumb Lake restoration project has one beneficial feature that many other such projects lack, namely well defined, achievable goals. Although it is much too early to draw robust conclusions on the success of the restoration, initial monitoring appears to suggest that the project is on the correct trajectory towards achieving its objectives. Baseline monitoring shows that water quality is within the threshold limits for the fish species of the fishery and if maintained this will not prove to be a constraint on fish recruitment. Macroinvertebrate sampling demonstrated noticeable differences between Reference and Impact sites. This means that successful establishment of vegetation will lead to improved macroinvertebrate communities in the lake as a whole as Impact sites converge towards Reference conditions. Unfortunately, no analysis of angler survey data could be carried out but it is hoped these data will show a good proportion of new and priority group anglers using the Lake, helping towards achieving the Angling 2015 goals.

Although the fish water quality threshold system is not a comprehensive indicator of fishery health, it represents a simple and hopefully useful tool for lake managers. This system coupled with the monitoring guidelines will allow lake managers to continually assess lake status, with regards to fish requirements, and actively manage any potential problems. Continued monitoring over the coming years will begin to paint a picture of the long-term sustainability of Tom Thumb Lake. Hopefully this monitoring will show a good standard of water quality maintained, improved macroinvertebrate and macrophyte communities and a diverse range of anglers using the Lake. Regardless of whether or not the project is successful in meeting its objectives, the continued monitoring will allow valuable lessons to be learnt and shared, helping to improve the science of restoration ecology.

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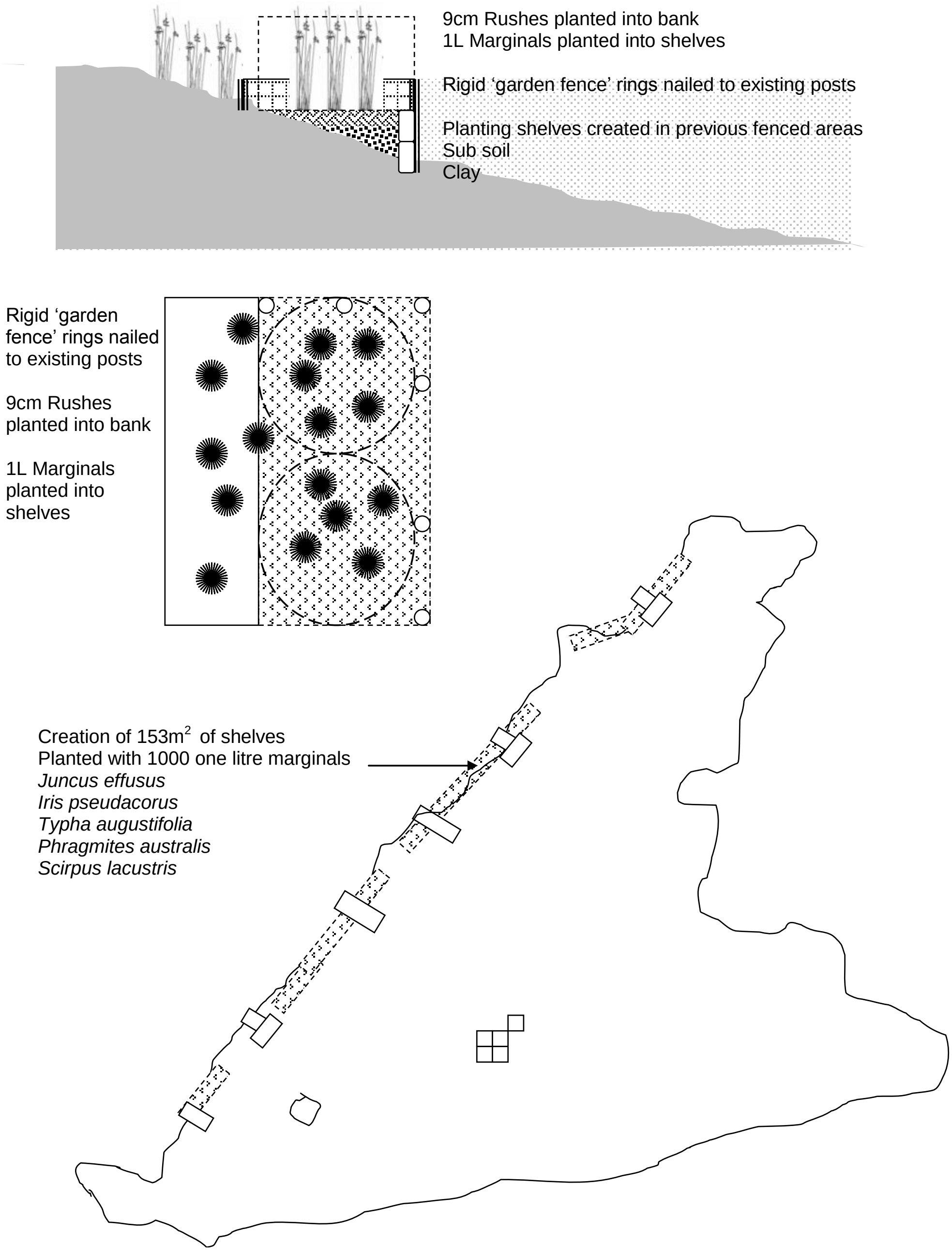
9 APPENDICES

9.1 Appendix A: Aquatic planting plan

Supplied by Trust for Urban Ecology through Patrick West (pers. comm., 2008); total cost £8300.



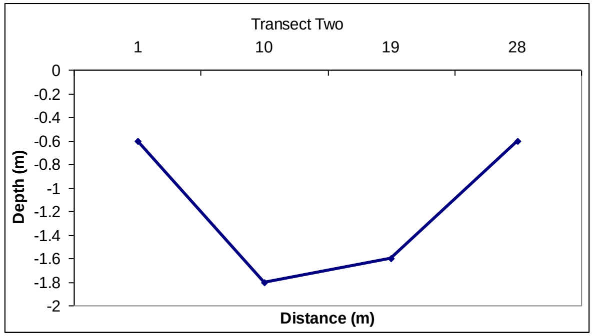
9.2 Appendix B: Fish species water quality tolerances from literature

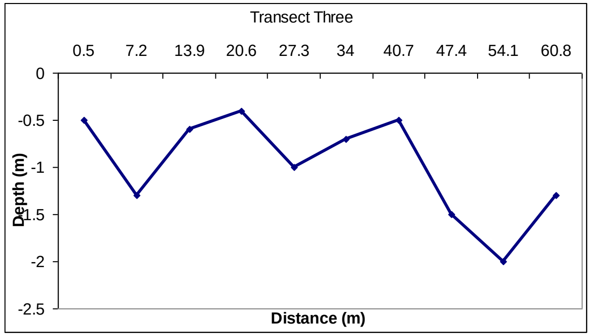
Parameter and data source

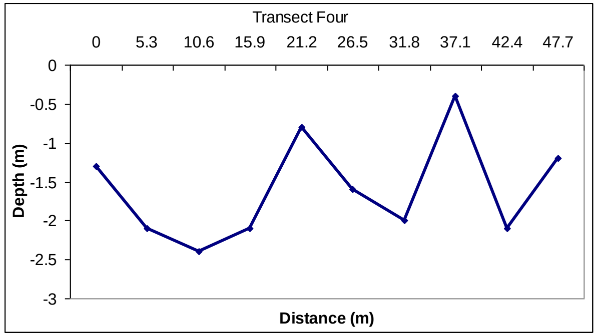
SPECIES	Temperature		pH
Tinca tinca	no ovarian development below 10ºC (Breton *et al* , 1980) peak growth at 24-30ºC (Backiel, 1986) tolerated range 16.5-31ºC upper avoidance 26ºC (Coutant, 1977)	Upper level 9 from ECOFRAME moderate level (Moss *et al* , 2003)	no survival of eggs below pH 4.75 (Duis, 2001)
Perca fluviatilis	24ºC optimum growth for Yellow Perch chronic stress above 28ºC (Tidwell *et al* , 1999) overall range 0-29.7ºC for Yellow Perch (Hart, 1947) upper avoidance 28.5ºC (Coutant, 1977) high egg mortality below 8 and above 12ºC (Guma'a, 1978)		59% egg mortality at pH 4.5 no egg hatching at pH 3.5 (Rask, 1983)
Carassius carassius	0-38.5ºC+ (Hellawell, 1986)		
Scardinius erythrophthalmus	upper avoidance 28.5ºC (Coutant, 1977) 2-22ºC (FishBase, 2008)		same as per *Rutilus rutilus* (other *Cyprinid*)
Rutilus rutilus	can survive temps between 4-30ºC (Hardewig and van Dijk, 2003) for 5-20cm prefer 27ºC, avoid 28.5ºC (Countant 1977) growth ceases below 12ºC temperatre rise study, acclimated Roach can survive up to 33.5ºC (Cocking, 1959)		significant fall (50%) in reproduction below pH 5.6 almost no reproduction below pH 4.6 (Johansson and Milbrink, 1976)

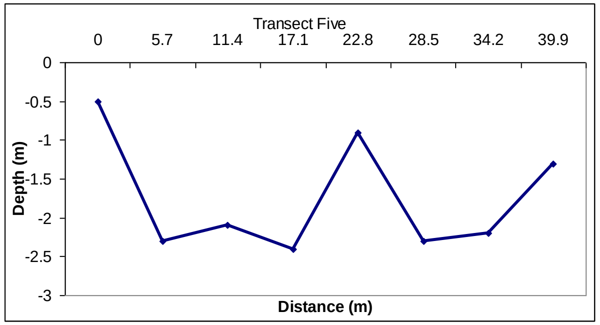
SPECIES	DO	N	P
Tinca tinca	7.5cm fish 50% survival at 0.2-0.4mg/l at 10-16ºC (Doudoroff and Shumway, 1970)	20mg/l from EA GQA Grade 3 Moderate (EA, no date)	100µg/l from EA GQA Grade 3 Moderate (EA, no date)
Perca fluviatilis	fingerling 100% death, 0.7-19mg/l at 10-20ºC (Doudoroff and Shumway, 1970) Yearling 100% death at 0.4-0.9mg/l at 11-24ºC (Doudoroff and Shumway, 1970_ Adult lower limits at 0.4mg/l (15ºC) and 1.4mg/l (25ºC) (Doudoroff and Shumway, 1970)		
Carassius carassius	Very anoxia tolerant, can survive days to months depending on temperature can survive 0mg/l for 2 months at 5ºC (Doudoroff and Shumway, 1970)		
Scardinius erythrophthalmus	same as per *Rutilus rutilus* (other *Cyprinid*)		
Rutilus rutilus	50% deaths at 0.4-1.2mg/l for 10cm fish at 10-20ºC for 7 days (Doudoroff and Shumway, 1970) adult fish 100% death at 0.1-0.4mg/l at 0-10ºC (50% death at 0.4-2.2mg/l at 15-25ºC (Doudoroff and Shumway, 1970)		

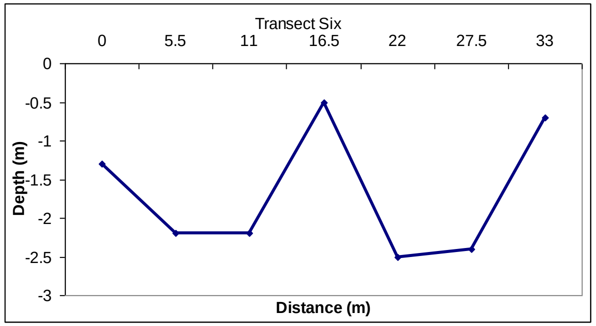
9.3 Appendix C: Depth transect plots











9.4 Appendix D: Raw macroinvertebrate data

First repeat 11/06/2008

INV1REF				
Species	Description	Abundance		
8. Cladocera		numerous	Number of species:	10
6. Corixidae	2 spp?	10	Total individuals:	49
3. Gammaridae		12	Chao (quantitative)	10
1. Chironomidae		3	Shannon-Weiner (H)	1.75
9. Asellidae	4 pairs legs?/2 tails	1	Simpson Index (D)	4.74
11. Astacidae		1		0.31
12. Tricladida	suckers?	1	McIntosh U	22.52
7. Lymnaeidae	right handed	15	McIntosh E	0.79
14. Physidae	left handed	5		
15. Argyroneta aquatica	water spider	1		

INV2REF				
Species	Description	Abundance		
1. Chironomidae		4	Number of species:	7
3. Gammaridae		3	Total individuals:	25
4. Oligochaeta	true worm	1	Chao (quantitative)	7
5. Diptera pupa	wing cases	1	Shannon-Weiner (H)	1.45
6. Corixidae	2spp?	12	Simpson Index (D)	3.34
7. Lymnaeidae	no operculum	4	Berger-Parker Dominance	0.48
8. Cladocera		numerous	McIntosh U	13.67
			McIntosh E	0.73

INV3REF				
Species	Description	Abundance		
1. Chironomidae		8	Number of species:	7
6. Corixidae		12	Total individuals:	27
3. Gammaridae		3	Chao (quantitative)	9
4. Oligochaeta		1	Shannon-Weiner (H)	1.40
7. Lymnaeidae		2	Simpson Index (D)	3.27
19. Hydracarina		1	Berger-Parker Dominance	0.44
8. Cladocera		numerous	McIntosh U	14.93
			McIntosh E	0.72

INV4REF				
Species	Description	Abundance		
6. Corixidae		5	Number of species:	8
3. Gammaridae		3	Total individuals:	24
1. Chironomidae		12	Chao (quantitative)	8
4. Oligochaeta		1	Shannon-Weiner (H)	1.46
14. Physidae		1	Simpson Index (D)	2.81
5. Diptera pupa		1	Berger-Parker Dominance	0.50
17. Hirudinidae		1	McIntosh U	13.49
8. Cladocera		numerous	McIntosh E	0.68

INV1IMP				
Species	Description	Abundance		
6. Corixidae		7	Number of species:	6
10. Haliplidae	beetle? Whirlygig?	2	Total individuals:	25
3. Gammaridae		3	Chao (quantitative)	6.5
18. Coleoptera	beetle?	1	Shannon-Weiner (H)	1.29
7. Lymnaeidae		12	Simpson Index (D)	3.02
8. Cladocera		numerous	Berger-Parker Dominance	0.48
			McIntosh U	14.39
			McIntosh E	0.72

INV3IMP				
Species	Description	Abundance		
14. Physidae		3	Number of species:	6
7. Lymnaeidae		2	Total individuals:	47
1. Chironomidae		4	Chao (quantitative)	6
3. Gammaridae		2	Shannon-Weiner (H)	0.86
6. Corixidae		36	Simpson Index (D)	1.66
8. Cladocera		numerous	Berger-Parker Dominance	0.77
			McIntosh U	36.46
			McIntosh E	0.38

INV4IMP				
Species	Description	Abundance		
6. Corixidae		4	Number of species:	4
1. Chironomidae		2	Total individuals:	7
20. Planorbiidae	ramshorn	1	Chao (quantitative)	4.5
8. Cladocera		numerous	Shannon-Weiner (H)	0.96
			Simpson Index (D)	2.33
			Berger-Parker Dominance	0.57
			McIntosh U	4.58
			McIntosh E	0.69

Second repeat 28/07/2008

INV1REF				
Species	Description	Abundance		
8. Cladocera		280	Number of species:	10
6. Corixidae		97	Total individuals:	474
3. Gammaridae		9	Chao (quantitative)	10.5
1. Chironomidae		3	Shannon-Weiner (H)	0.96
4. Oligochaeta		1	Simpson Index (D)	2.48
17. Hirudinidae		2	Berger-Parker Dominance	0.59
12. Tricladida		3	McIntosh U	300.90
7. Lymnaeidae		40	McIntosh E	0.53
21. Ephemeroptera	mayfly nymph	8		
14. Physidae		31		

INV2REF				
Species	Description	Abundance		
1. Chironomidae		9	Number of species:	9
3. Gammaridae		4	Total individuals:	503
12. Tricladida		1	Chao (quantitative)	9
21. Ephemeroptera		9	Shannon-Weiner (H)	0.71
6. Corixidae		37	Simpson Index (D)	0.59
7. Lymnaeidae		5	Berger-Parker Dominance	0.83
8. Cladocera		420	McIntosh U	422.21
14. Physidae		17	McIntosh E	0.24
10. Haliplidae		1		

INV3REF				
Species	Description	Abundance		
1. Chironomidae		8	Number of species:	10
6. Corixidae		22	Total individuals:	544
3. Gammaridae		9	Chao (quantitative)	10.5
17. Hirudinidae		2	Shannon-Weiner (H)	0.59
7. Lymnaeidae		5	Simpson Index (D)	1.28
14. Physidae		8	Berger-Parker Dominance	0.88
8. Cladocera		480	McIntosh U	480.80
12. Tricladida		1	McIntosh E	0.17
21, Ephemeroptera		4		
22. Zygoptera		5		

INV4REF				
Species	Description	Abundance		
6. Corixidae		41	Number of species:	10
3. Gammaridae		21	Total individuals:	575
1. Chironomidae		1	Chao (quantitative)	14.5
7. Lymnaeidae		4	Shannon-Weiner (H)	0.82
14. Physidae		23	Simpson Index (D)	1.54
22. Zygoptera		2	Berger-Parker Dominance	0.80
17. Hirudinidae		1	McIntosh U	463.37
8. Cladocera		460	McIntosh E	0.28
9. Asellidae		1		
21. Ephemeroptera		21		

INV1IMP				
Species	Description	Abundance		
6. Corixidae		25	Number of species:	6
14. Physidae		1	Total individuals:	117
21. Ephemeroptera		1	Chao (quantitative)	6
23. Notonectidae		1	Shannon-Weiner (H)	0.91
7. Lymnaeidae		9	Simpson Index (D)	1.93
8. Cladocera		80	Berger-Parker Dominance	0.68
			McIntosh U	84.31
			McIntosh E	0.47

INV2IMP				
Species	Description	Abundance		
14. Physidae		12	Number of species:	8
7. Lymnaeidae		11	Total individuals:	165
17. Hirudinidae		2	Chao (quantitative)	12.5
19. Hydracarina		1	Shannon-Weiner (H)	0.98
6. Corixidae		17	Simpson Index (D)	1.82
8. Cladocera		120	Berger-Parker Dominance	0.73
18. Coleoptera		1	McIntosh U	122.32
21. Ephemeroptera		1	McIntosh E	0.40

INV3IMP				
Species	Description	Abundance		
6. Corixidae		53	Number of species:	11
1. Chironomidae		1	Total individuals:	182
14. Physidae		6	Chao (quantitative)	11
8. Cladocera		80	Shannon-Weiner (H)	1.53
3. Gammaridae		10	Simpson Index (D)	3.40
7. Lymnaeidae		12	Berger-Parker Dominance	0.44
18. Coleoptera		1	McIntosh U	98.74
9. Asellidae		1	McIntosh E	0.65
4. Oligochaeta		1		
21. Ephemeroptera		1		
22. Zygoptera		16		

INV4IMP				
Species	Description	Abundance		
4. Oligochaeta		1	Number of species:	6
17. Hirudinidae		1	Total individuals:	27
1. Chironomidae		2	Chao (quantitative)	8.25
3. Gammaridae		1	Shannon-Weiner (H)	0.97
6. Corixidae		2	Simpson Index (D)	1.77
8. Cladocera		20	Berger-Parker Dominance	0.74
			McIntosh U	20.27
			McIntosh E	0.42