Investigating the effect of low head micro-hydropower on river aquatic fauna.

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Statistical analysis and calculations were done using Microsoft Office Excel 2007. Maps used were from Edina Digimap.

Abstract

The aim of this project was to determine if micro-hydropower (MHP) is affecting river aquatic fauna. MHP is objected to because it is thought to kill fish. These objections are based on the effect of large hydropower. The Environment Agency are also currently undergoing a consultation reviewing the amount of water that can be used by MHP, the proposals will render MHP financially unviable.

Installers and owners of MHP claim that river fauna is not affected and that MHP may be beneficial. This study tests the claim that MHP is beneficial to aquatic fauna, improves water quality and to determine any problems for movement of fauna up and downstream.

Invertebrates were sampled upstream and downstream of three MHP schemes. The samples were used to calculate diversity using the Simpson Index and as an indicator of water quality using the British Monitoring Working Party, average score per taxon. At one MHP site the results of this study were compared to a pre-installation study and other post installation data to determine if there had been an effect on the invertebrates since the MHP installation.

It was found that at the sites sampled, invertebrate diversity was significantly improved downstream of all the MHP sites, there was no significant difference in water quality downstream of the MHP sites and that historical data varied each year showing no correlation to the MHP installation . It was concluded that the built environment associated with MHP provides many habitats, improving diversity but may not improve water quality. Currently, standard rules are applied to the amount of water that can be used by MHP and what must be installed to protect fauna. It is recommended that each MHP site is assessed individually.

Declaration

No part of this thesis has been submitted in support of an application for any degree or qualification of the Keele University or any other University or Institute of learning.

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1 Introduction

1.1 Background

Greenhouse gas emissions are acting to warm the planet, causing climate change which has implications for all life on earth. In 1997 the Kyoto Protocol required the major industrial nations to reduce greenhouse gas emissions by 12.5% of 1990 levels by 2012. The European Commission in 2006 reiterated this with Directive 2003/87/EC and in the UK the 2008 Climate Change Act set the goal of reducing greenhouse gas emissions by 80% below 1990 levels by 2050 (DECC, 2012a).

The main source of greenhouse gases is the burning of fossil fuels most of which is used to generate electricity (DECC, 2013a). In the UK coal fired power stations are being decommissioned and replaced with gas power stations which produce half the CO_2 emissions of coal (Parliamentary Office of Science and Technology, 2006) but most of this gas must be imported (DECC, 2011). This has implications for our electricity supply because gas is purchased in international markets and is therefore susceptible to price volatility, may be used strategically by terrorists and must be piped across Europe along a network of leaky pipes or shipped from Qatar along a route prone to piracy (DECC, 2011; US Energy Information Administration, 2012; Phillips *et al.,* 2013). MHP provides a means to contribute to the transition from using fossil fuels for electricity generation to producing electricity locally, cleanly, securely and renewably.

Hydropower is the generation of electricity using moving water to drive a turbine. Large and small hydropower stores water in a reservoir behind a dam. The turbines are situated in the dam and the water is allowed through when electricity is needed. Conversely micro-hydropower (MHP) impounds river water behind a weir, diverting a proportion of the flow via a leat to a turbine, the rest of the water continues downstream over the weir. MHP is further divided into low head and high head. High head MHP takes water from high in a catchment and pipes it down using gravity to a turbine at the bottom of a catchment, this form of MHP is not within the scope of this study as the steep gradients needed for such installations act as a natural barrier to river fauna. Low head MHP is usually installed in former water mills

Since the introduction of the Feed-in Tariff (FIT) in the UK in April 2010 (DECC, 2012b), there has been a six fold increase in the installation of MHP in England and Wales (Environment Agency, 2011). MHP has less of a visual impact on the environment than other types of renewable electricity generation e.g. wind turbines (Boyle, 2004), produces large amounts of electricity in comparison to photovoltaic panels (Boyle, 2004; Paish, 2009), has the lowest carbon emissions of any method of electricity generation

(Parliamentary Office of Science and Technology, 2006) and schemes can distribute electricity locally negating the need for pylons (Olsson, 2012).

MHP however has its objectors. Wildlife conservation groups and anglers are concerned that MHP and the associated weir are detrimental for fish (Angling Trust, 2011, Rivers Network, 2011). Weirs fragment fish populations and hinder migration, turbines are considered to kill and harm fish and diverted water courses and altered flow regimes change habitats. Many of the objections cite evidence from large and small hydropower (British Hydropower Association, 2011) where the river is dammed, flow is intermittent and fish can pass through the turbines. MHP is sometimes compared to large and small hydropower when the environmental impacts will differ.

The Environment Agency (EA) under the Water Framework Directive must legally improve the ecological status of rivers (Environment Agency, 2012). To determine this status many measurements are taken and the lowest indicator is then used to classify the river (Cunningham, 2012). The EA therefore insist that when MHP is installed weirs are improved with a fish pass, turbine intakes and outflows are screened, turbine operation is halted when fish are migrating, water flow is slow enough at the intake to allow fish to swim away and the leat has a return channel to allow impounded fish to escape.

Consultants, owners and suppliers of turbines argue that MHP may be beneficial to wildlife by filtering rubbish and detritus, enhancing part of the river habitat by impounding sediment, providing a range of habitats that were formerly not suitable for aquatic wildlife and aeration of the water by the weir and the turbine.

Several MHP turbines have been installed along the River Frome, Somerset and one of its tributaries the River Mells – providing an opportunity to test the claimed environmental benefits of MHP.

Oxygenated, clean, clear water provides ideal conditions for healthy and balanced river ecosystems that are biologically diverse. Invertebrates can only be present in abundance if the micro-organisms, plants and animals below them in the food chain are abundant. Conversely the invertebrates are themselves predated by animals further up the food chain. Invertebrates are commonly used as indicators of water quality because they are ubiquitous, sampling equipment is simple and cheap, they are easily sampled and identified, knowledge of their tolerance to pollution is extensive and populations quickly respond to environmental changes (Jeffries & Mills, 1990).

1.2 Research aim and objectives

1.2.1 Aim

To determine if there is an observable difference in the diversity of invertebrates and biological water quality as indicated by the benthic invertebrate population caused by the presence of low head micro-hydropower (MHP).

1.2.2 Objectives

Objective 1: Compare the biodiversity of populations of invertebrates upstream and downstream of MHP installations using the Simpson Index.

Objective 2: Evaluate the biological water quality using the British Monitoring Working Party (BMWP), average score per taxon (ASPT).

Objective 3: Compare the ASPT and Simpson Index at Tellisford Mill to two previous studies.

Objective 4: Assess each location for potential problems for fish movement and sources of pollution, using a visual evaluation and knowledge gained from the literature review.

Objective 5: Formulate recommendations for further research.

1.2.3 Hypothesis to be tested

There is no difference in invertebrate diversity and water quality as indicated by the invertebrates downstream of MHP.

1.3 Value of research

During the first half of 2013 the EA conducted a consultation regarding MHP and water abstraction (Environment Agency, 2013a). In July 2013 the EA proposed changing the current guidelines, resulting in a reduction of the amount of water to be used by a turbine which could render schemes uneconomical to develop (Micro Hydro Association, 2013). The Micro Hydro Association (MHA) and the British Hydropower Association (BHA) are requesting that there is no change to the current rules for water abstraction, arguing that there is no scientific evidence to suggest that MHP is damaging to river ecology. This study will start to provide a scientific basis for a dialogue between all stakeholders to ensure the installation of wildlife sensitive MHP.

2 Literature Review

MHP in the UK is defined as electricity generation up to 50 kW (DECC, 2013b), in most other countries it is defined as less than 100 kW (Moreire & Poole, 1993). Any legislation or guidelines used in this literature review refer to England and Wales only. Typical mill structures are illustrated in Figure 1.

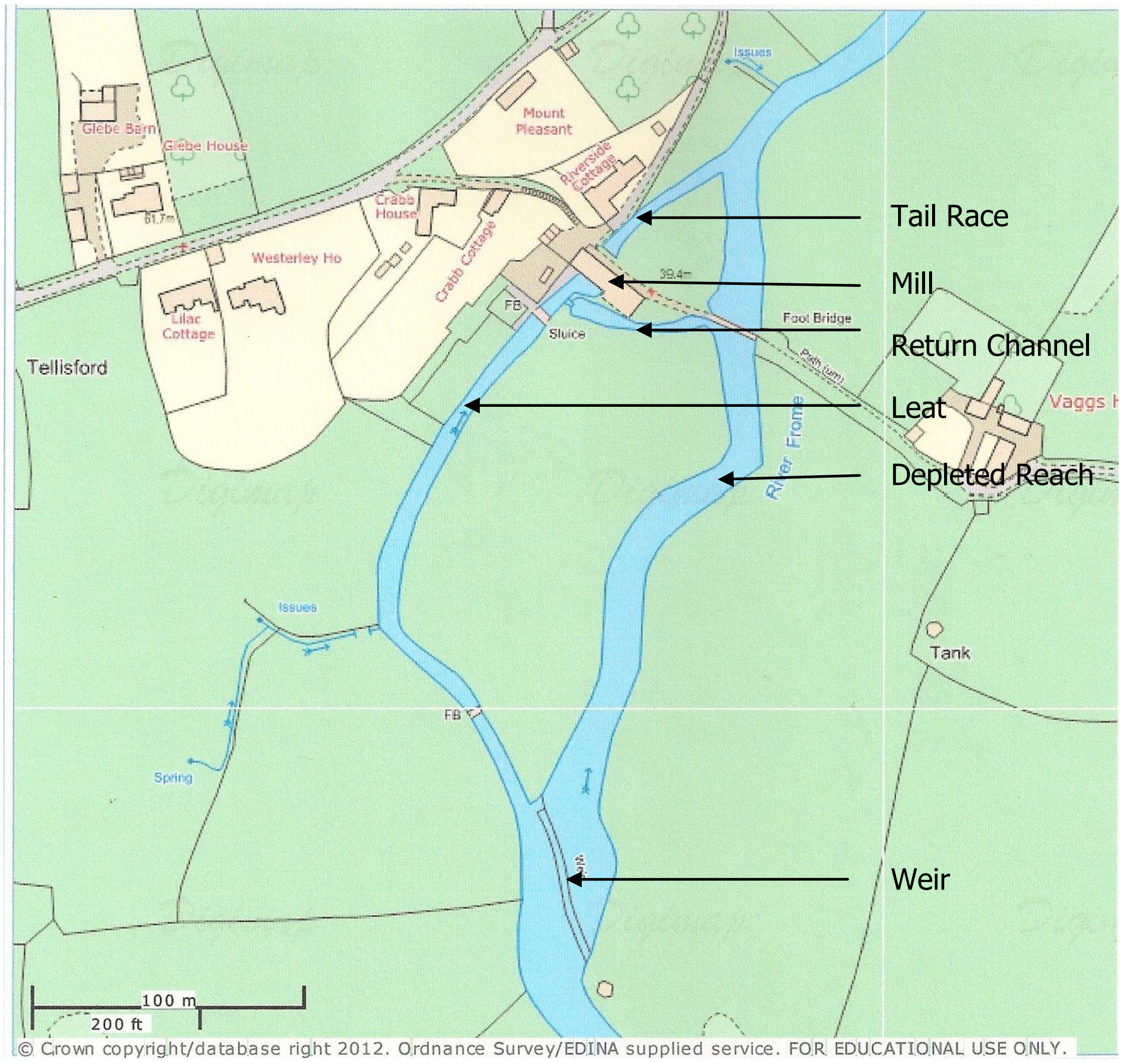

Figure 1: A Typical Water Mill/MHP Site, River Frome, Somerset (Edina, 2013).

In the process of reviewing the literature the differing definitions of hydropower needed to be taken into account and studies that were biologically focused may have omitted the size of the hydropower, making like for like comparisons difficult. It was necessary to determine if the installation included a weir or a dam. There is a large body of research into the effect of dammed hydropower on aquatic fauna, of these impacts obstacles to fish migration and movement and changes in sedimentation and water flow are applicable to MHP. The impacts of MHP will differ from dammed hydropower in that a reservoir is not created, the obstacles are smaller and less complex, fish do not pass through the turbine, water flow is not determined by the need for electricity and the flow of the river and the associated built environment is different.

Studies into turbine passage of fish are not relevant to MHP because turbine intakes and outflows are screened. The mesh size of the screen is specific to the turbine type. Fish passage through a Crossflow turbine may lead to death (Dubois & Gloss, 1993) screen mesh size is therefore 6 mm (Environment Agency, 2012). Archimedes screws require a screen to stop trash only from entering; most species of fish can pass through safely. However eels are prone to injury from the leading edge of the screw and it is therefore fitted with a bumper (Kibel *et al.*, 2009). Turbine passage studies are therefore not comprehensively reviewed, but to summarise, it is found that fish can be killed, injured, distressed or disoriented when passing through a turbine due to blade strike, barotrauma, cavitation and turbulence. Survival rates are determined by the turbine type, and the age and species of fish.

2.1 Micro-hydropower and its effect on river aquatic fauna

Prior to a MHP installation the built environment is usually neglected. Behind weirs, leats and tail races are silted and anoxic with unfavourable pH (Santucci *et al.* 2005) and accumulated toxins (Davies *et al.*, 1998; Brekhovskikh *et al.*, 2002; Wildi *et al.* 2004; Kövecses & Marcogliese, 2005; Wang *et al.*, 2008; Colas *et al.*, 2011, 2013).

2.1.1 Weirs

It is claimed by anglers and wildlife conservation groups that weirs are detrimental for fish (Anglers Trust, 2011; Rivers Network, 2011) this is not always the case. Salmon have been seen to leap weirs (Teme Weir Trust, 2013), migration may not be significantly affected (Smith *et al.,* 1997) and weir pools and riffle areas between weirs can be advantageous for Brown Trout (Fjellheim & Raddum, 1996). The height of the weir does not determine if it is passable or not, other factors are involved; flow, water temperature, fish species and size and water depth pre and post the weir (Ovidio & Phillipart, 2000; Larinier, 2001). Weirs can result in salmonids laying eggs in suboptimal sites. These sites are imprinted in the young creating a year on year decline in reproductive success (Gosset *et al.*, 2006). Other reasons for fish decline are discussed in the context that they are exacerbated by weirs. The concentration of fish in weir pools makes them vulnerable to predation by otters (Aarestrup & Koed, 2003) and anglers (Karppinen *et al.*, 2002). Resident fish (i.e. not migratory) populations can become fragmented by a weir, upstream populations become depleted due to passive downstream migration, which cannot be compensated by fish moving back upstream (Meldgaard *et al.,* 2003; Robson *et al.,* 2011). This leads to less genetic diversity, increased susceptibility to disease and extirpation (Meldgaard *et al.,* 2003). Larger fish of a species may be able to overcome some weirs which can result in age class interbreeding, again leading to a decline in genetic diversity (Taggart *et al.*, 2001).

Freshwater mussels have been found to become depleted due to weirs restricting the movement of the fish species they rely on for distribution (Brainwood *et al.,* 2008) and weirs without passes have been found to restrict the movement of crustaceans (Herke *et al.,* 1992). Other studies found that weirs changed zooplankton and invertebrates assemblages, but not necessarily size of populations (De Ruyter Van Steveninck *et al.,* 1990; Pollard & Reed, 2004; Fjellheim *et al.*, 1989; Poulet, 2007; Komolafe & Arawomo, 2008; Butler & Wahl, 2011).

Studies do not consider weir design in relation to movement of fauna or how future extreme weather may change the environmental impact of weirs (Whitworth et al., 2012).

A cheaper alternative to weir improvement is weir removal (Garcia de Leaniz, 2008) and some argue that weirs should be removed (Rivers Network, 2011). Weirs associated with MHP are part of historical mill complexes and have been *in situ* for many centuries, they are of historical importance and for this reason removal is not permitted. Therefore weir removal is not comprehensively reviewed but to summarize, some studies found that weir removal was beneficial due to the recreation of former river habitats (Garcia de Leaniz, 2008; Im *et al.*, 2011). These studies only looked at key species of fish not the whole fish assemblage, other fish species have been found to decline (Fjeldstad *et al.,* 2012). The removal of a weir may have other unintended consequences (Thomson *et al.*, 2005), the modern environment is different to when weirs were built. There are now good reasons to keep weirs e.g. flood control and water storage (Olsson, 2012), weir removal must be considered case by case (Rickard *et al.,* 2003).

2.1.2. Fish ladders/fish ways/fish passes

The EA have a statutory duty under the Water Framework Directive to ensure that when MHP is installed it includes improvements to the weir that allow fish passage. It is commonly quoted that the weir improvements associated with MHP allow access to upstream reaches although this exclusively refers to fish (Anglers Trust, 2011, Rivers Network, 2011).

Studies in this area have found this to be incorrect (Jungwirth, 1996; Makrakis *et al.* 2011; Ordeix *et al.*, 2011; Prchalova *et al.* 2011; Fjeldstad *et al.*, 2012). All these studies found that not all species of fish or all ages of species of fish use passes. Studies concentrate on Figurehead species and conclusions can be made that a pass is satisfactory because e.g. Salmon are using it without accounting for other fish species. Grayling a culturally important fish in Denmark, is found not to use passes and restocking upstream reaches with locally sourced, genetically diverse fish is recommended (Jungwirth, 1996). The installation of multiple passes allowing all fish species to negotiate the weir has been suggested (Boubee and Williams, 2006) this however would be very expensive and may make the MHP uneconomical to install (Duley, pers. comm. 2012)[1].

The few studies that have looked at invertebrate use of passes conclude that they restore natural movement up and downstream (Thiele *et al.,* 1998, Luederitz *et al.,* 2013).

2.1.3 Altered flow and water diversion

The turbine operation depends on diverted water flow via leats. The EA guidelines require that the amount of water that flows over the weir must maintain sufficient flow in the depleted reach. These guidelines may be changed depending on the substrate of the river, the fish species present and the length of the depleted reach. These stipulations are currently being reviewed by the EA with a decision due later in 2013 (Environment Agency, 2013a).

Research shows that plants, invertebrates and fish assemblages in the depleted reach are changed (Morgan *et al.,* 1991; Eglund and Malmqvist, 1996; Wood *et al.*, 2000; Bunn and Arthington, 2002; McIntosh *et al.,* 2002; Dewson *et al*., 2007a; Konrad *et al.*, 2008). These studies, whilst relevant, do not cite hydropower as the reason for the altered flow regimes, but are referred to when assessing the environmental impact of a proposed installation (Tiplady, 2006; Elvey, 2009). A long term study looking specifically at MHP found a change in invertebrate assemblages in the depleted reach but concluded that the change was not detrimental to the ecological status of the river (Aftergood & Damary-Homan, 2013). Fish biomass and numbers in the depleted reach in this study were found to increase although different species responded differently.

It has been found that some fish species migrate at night suggesting that reducing flow of water through turbines at night when less electricity is required may aid fish passage (Long, 1968).

The outflow from the tail race could attract migratory fish away from the main stem of the river (Giske *et al.*, 1998), this effect may be more pronounced on small rivers (Robson *et al.*, 2011). The outflow from the tailrace should ideally be placed near the fish pass, however in many cases this is not possible (O'Connor *et al.*, 2006).

William Duley, Director, Neen Sollars Community Hydro[1]

Previous studies detailed above do not consider the habitats created by MHP. Fauna populations in the depleted reach are affected but if this is compensated for with the creation of deep slow flowing habitat in the leat and behind the weir and shallow fast flowing habitat in the tail race is not studied.

2.1.4 Sedimentation

Free movement of sediment within a river distributes nutrients and provides different habitats. Studies show that weirs, leats and sluice gates act as barriers to this movement resulting in accumulation of sediment and changed sediment distribution and invertebrate habitats (Chutter, 1969; Gray & Ward, 1982; Fjellheim *et al*., 1989; Rice *et al.,* 2001; Jackson *et al.* 2007; Bruno *et al*., 2009). Inorganic sediments; silt, sand and clay, affect invertebrates and zooplankton by reducing the quality of their environment to move, feed and reproduce, and abrades their exoskeleton (Watters, 1999; Kent & Stelzer, 2008). High levels of organic sediments; plant and faecal matter, encourage bacterial growth, reducing pH and oxygen levels (Lemly, 1982, Environmental Protection Agency, 2013).

Sediment has been found to contain toxic heavy metals (Brekhovskikh *et al*., 2002; Wildi *et al.* 2004; Wang *et al*., 2008), agricultural organic matter, phosphorus, nitrogen (Lemly, 1982; Gorham, 2010) and avermectins, anti-parasitic medicines used in agriculture and aquaculture which have been found to be toxic to invertebrates at low doses (Davies *et al.* 1998; Boxall *et al.,* 2003; Kövecses & Marcogliese, 2005). Studies into the environmental impact of the accumulation of toxic sediment behind weirs have been found to change invertebrate assemblages (Colas *et al*., 2011, 2013).

Invertebrates are vital to the river ecosystem, feeding on and removing organic matter and as a food source for fish, they are routinely used as indicators of water quality and ecosystem health due to ease of sampling and identification and the sensitivity of some species to dissolved oxygen levels and pollution (Konrad *et al.* 2008; Jyväsjärvi *et al.,* 2013).

Whether it is better to use the weir to collect sediment or allow it to infiltrate larger stretches of the river or be washed away to sea is not discussed by the authors. The impacts of toxic sediments are not diminished in the marine environment (Carrasco *et al.,* 2007; Garnier *et al.,* 2012*)* leading to the conclusion that unimpeded water flow containing toxic sediments only moves the problem downstream and containment at a weir may be preferential by allowing easier excavation.

2.1.5 Leats and tail races

Fish can become impounded in leats when moving downstream or in tail races when moving upstream. Migration can be delayed stressing the fish and reducing the success and viability of spawning or juveniles returning to sea (Berg *et al*., 1986; Gerlier & Roche, 1998; Gowans *et al*., 1999; Aarestrup &

Koed, 2003; Geist *et al.*, 2003, Rivinoja, 2005). Fish have to undergo physiological changes that enable survival in a different osmotic environment, migration must be achieved in a certain time window and delay could result in death (Scruton *et al.*, 2007). Studies into delayed migration have found that large hydropower impoundments do not always delay migration and that migration rates are also dependent on water flow, water temperature and health of the individual fish when starting migration (Raymond, 1968; Venditti *et al.,* 2000; Salinger & Anderson, 2006; Caudill *et al.,* 2007).

Impounded resident fish can become stressed and more susceptible to disease if they are unable to reach specific habitats at specific times (Turnbull, 2012). Fish can become entrained in the water flow entering the turbine (Robson *et al.*, 2011), the EA insist on reduced flow at the intake and a return channel to allow entrained and impounded fish to escape from the leat (Environment Agency, 2012). There is no means of escape for impounded fish from the tail race other than returning downstream to the main stem of the river.

Leats and tails races will affect invertebrates by changing water flow and sedimentation, the effects were discussed above. No studies have been conducted into the potentially enhanced environment in leats and tailraces pre and post MHP installation.

2.1.6 Other effects of hydropower

Eels have been found to be reluctant to pass hydropower facilities (Duriff *et al.*, 2002; Haro *et al.,* 2000). They migrate in "meteorological windows" and it has been suggested that with the favoured conditions for migration, to stop the turbine (Duriff *et al.*, 2002). The reason for the reluctance to pass hydropower is not known and may not be applicable to MHP. The EA may impose the condition that the turbine is stopped when fish are migrating (Duley, pers. comm., 2012). Eels prefer to migrate at night and tend to stay near the river bed (Don, 2013; Environment Agency, 2013b). Eel pipes can facilitate the passage of adult eels impounded in leats (Don, 2013).

Eggs do not pass through turbines because they are anchored but could be exposed and dehydrated as water levels decrease or subjected to increased hydrostatic pressures if water levels increase (Cada, 1990a). Two studies of larval turbine passage predicted a loss of less than 5% (Cada, 1990a, 1990b), it must be noted that prediction was based on a statistical model and has not been investigated in the field, these losses could be within normal parameters for loss of larvae, although multiple MHP installations on a river may have a cumulative effect, no research has been done to test this.

2.2 Micro-hydropower and water quality

Water quality research is related to reservoirs and large hydropower no studies have looked at MHP turbines and water quality, although weirs, even low ones, efficiently oxygenate water (Kim & Walters, 2001). Large hydropower turbines effect aeration minimally due to abstraction from the bottom of the dam where the water is cold and anoxic (Daniil *et al.*, 1991; Bunea *et al*. 2010) Dissolved oxygen content, nutrients, pollution and dissolved nitrogen exist at levels detrimental to wildlife just below the dam and improves with distance (Ashby, 2009); these effects are not applicable to MHP. No research has been conducted into the holistic impact of the whole MHP installation and water quality.

2.3 Gaps in knowledge

Further study is required into the cumulative effect of multiple micro-hydropower installations on one river, the layout of the installation in relation to water flow, weir design, investigating the effects on all fauna not just iconic fish species, turbine passage of fish larvae, MHP turbine aeration and filtration of water, improvement in fish ladder design to allow use by all species, the implications of upstream restocking of depleted fish populations, censuses of all species in each river and historical comparisons to determine whether the river is now able to provide the necessary habitats for reintroduction.

Research currently tends to looks at one aspect of the effect of hydropower on aquatic fauna, more holistic studies need to be carried out. Long term studies also need to be done on the effect of agricultural, industrial and urban pollution on the river ecosystem against the background of climate change, to determine if MHP and the associated built environment mitigates or exacerbates these impacts.

2.4 Conclusion

Assumptions have been made about the environmental impact of MHP largely based on research of dammed hydropower looking at the potential for environmental damage not enhancement. Some of these assumptions are incorrect and may or may not apply at different MHP installations.
Research is biased towards fish species of recreational and economic importance; other species are usually not studied but are still important for the river ecosystem (Thompson *et al.* 2012).
The effect of MHP on invertebrates has not been considered. Studies have found that there are many factors that affect them: the quality of the catchment environment, river bed changes, water quality and quantity, flood and drought, temperature and fish numbers (Fjellheim & Raddum, 1996; Seddon, 2000; Cheeseman *et al.,* 2010; Schäfer *et al.,* 2012; Beketov *et al.,* 2013).Their importance in the ecosystem, particularly as a food source for fish makes this an essential area of investigation especially considering how they are affected by sedimentation.

Robson *et al.* (2011) highlighted the range of results of the impact of hydropower, noting the lack of research specific to MHP. Studies have highlighted the importance of the layout of the installation, the different species that exist or have existed in the river and other river uses and the potential for environmental damage from these uses. Major threats to aquatic fauna include; sediment loading, eutrophication and pollution from agriculture (Schäfer *et al.,* 2012; Beketov *et al.,* 2013), invasive species (Defra, 2010), altered water flow (Richter *et al*. 1997) and climate change (Whitworth *et al*., 2012; Verdonschot, 2013). The impact of MHP on aquatic fauna must be assessed site by site taking into account these other threats.

3 Research Methods

The literature review highlighted the contradictory results of the few studies that have looked specifically at MHP and its effects on aquatic fauna and water quality. There is a well understood correlation between the presence of certain invertebrate species and water pollution and oxygenation and for this reason invertebrates are used as an indicator of biodiversity and water quality. The control samples were taken upstream of three MHP sites, the other samples were taken downstream of the MHP sites. By comparing the two different sets of samples one can determine if the MHP is increasing biodiversity (objective 1) and improving water quality (objective 2). Upstream control samples were downstream of a weir so that the samples could be fairly compared. The diversity and ASPT at Tellisford Mill were compared to the results of a pre-installation study (Tiplady, 2006) and a post installation study (Elvey, 2009) (objective 3). Using knowledge gained from the literature review a visual assessment of each site was also conducted to determine any possible problems posed to fish movement and potential sources of pollution in the riparian environment (objective 4).

This section will detail the quantitative part of the research; the sampling sites and why they were chosen and how samples were collected and analysed.

3.1 Sampling sites

3.1.1 The River Frome, Somerset

The River Frome and its tributary the River Mells start as groundwater springs in the limestone of the Mendip Hills and the chalk Cranbourne Chase (Figure 2). This river was chosen because there are a number of MHP installations in the vicinity and by sampling one river would eliminate the variable of sampling from different rivers with different geology and environment. Downstream of Frome town the river is listed by the EA as being of poor ecological quality and the upper reaches are designated a nitrate vulnerable zone (Environment Agency, 2013d). The upper reaches are a priority catchment highlighted by Natural England due to phosphate and ammonia contamination and sedimentation due to agricultural soil erosion (Natural England, 2013). Migratory fish species found in the river are eel (Tiplady, 2006). Rainbow Trout and Brown Trout are restocked by the local angling club at Tellisford (Lewin Fryer, 2004).

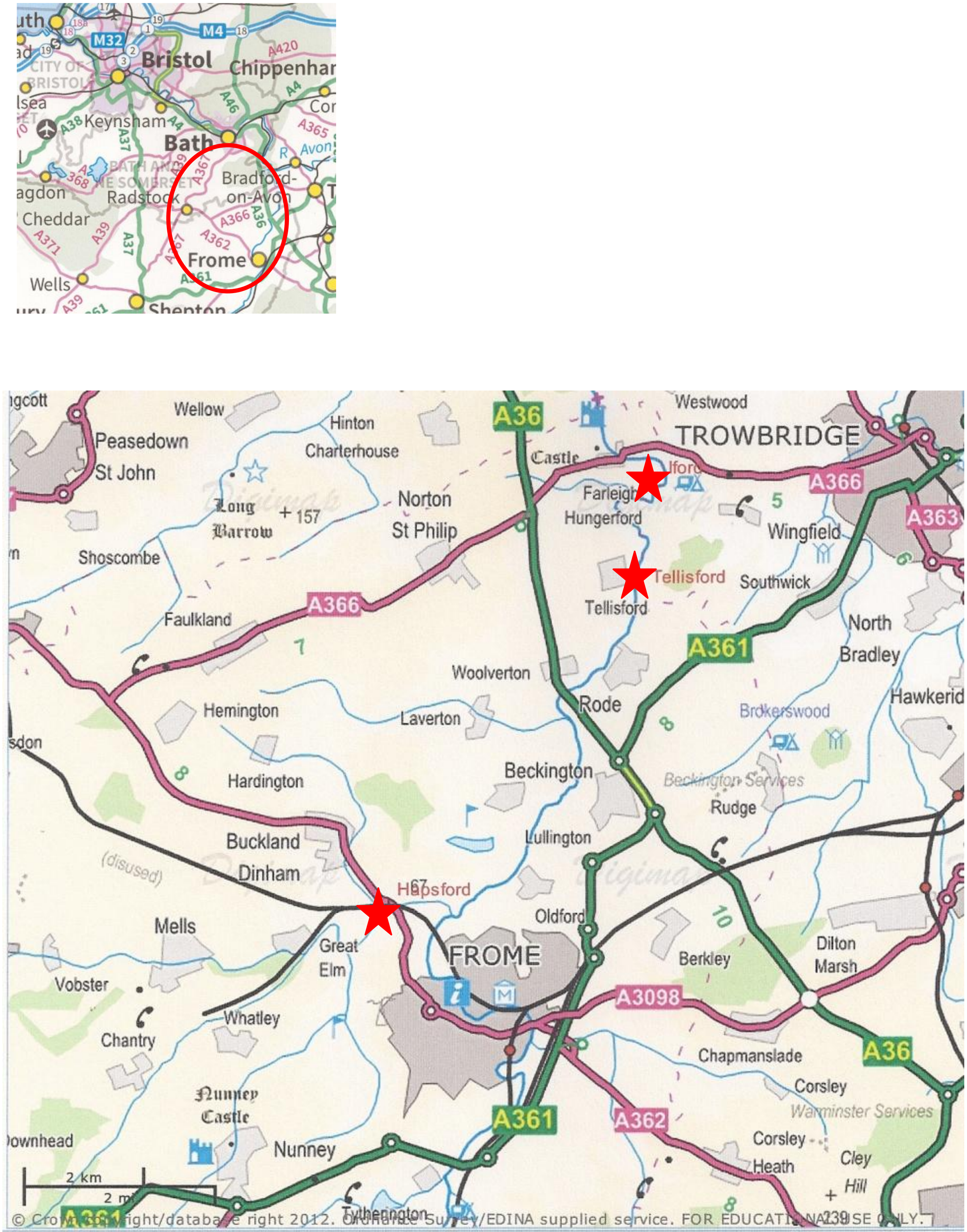

Figure 2: Location of the mill sites (Edina, 2013).

The river historically had a mill every half a mile (Battersby & Feilden, 2009) which has resulted in many changes to its course. Currently there are seventeen weirs between Hapsford and the River Avon, varying in height and design, creating navigable stretches for canoeing and deep pools used locally for swimming. The mills in the study are part of Mendip Power Group; their involvement was kindly coordinated by the chairman Anthony Battersby.

The river was sampled on the 28th - 30th July 2012 when flow at Tellisford was measured as 6 m³/s and 22nd – 24th July 2013 when flow was measured as 2.6 m³/s. Flow in the river has been measured from 116 m³/s to 0.7 m³/s with an average flow of 3.8 m³/s (Battersby, pers. comm., 2013c).

3.1.2 Hapsford Mill (OS grid ref: ST760495)

Hapsford Mill (Figure 3) was built in the 18th Century and is the furthest upstream of the sites.

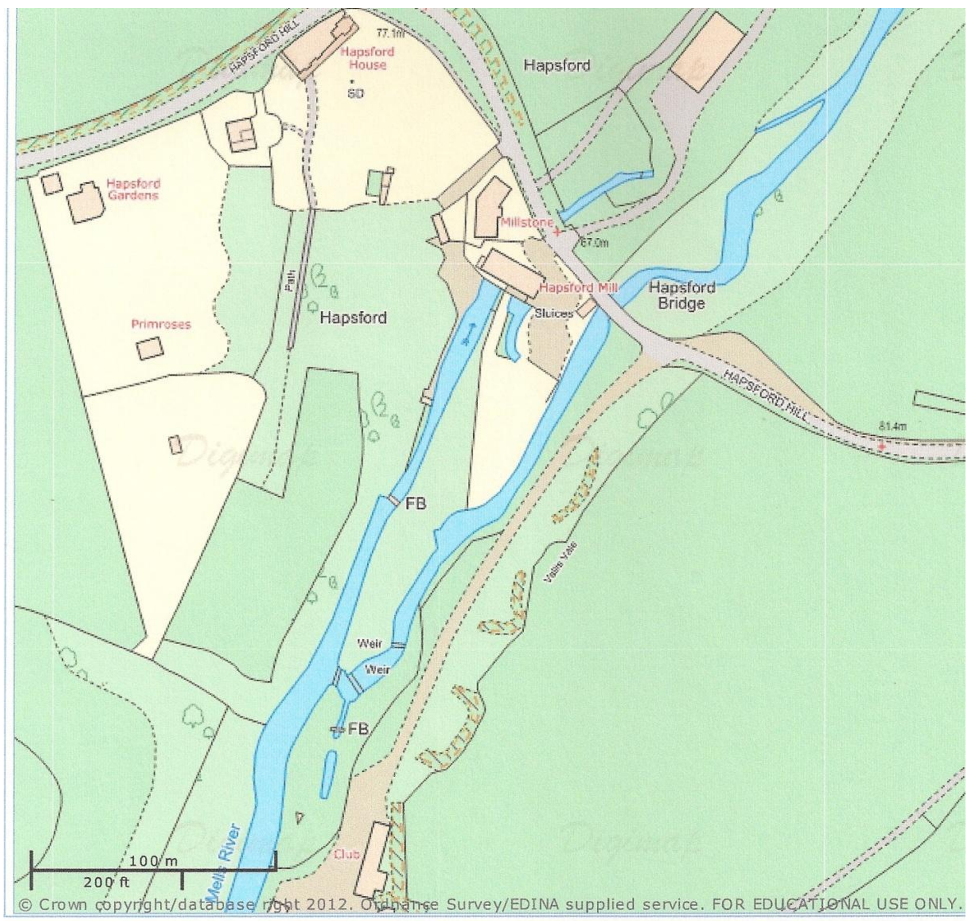

Figure 3: The river at Hapsford Mill (Edina, 2013).

It was fitted with a Crossflow turbine in July 2010, the height of the weir was raised and as yet a fish pass has not been installed (Figure 4). The abstraction licence requires that flow over the weir is maintained above 0.253 m^3/s. If flow drops below this amount the turbine operation must be stopped; known as hands off flow. This ensures flow in the depleted reach that occurs 95% of the time (Q95). The tail race has been excavated and is now free flowing, not as illustrated in Figure 3. The downstream sampling site was one hundred metres downstream of the mill. The control site was 600 m upstream of the mill.

Figure 4: Weir at Hapsford Mill (Somersetrivers.org, 2013)

The riparian environment is deciduous woodland with a small industrial estate with diesel pumps for a haulage company. There is a quarry outflow two kilometres upstream and surface water runoff drainage into the river between sampling sites (Jones, pers. comm., 2012)[2].

3.1.3 Tellisford Mill (OS grid ref: ST805555)

Tellisford Mill (Figure 1, Chapter 2) is first mentioned in the Doomsday Book. The mill was restored and fitted with a Kaplan turbine in 2007 the weir improvements included the addition of a fish notch

[2] Dave Jones, Regulatory Scientist, Wessex Water

(Figure 5). The downstream sampling site was just beyond where the tail race joins the river, the control sampling site was 500 m upstream of the mill at Langham Farm.

Figure 5: Weir at Tellisford with fish notch (Battersby, 2005).

Tiplady (2006) conducted a pre-installation study which was followed by a comparitive study post installation (Elvey, 2009). The results from these were used for a historical comparison. The sampling location is the same in all the studies. The licence requires a hands off flow of 0.33 m^3/s. This ensures flow in the depleted reach that occurs 95% of the time (Q95). The riparian environment is agricultural, cattle wade into the river on the opposite bank to the mill for drinking, there is also a sewage treatment works 1 km upstream.

3.1.4 Iford Mill (OS grid ref: ST799587)

Iford Mill (Figure 6) is part of the medieval Iford Manor estate and is the furthest downstream of the sampling sites. An Archimedes screw was installed on the weir in December 2011, the weir was improved and includes a fish pass (Figure 7) and an eel pass (Figure 8). The downstream sampling site was below the weir (X in Figure 6), the control sampling site was one kilometre upstream of the mill by the bridge at Farleigh Hungerford. In 2013 the weir was undergoing repairs. The riparian environment is park and agricultural land.

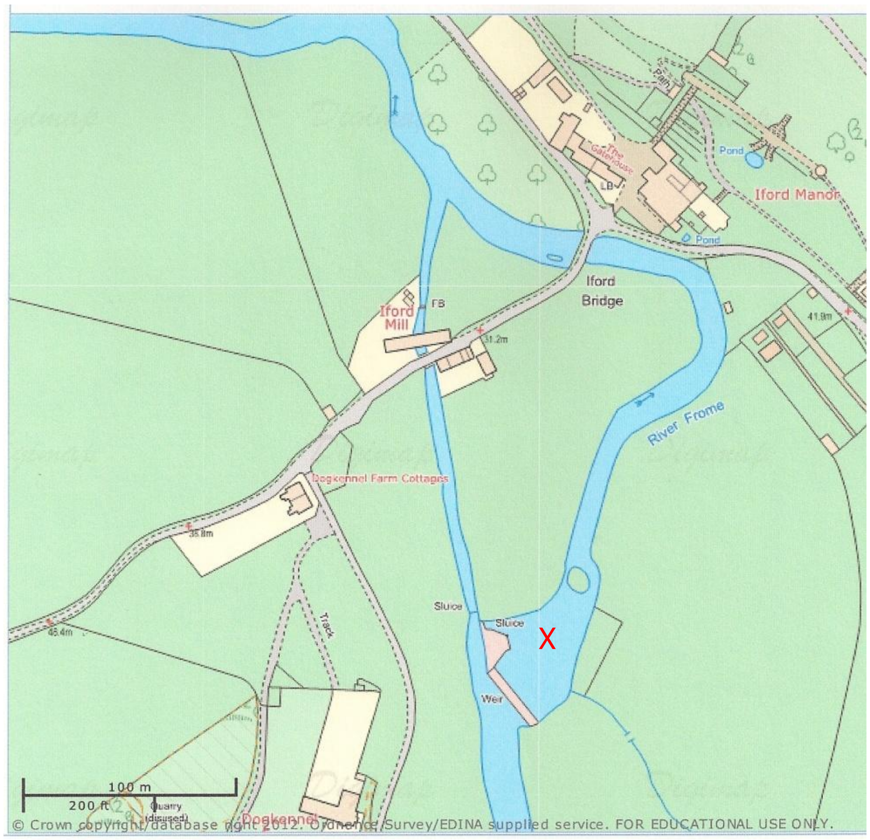

Figure 6: The river at Iford (Edina, 2013).

Figure 7: Fish pass Iford Weir (Edwards, 2013).

Figure 8: Eel pass Iford Weir (Edwards, 2013).

3.2 Sampling

The sampling method was chosen because it is the standard used by the EA (Murray-Bligh, 1999) and allowed comparisons to previous (Tiplady, 2006; Elvey, 2009) and any subsequent studies.

The three sites were sampled, downstream at an accessible and safe point beyond where the tail race joined the river. Three samples were taken, one from the main flow of the river, one from the river edge at 20 cm depth and one from a depth halfway between the two. This ensured that all species had the best chance of being sampled (Environment Agency, 2003). The upstream control sampling sites were located downstream from a weir, not associated with MHP. This was to eliminate the variable of the weir at the downstream sampling sites. The upstream control sites were situated in a free flowing stretch of river, similar to the downstream sites and were beyond any pooling or stagnation effects created by the weir.

The river bed was sampled using a 1 mm Surber sampler (Figure 9). With the 0.3m x 0.3 m frame in position and the net facing downstream the river bed was agitated by kicking in the area framed by the Surber sampler for three minutes, timed using a stop watch. Stones were then gently rubbed for a further minute to remove any attached invertebrates.

Figure 9: Surber Sampler (http://www.dnr.state.md.us/education/envirothon/2004art/surber_sampler.jpg).

Invertebrates dislodged were caught in the net and transferred to a white tray for identification. The net was checked for any invertebrates entangled in the mesh. The invertebrates were identified to species using Olsen *et al.* (2009), counted and logged and returned to the river. To avoid contamination sampling was conducted in an upstream direction.

3.3 Analysis

3.3.1 Diversity

Diversity was measured using the Simpson Index 1-D:

$$D = \sum (n/N)^2$$

n = total number of organisms of a species

N = total number of organisms of all species

The result is a value between 0 and 1, 1 being the most diverse. This index was used because it is considered the best measure of species richness and evenness and is not sensitive to the presence of a low number of rare species (Wheater *et al.,* 2011). An ecosystem can have e.g. 10 species (richness) but may only have 1 individual of 9 species and lots of individuals of 1 species, this is not considered as diverse as an ecosystem with 10 species equally abundant (evenness). Because of the small number of samples at each location all the upstream Simpson Index results were considered together and the mean calculated. This was repeated for the downstream Simpson Index results and the means compared for significant difference using a paired t test. Calculations and statistical analysis were calculated using Excel.

3.3.2 Biological water quality

To make this study comparable to the previous studies ASPT was used. ASPT is a method used by the EA (Tiplady, 2006) to indicate biological water quality. This is defined as the water quality assessed using biological indicators, differing from physical and chemical water quality. ASPT uses invertebrates as indicators of organic pollution e.g. pollution from sewage treatment outflows or from agricultural livestock. These are the most likely sources of pollution in the River Frome. Organic pollution encourages rapid algal growth (eutrophication) which lowers the amount of dissolved oxygen in the water available for other aquatic wildlife.

ASPT is calculated from the British Monitoring Working Party (BMWP) score. Certain invertebrate families are assigned a value 1 – 10, 1 is the value given to families that are tolerant to pollution and low water oxygenation e.g. *Tubificidae*. Families with low tolerance to pollution and needing high water oxygenation are assigned the value of 10 e.g. *Ephemeridae*. The list of families used to calculate ASPT can be found in Appendix A. The BMWP score is the total of these values. The ASPT was calculated by dividing the BMWP by the numbers of families found, the result being between 1 and 10. Using ASPT as an indication of the biological quality of the water Murray- Bligh (1999) provides the following ranking:

Very good biological quality + 5.4

Good biological quality 4.8 – 5.4

Fair biological quality 4.2 – 4.8

Poor biological quality 3.6 – 4.2

Very poor biological quality 3.6 or less.

Because of the small number of samples at each location all the upstream ASPT results were considered together and the mean calculated. This was repeated for the downstream ASPT results and the means compared for significant difference using a paired t test. Calculations and statistical analysis were calculated using Excel.

3.3.3 Comparison to historical data at Tellisford

From previous studies conducted at Tellisford in 2006 and 2009 (Tiplady, 2006; Elvey, 2009) the raw data were used to calculate the Simpson Index (see Appendix B). These studies sampled twice in the main flow of the river, not at the river margin. Not all species will be represented in this habitat and so is not ideal for measuring diversity. Invertebrate families in fast flowing water (lotic invertebrates) score a higher ASPT than invertebrate families in slower flowing water (lentic invertebrates). When making comparisons between the previous studies and this study only the data from the two faster flowing samples were used i.e. samples taken at 30 cm and 40 cm depth. This is not the best measure of diversity but made the data comparable.
The previous studies included insects on the water surface which were picked separately to the kick sample; these are not differentiated in the raw data.

The Simpson Index and ASPT were compared to water flow to determine if there was a significant correlation. Graphs and statistical analysis were produced using Excel.

3.3.4 Visual assessment

At each mill the leat, tail race, weir, fish pass and anything pertinent to the study between the sample sites were looked for, based on knowledge attained from the literature review. This included sources of non- diffuse e.g. outfall from sewage treatment works and diffuse pollution e.g. surface water runoff (Defra, 2008). Photographs were taken to qualitatively determine the accessibility of upstream reaches to aquatic fauna and anything with the potential to affect water quality. Because not all sources of river pollution are visible, Wessex Water was contacted for further information on potential pollution sources and an Ordnance Survey map consulted.

4 Results

There were four different areas of study:

1. Investigating the effect of three MHP sites on the diversity of invertebrates.
2. Investigating the effect of three MHP sites on biological water quality.
3. Comparison of Simpson Index, a measure of diversity, and ASPT, a measure of biological water quality, to two previous studies at Tellisford Mill.
4. Visually assessing each mill for accessibility to upstream reaches by aquatic fauna and for potential sources of pollution.

4.1 Invertebrate diversity

The Simpson Index measured at each site and for each year is detailed in Table 1. The raw data obtained at all the sampling sites and the calculations for the Simpson Index are detailed in Appendix C. The Simpson Index has values between 0 and 1, 1 being the most diverse.

Simpson Index				
Site	2012		2013	
	upstream	downstream	upstream	downstream
Hapsford	0.44	0.81	0.79	0.88
Tellisford	0.68	0.75	0.81	0.91
Iford	0.73	0.80	0.74	0.93

Table 1: Simpson Index at each MHP sampling site, measured in 2012 and 2013.

In 2012 invertebrates were present in higher numbers but the populations were made up of fewer species; they were less diverse than 2013. The Simpson Index improved most downstream at Hapsford in 2012 with an increase of 0.37. Upstream 80 individuals were sampled made up of 9 species and downstream 100 individuals were sampled made up of 13 species. All other increases were of similar magnitude ca. 0.08, except at Iford in 2013, which had an increase of 0.19. Figure 10 shows the changes in Simpson Index moving downstream from the first sampling point.

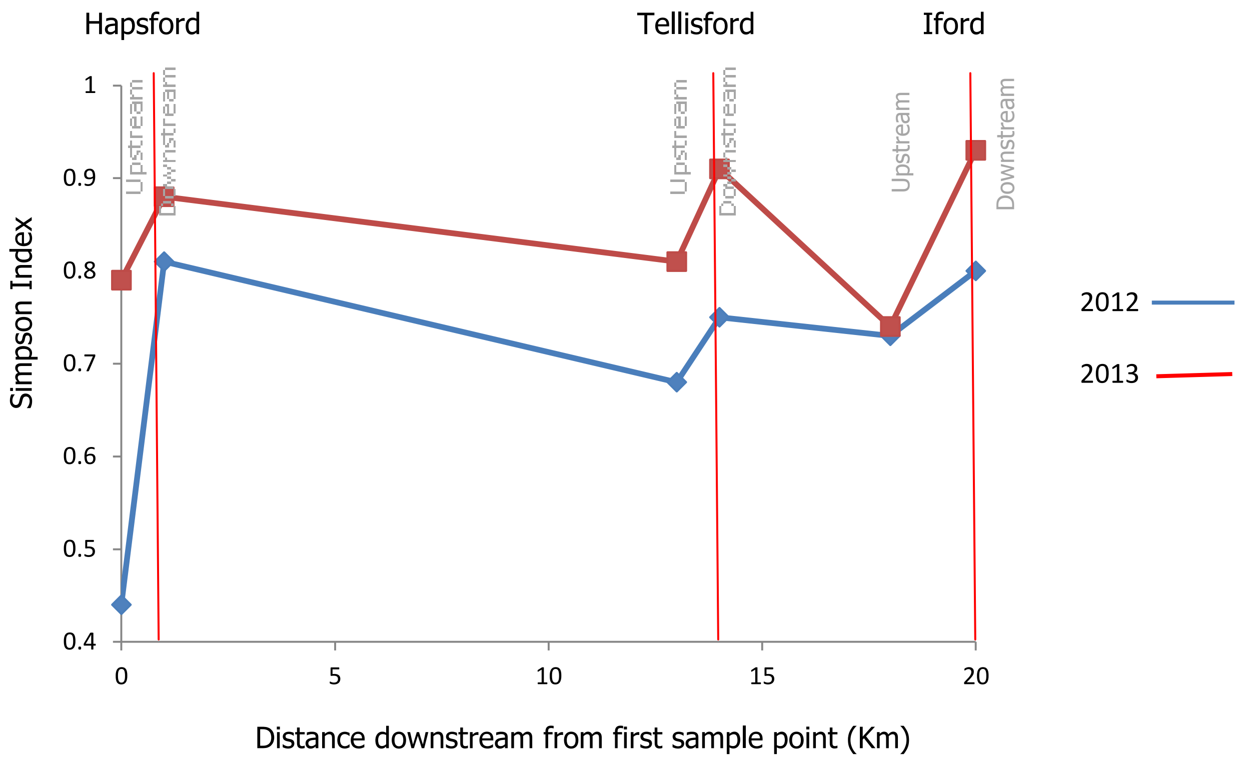

Figure 10: Simpson Index at each MHP sampling site, measured in 2012 and 2013.

Invertebrate diversity, as measured by the Simpson Index, was significantly higher ($p = 0.027$) downstream of all the MHP installations for both years, when compared to upstream. Statistical significance was accepted at $p<0.05$. The trend was for diversity to slightly increase moving downstream along the river. Populations at each individual MHP site could not be compared due to the number of samples being insufficient and so the mean Simpson Index of all upstream and all downstream samples were compared (Figure 11).

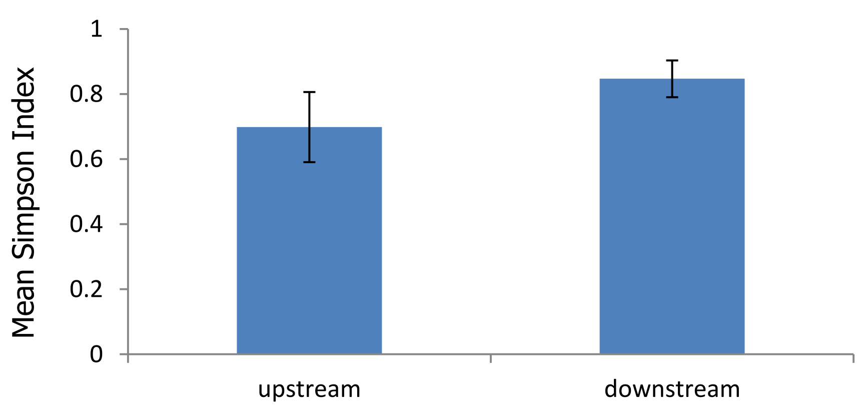

Figure 11: Means of Simpson Index upstream and downstream at all MHP sites for both years, error bars are the 95% confidence limits.

4.2 Biological water quality

The ASPT measured at each site and for each year is detailed in Table 2. The raw data obtained at all the sampling sites and the calculations for the ASPT are detailed in Appendix C. The higher the ASPT the less polluted and more oxygenated the water, scale from 1 – 10, 1 being very poor biological water quality.

Average score per taxon				
Site	2012		2013	
	upstream	downstream	upstream	downstream
Hapsford	7.0	6.7	6.4	5.4
Tellisford	6.4	5.0	5.1	4.6
Iford	5.2	5.0	4.7	4.9

Table 2: ASPT at each MHP sampling site, measured in 2012 and 2013.

Biological water quality was lower downstream of all the MHP installations for both years, except Iford in 2013. In both years the trend was for biological water quality to decrease downstream. The largest decrease in biological water quality was at Tellisford 2012; upstream the BMWP was 64 made up of 10 families, giving an ASPT of 6.4. Downstream BMWP was 55 made up of 11 families, giving an ASPT of 5. Biological water quality in 2012, as indicated by the invertebrates present, was better than in 2013. Figure 12 shows the changes in ASPT moving downstream from the first sampling point and biological water quality categories. Murray-Bligh (1999) categorised biological water quality based on the ASPT. Biological water quality in the River Frome was fair to very good in 2012 and 2013.

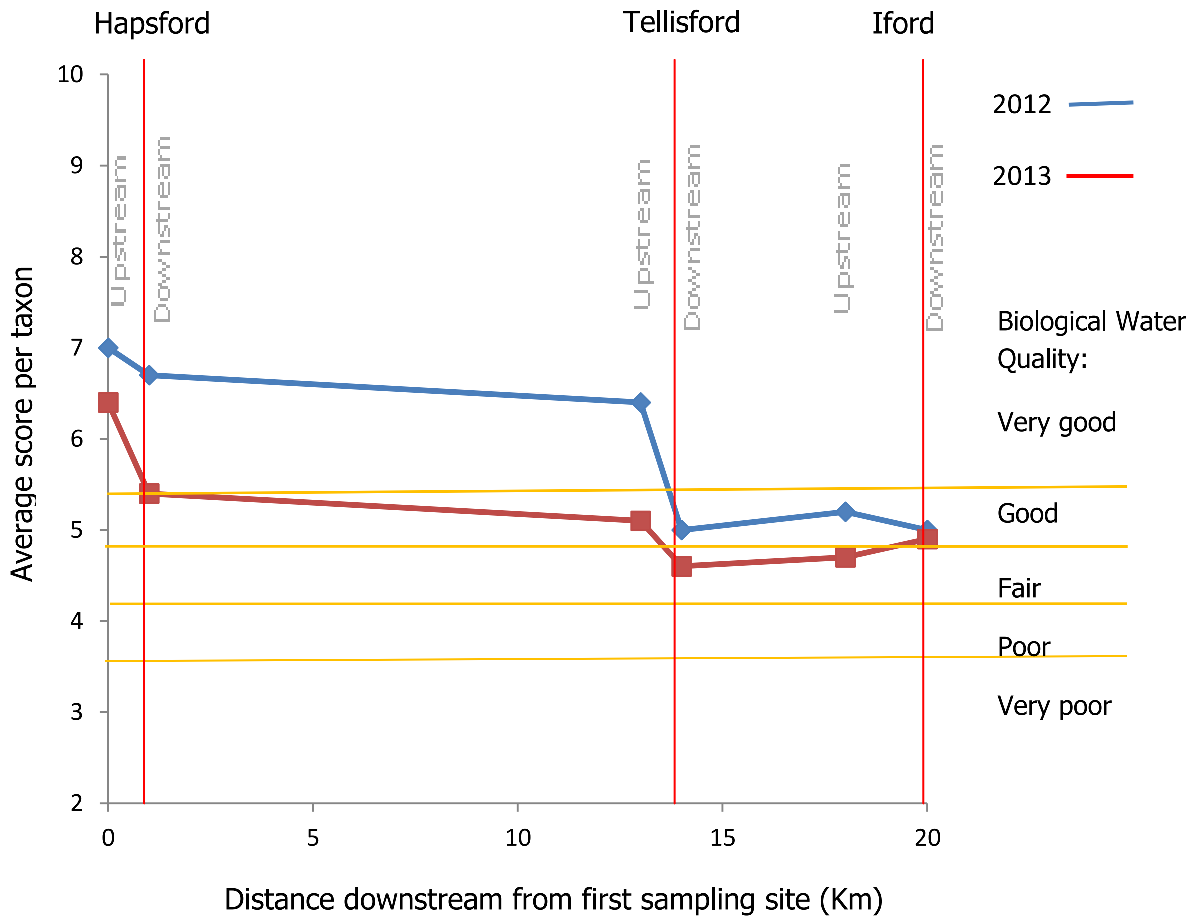

Figure 12: ASPT changes with distance downstream as measured in 2012 and 2013 with biological water quality categories (Murray-Bligh, 1997).

All downstream samples were compared for significant difference, using a paired t test, to upstream samples. The mean ASPT of the upstream invertebrate populations was slightly higher than the mean ASPT of the downstream invertebrate populations but the difference was not significant ($p = 0.07$) at the 5% significance level (Figure 13).

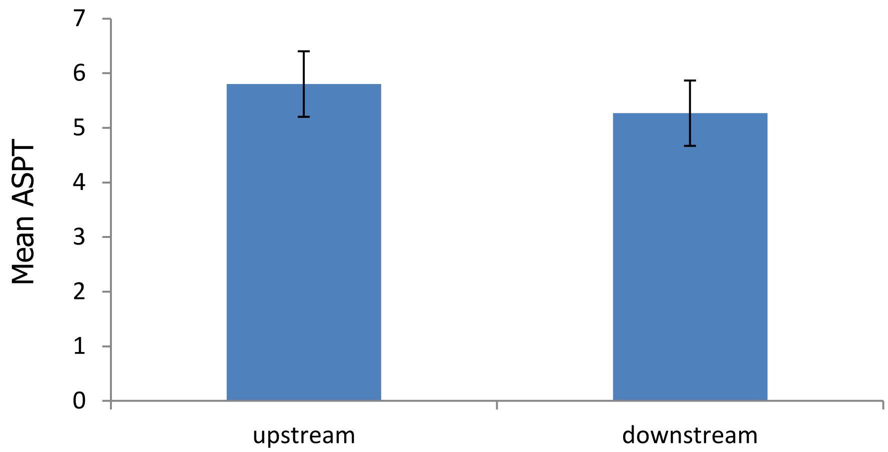

Figure 13: Means of ASPT upstream and downstream at all sites for both years, error bars are the 95% confidence limits.

4.3 Comparison to historical data at Tellisford

The data from two previous studies (Tiplady, 2006; Elvey, 2009) were compared to the results of this study found at Tellisford downstream site (Figures 14 and 15). Data for 2008 samples were not taken at the same time of year and so were not comparable. The raw data are detailed in Appendix B. The SI and ASPT results for 2012 and 2013 differ from the previous sections due to using the two samples taken in the areas of the river with higher flow and excluding the sample taken in the area of lower flow.

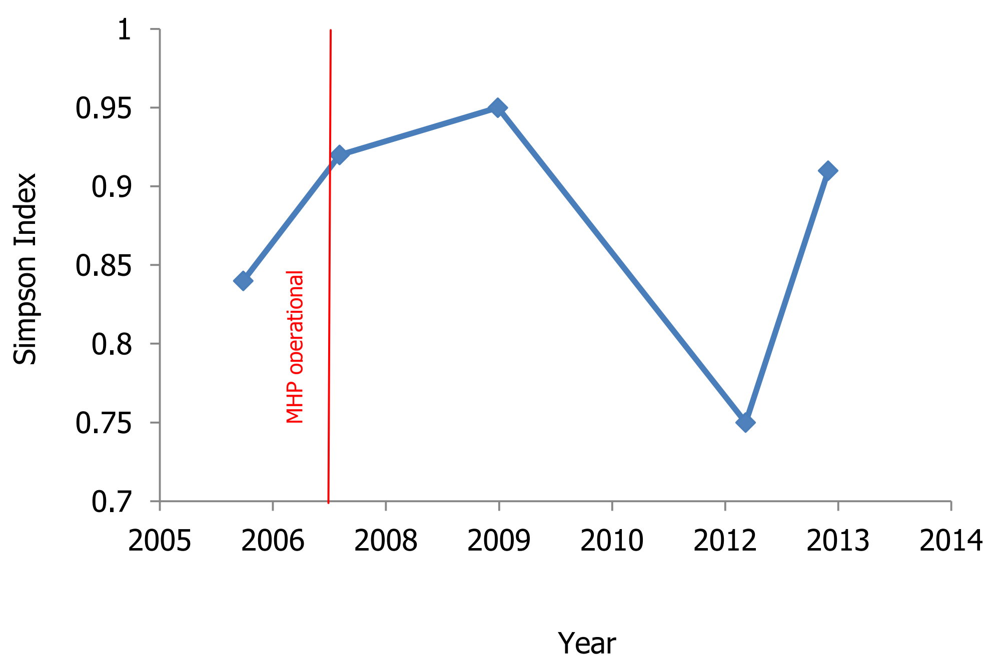

Figure 14: Simpson Index at Tellisford downstream site over time (2006 – 2013).

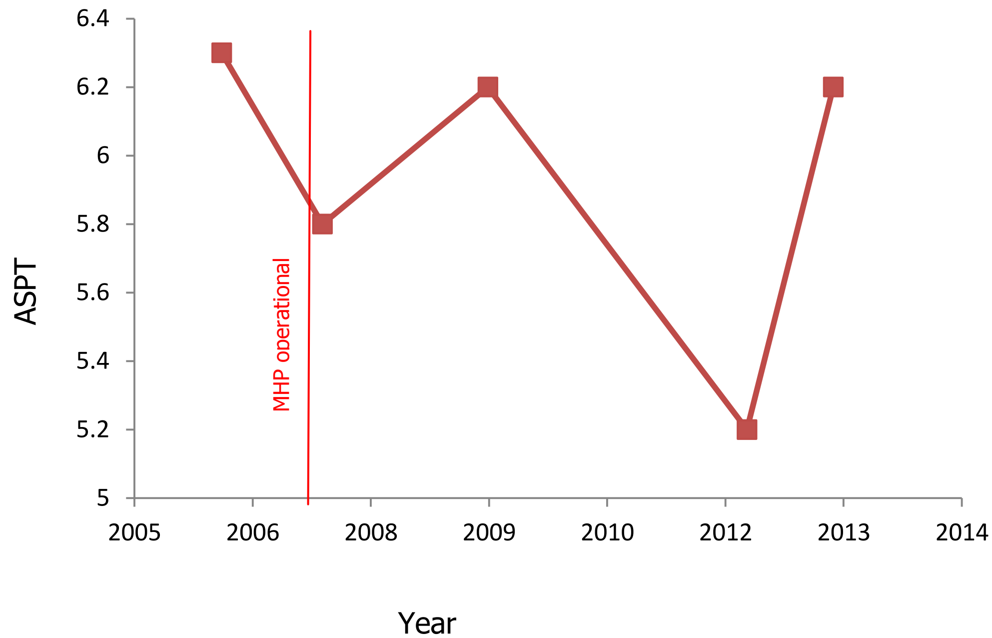

Figure 15: ASPT at Tellisford downstream site over time (2006 – 2013).

Invertebrate diversity and biological water quality were variable from year to year and did not show any correlation to the MHP installation. Using data from Tellisford flow gauge, the correlation between flow, Simpson Index and ASPT, was investigated. Flow on the specific dates of sampling is shown in Figure 16.

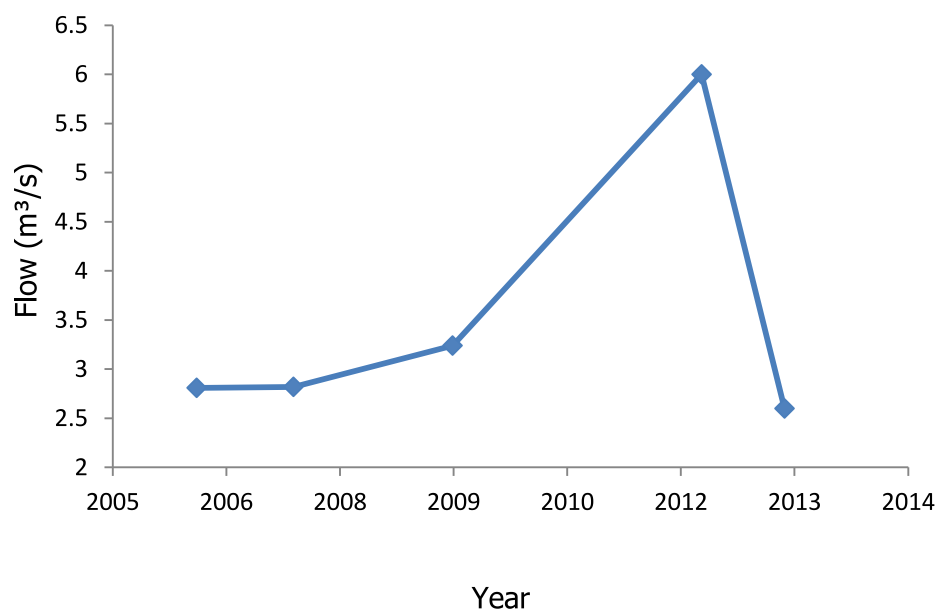

Figure 16: Flow at Tellisford at corresponding dates for ASPT and Simpson Index Sampling.

Regression analysis did not identify a significant relationship between flow and Simpson Index ($p=0.06$), (Figure 17) or ASPT ($p=0.08$), (Figure 18). Both analyses showed a negative trend with decreasing Simpson Index and ASPT as flow increased.

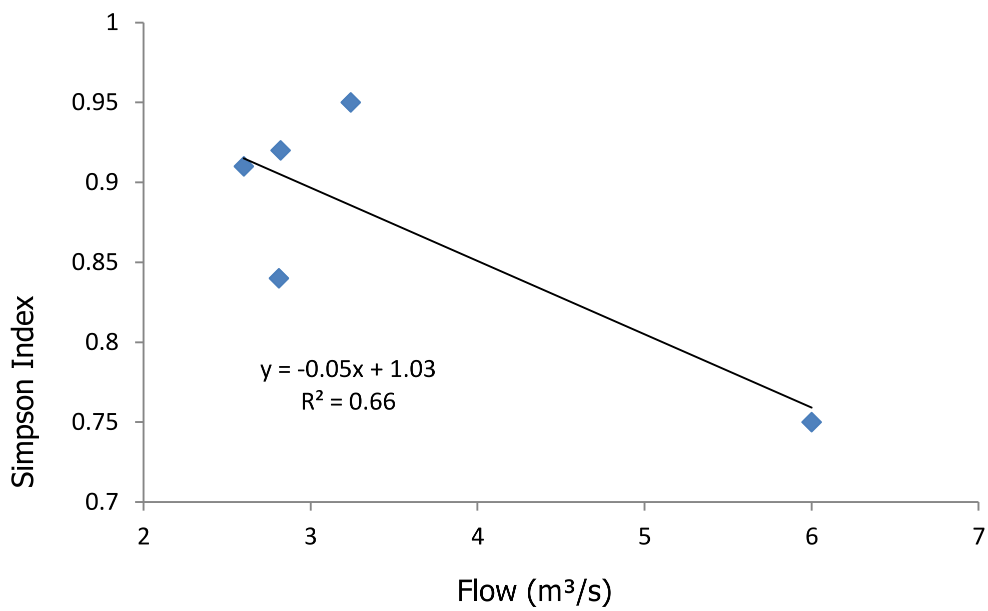

Figure 17: Simpson Index in relation to flow

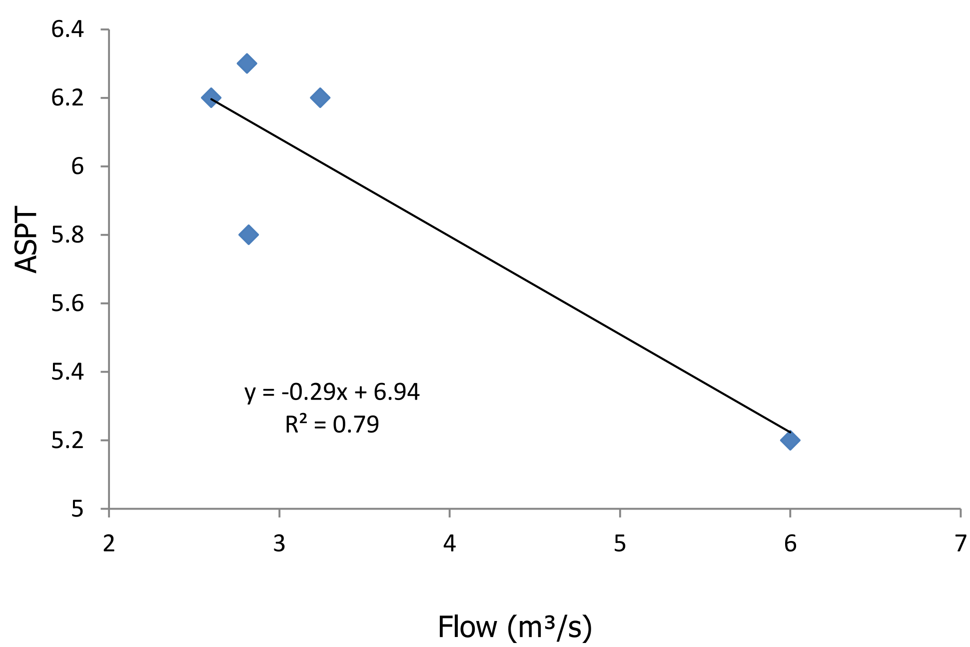

Figure 18: ASPT in relation to flow

4.4 Visual assessment

4.4.1 Hapsford

It has been suggested that the stronger flow from the tail race could attract fish away from the main river (Figure 19), where they may become impounded (Robson *et al.*, 2011).

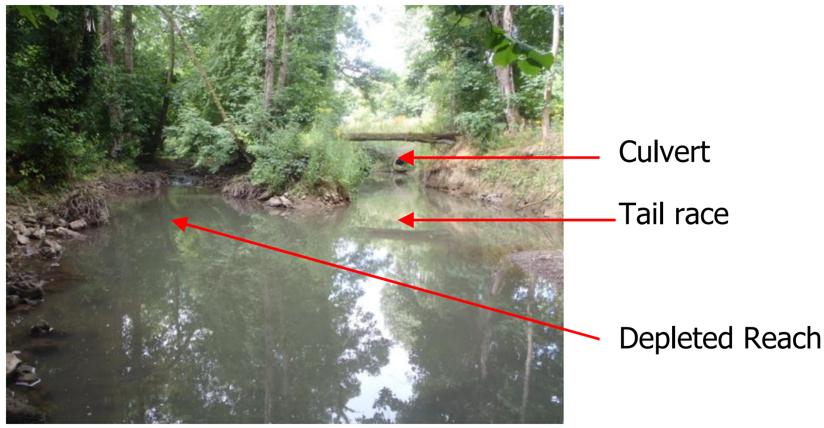

Figure 19: Hapsford tail race joins the river (Edwards, 2013).

The water in the depleted reach was shallow (Figure 20) in some areas for both 2012 and 2013. The weir has not yet been fitted with a fish pass (Figure 4, Chapter 3).

Figure 20: Depleted reach at Hapsford (Somersetrivers.org, 2013)

4.4.2 Tellisford

Natural England discourages farmers from allowing their livestock to use the river as a source of drinking water (Natural England, 2013). At Tellisford the river was not fenced off, allowing a herd of cattle to use the river for drinking (Figure 21 and 22).

Figure 21: Evidence of cattle wading into the river for drinking water (Edwards, 2013).

Figure 22: Evidence of cattle wading into the river for drinking water (Battersby, 2013)

As at Hapsford the flow from the tail race is higher than in the main river (Figure 23), (Robson *et al*., 2011).

Figure 23: Tellisford tail race (Somersetrivers.org, 2013).

Little water was cresting the weir in 2013 (Figure 24), possibly creating an impassable barrier upstream for resident fish. Adult eels will be able to crest the weir regardless of flow. The weir is fitted with a fish notch to allow fish passage (Figure 6, Chapter 3) during higher flows. The depth of water within the depleted reach was sufficient for large fish (Figure 25) in 2012 and 2013.

Figure 24: Tellisford weir at low flow (Battersby, 2013)

Figure 25: Tellisford depleted reach during low flow (Edwards, 2013).

4.4.3 Iford

No water was cresting the weir at the time of the 2013 sampling due to repairs being carried out. Figure 26 shows the weir at a flow of 5.78 m³/s (Battersby, pers. comm., 2013a).

Figure 26: Iford weir (Frome Canoe Club, 2011).

4.5 Other observations

Iford upstream sampling site was downstream of an unimproved weir. In 2013 no water was cresting this weir (Figure 27) although a low volume of water was passing through the reach possibly seeping under the weir.

Figure 27: Unimproved weir at Farleigh Hungerford (Edwards, 2013).

This reach had a very low flow of water (Figure 28). Brown Trout were trapped between the dry weir and the shallow water by the bridge.

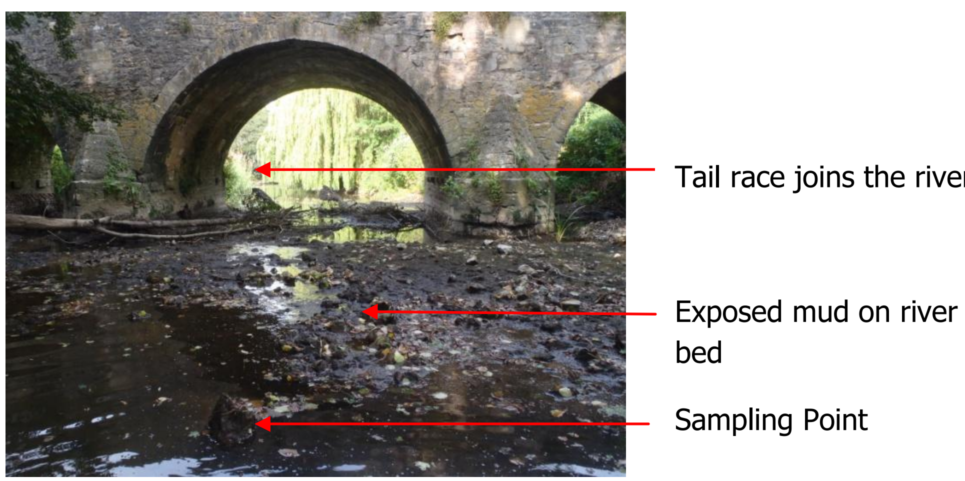

Figure 28: Depleted Reach, Iford Upstream site, Farleigh Hungerford (Edwards, 2013).

In 2013 the water at Hapsford was cloudy. This was possibly due to drainage of Whatley limestone quarry (Figures 29 and 30).

Figure 29: Cloudy water at Hapsford.

Figure 30: Cloudy water at Hapsford (underwater photograph).

5 Discussion

The overall aim of the research was to determine the effect of MHP on river aquatic fauna. The research objectives were to:

1. Ascertain if the diversity of the invertebrates was changed by the presence of MHP.
2. To determine if MHP improved river biological water quality.
3. To compare the results of this study with historical data at Tellisford, before and after the MHP installation.
4. To visually evaluate each mill for problems of movement of fauna to upstream reaches and potential sources of pollution.
5. To formulate recommendations for further research.

5.1 MHP and invertebrate diversity

All the sites showed a significant increase in invertebrate diversity downstream of the MHP for both years. The built environment associated with MHP provides many different habitats for invertebrates; deep, slow moving water in the leat and behind the weir and fast shallow water in the tail race and in front of the weir (Environment Agency, 2003). Invertebrates will move between these habitats to populate other areas of the river increasing diversity overall. Upstream sites were more homogeneous. The invertebrate populations also indicate that these MHP sites are not having a detrimental effect by e.g. killing large numbers of invertebrates due to turbine passage. A large and diverse population of invertebrates provides input near the bottom of the food chain and indicates a healthy aquatic environment.

The reduced diversity at Hapsford may be due to the cloudiness of the water, restricting photosynthesis, providing less food at the bottom of the food chain.

The invertebrate diversity was higher in 2013 than in 2012. This may be due to the long duration of high flow preceding sampling in 2012 which may have resulted in an environment favouring invertebrates that prefer high flow to the exclusion of invertebrates preferring low flow thus reducing diversity.

The Somerset Frome is a priority catchment due to, amongst other things, sediment loading from agricultural runoff (Natural England, 2013). Sediment trapped behind the weir may protect invertebrate habitats downstream from siltation (Aftergood & Damary- Homan, 2013) and whilst this accumulation is not beneficial to the invertebrates located behind the weir (Colas *et al.,* 2011, 2013) does allow easier excavation, redistribution and reuse of the sediment (Gorman, 2010).

5.2 MHP and biological water quality

The water quality, as indicated by the invertebrates present, in the River Frome is fair to very good (Murray-Bligh, 1999). Biological water quality reduced downstream of each MHP site except Iford in 2013 although these differences were not significant. At each site the reduced biological water quality could be explained by other confounding factors in the vicinity.

At Hapsford there is a small industrial park with diesel pumps for a haulage company between the two sample sites, a potential source of surface water pollution. If this finds its way into the river the chemicals present in diesel e.g. benzenes could have a deleterious effect on the wildlife (Agency for Toxic Substances and Disease Registry, 1995).

Between the two sample sites at Tellisford, cattle wade into the river to drink introducing organic matter in the form of manure, anthelmectins and sediment into the water Organic matter is a problem in rivers because it encourages algal growth which in turn reduces oxygen levels, which is deleterious for the other aquatic wildlife (Environmental Protection Agency, 2012). Anthelmectins, veterinary medicines used routinely to de-worm livestock, remain active once they have left the animal and have been found to affect invertebrates (Boxall, 2003; Kövecses & Marcogliese, 2005). Sediment fills the small spaces in the river bed (Defra, 2008), degrading the habitat for invertebrates by abrading their exoskeleton and reducing their ability to feed, move and reproduce (Watters, 1999; Kent & Stelzer, 2008). This may explain the reduction in biological water quality from very good to good in 2012 and good to fair in 2013.

Between the two sample sites at Iford there is the outfall from a small sewage treatment works introducing organic matter into the river. Nevertheless the invertebrate species present suggest that water quality in the vicinity is of good biological quality (Murray-Bligh, 1999). Biological water quality at the upstream sampling site was fair in 2013, which can be explained by the reduced flow of water due to the unimproved weir (Figure27, Chapter 4).

A hydropower turbine should not contribute to pollution of the water however the claim that MHP filters and aerates the water thus improving water quality has not been substantiated by this study.

The upstream sampling site at Iford was in a depleted reach (the reasons for which are explained in Section 5.9). In 2013 no water was cresting the weir upstream and the river became shallow enough further downstream to reveal the mud on the river bottom, stranding a population of Brown Trout. This explains the lower biological water quality result as the water flow was very low. Biological water quality in low flow reduces due to accumulated sediment and low levels of oxygenation (Environmental Protection Agency, 2012). The weir is not associated with hydropower and the leat and tail race are open and free flowing to allow the passage of fish.

The cloudiness of the water at Hapsford did not reduce biological water quality. The invertebrates present indicated very clean, highly oxygenated water but they were present in low numbers and not as diverse as the other sites. The ASPT is an indication of organic pollution, if the cloudiness of the water is due to limestone sediment which is inorganic this would not affect the ASPT score.

Biological water quality results were reduced in 2013 compared to 2012. This could be due to the higher water flow in 2012 diluting the pollutants entering the river from the riparian environment (Environmental Protection Agency, 2012).

Biological water quality is generally reduced the further downstream the water travels due to the accumulation of non-diffuse pollution e.g. sewage outfall and diffuse pollution e.g. from agriculture (Defra, 2008).

5.3 Comparison to historical data at Tellisford

Invertebrate diversity varied from year to year. In some years the variations were higher and in other years lower than before the installation of the MHP. There was no evidence that the turbine was impacting the invertebrate diversity detrimentally. This is despite the fact that in Tiplady (2006) the pre-installation study was done at a time when the leat had been blocked for two years to facilitate the mill restoration. All the water had been flowing down the depleted reach for two years. Whilst the amount of water flow beyond the tail race would not be changed the "baseline" could be unrepresentative due to the altered flow. For this reason Tiplady (2006) is not referred to as a baseline study.

In 2012 both the Simpson Index and the ASPT were low. The summer of 2012 witnessed exceptional weather with many weeks of rain. The weeks before sampling had above average flows in the river of 6 m^3/s. The low Simpson index may be due to the sustained high flows of water creating an environment more suited to invertebrates that prefer high flows. The corresponding low ASPT is not what would be expected to be measured; in high flows organic pollution should not accumulate. During flood events and therefore high flow invertebrates migrate to refuges with lower flow (Lake, 2000). hich were not included in this data. The 2012 Tellisford downstream data may indicate this. The sample near the river edge had 269 individuals. This sample was not included in the analysis for this part of the study as this habitat was not sampled in the previous studies. The other samples in the areas of higher flow had 58 and 72 individuals.

The effect of flow on diversity may increase to an optimum and then decrease. This may be illustrated in the results for 2009 and 2012. The Simpson Index in 2009 was recorded at its highest (0.95) when flow was measured at 3.25 m^3/s. In 2012 the Simpson Index was recorded at its lowest (0.75) when flow was measured at 6 m^3/s. The optimum flow for diversity may be around 3.25 m^3/s with higher flows possibly resulting in reduced diversity.

Biological water quality was measured at its highest before the MHP installation. The method of invertebrate identification in the two previous studies was more detailed than in this study and included insects living on the surface of the water; this would lead to better scores. There was no trend to indicate that the MHP is affecting biological water quality. The sampling in Tiplady (2006) was conducted in June. In Elvey (2009) and this study the sampling was conducted in July, which may give differing results.

Sampling done in 2007, just after the MHP installation, found a drop in biological water quality. This may be due to disturbances in the environment caused by works associated with the mill restoration (Robson *et al.,* 2011).

The annual variations in diversity and pollution showed no significant correlation to flow. These results must be treated with caution as there are few data points and the outlying data points at 6 m^3/s had a large leverage on the regression lines. A significant correlation between diversity, biological water quality and flow may have been demonstrated in this study with more data. It is generally accepted that diversity decreases with decreased flow, due to increased sedimentation and the anoxic environment created by this (Defra, 2008; Environmental Protection Agency, 2012). It is also usually found that pollution decreases with increased flow due to dilution (Defra, 2008; Environmental Protection Agency, 2012).

5.4 Visual assessment

5.4.1 Hapsford

The depleted reach is very shallow in parts and may be difficult for large fish to navigate. The weir as yet has no fish pass and upstream reaches are not accessible to resident fish. It has not been possible to ascertain if fish are restocked in this locality, by the local angling club.

Yellow eels (eel life cycle stage after glass eels) may be able to pass upstream over the weir via the vegetation to the side. Adult eels are able to crest the weir or if in the leat, continue downstream via the return channel. There is sufficient depth of water in the depleted reach for eels to navigate downstream but they may be vulnerable to predation. Other issues arise because the tail race is deep and fast flowing which could encourage fish preferentially up the tail race, where they may become impounded. Impounded resident fish may be prevented from reaching different habitats of the river at particular times of year. However most of the tail race at Hapsford is in a culvert (Figure 16, Chapter 4) which may deter resident fish from swimming further up (Broadhead, pers. comm., 2013)[3].

Impounded eels are able to survive in this habitat but if they are present in large numbers may compete for food and space, causing stress and vulnerability to disease and predation. The tail race being in a culvert may not deter eels as they prefer to move at night along the river bed.

5.4.2 Tellisford

Resident fish can move upstream via the fish notch when there is sufficient flow. Elvey (2009) reported an improvement in the fish population biomass, after the MHP installation. The greatest improvements were found in fish species that were not restocked.

As at Hapsford yellow eels in the river will be able to migrate over the weir using the vegetation at the river edge or may become impounded in the tail race. Adult eels impounded in the leat can continue downstream via the return channel or the eel pipe and although this is prone to blockage the sluice to the return channel is slightly opened to stop the water in the return channel from becoming stagnant (Battersby, pers. comm., 2013b).

5.4.3 Iford

A low level of flow is maintained in the leat and tail race controlled by a sluice gate, which is occasionally opened when the trash rack is being cleared (Battersby, pers. comm., 2013b, 2013c). The leat therefore has a slow flow of water; the slow flow will not attract fish into the tail race and should result in them continuing upstream via the main river. Fauna can move up and downstream over the weir via the fish and eel passes. Whether water crests the weir at low flows since the turbine installation, is still to be determined.

5.4.4 Other observations

Hapsford Mill is the most upstream of the mills and yellow eels travelling this far upstream not only have the problem of an impassable mill and weir only passable via the bank, but are likely to be

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[3] Adam Broadhead, Ph.D. student, Sheffield University.

predated by non-indigenous American Signal Crayfish that are abundant in this area and further upstream.

The likely source of the cloudiness seen in the water at Hapsford in 2013 is the limestone quarry discharge upstream which may introduce fine sediment. The weir did not appear to aid the settling out of this sediment but was not evident at the next downstream sampling site, probably due to dilution. However the water input for the quarry drainage may be maintaining flow in the river higher than it would ordinarily be (Lewin Fryer, 2004).

The sewage treatment works upstream at Tellisford seems to have effective storm management and very rarely needs to discharge into the river (Jones, pers. Comm., 2012) this is backed up by the invertebrate species present; indicating water of very good biological quality (Murray-Bligh, 1999).

5.5 Further research

Studies should be undertaken to determine which fish are habiting the tail races at Hapsford and Tellisford and in what numbers, which will ascertain if there is a need to screen the entrance to the tail races to prevent fish from becoming impounded.

The EA have conducted fish surveys at Tellisford and have a record of which species are present in the river. However all the local angling groups along the river should be contacted to determine which fish species are restocked and in what numbers. This may provide a clearer indication of movement of fish upstream and downstream over the weirs.

It was not within the scope of this study to sample the depleted reach. Elvey (2009) found no significant change in the invertebrates post installation, although this study was only conducted over two years. Subsequent EA monitoring (2009-2013) of the depleted reach has found changes in the invertebrate assemblages but not a decrease in the ecological status (Aftergood & Damary-Homan, 2013). A detailed longitudinal study of the river around a MHP scheme may ascertain a greater understanding of the changes in diversity and water quality, including upstream beyond the impounded water, the impounded water, leat, depleted reach, tail race and downstream.

There are variables e.g. pollution and temperature that require further investigation to determine what is causing the year to year variations observed at Tellisford.

Chemical and physical water qualities could be measured for a more accurate assessment of whether the turbine is changing these qualities.

Assessing the nature of the sediment behind the weirs may give an indication of other externalities that are affecting the river fauna e.g. anthelmectin contamination and may determine if the weirs are acting to improve the river habitats downstream.

This research and suggested further study should be extended to other sites on other rivers.

Research into migration delay exclusively studies large hydropower (Raymond, 1968; Venditti *et al.,* 2000; Salinger & Anderson, 2006; Caudill *et al.,* 2007) more research should be done specifically in relation to MHP.

In the UK climate change is already resulting in longer periods of drought interspersed with heavier, more prolonged episodes of rainfall (Environment Agency, 2013c). This results in more frequent extremes of water flow in the rivers. Modern agriculture exacerbates this problem by not facilitating rainwater to penetrate the ground leading to surface water runoff and inundation (Pattison & Lane, 2012). Because the groundwater is not recharged adequately, the base flows in the river run lower in drier periods (Pang *et al*., 2010). Further research needs to be conducted into how to store water in the agricultural landscape and facilitate groundwater recharge. This will slow water flow from the catchment into the rivers, helping to mitigate the flood/drought cycle and improve the ecological status of rivers (De Laney, 1995; Aldous *et al.,* 2011).

5.6 Recommendations

It is recommended that the planned fish pass installation on the weir at Hapsford is started.

If eels are found to be living in the tail races in large numbers it may be preferential to relocate them. Glass eels returned to rivers in high numbers during a 2013 (Gray, 2013). From this it would be expected that if eels were impounded in tail races they would be present in high numbers; there was no evidence of this occurring (Battersby, pers. comm., 2013b).

The EA should explain clearly to MHP owners the reasons for the measures they require to be put in place to protect wildlife. Owners of MHP schemes may not have an extensive knowledge of river ecology or an appreciation of the EA’s position.

Each mill site and each river has an individual set of circumstances that result in different impacts on the wildlife by MHP, each site must be assessed individually (Robson *et al.,* 2011).

Throughout Europe fishing of the critically endangered European Eel (*Anguilla anguilla*) should be halted as one of the many measures that could be implemented to allow numbers to recover.

The EU should reconsider the rules for assessing the ecological status of a river under the Water Framework Directive which can result in an unrepresentative evaluation (Cunningham, 2012).

5.7 Contribution to knowledge

This is the only study that has investigated the diversity of invertebrates and MHP in more of the river system, not just the depleted reach. Stakeholders need to take into account environmental impact of the whole MHP installation. The EA routinely test the depleted reach for invertebrates indicating water flow (Sisson, pers. comm., 2012)[4]. This may not be a fair assessment of the ecological status of a river (Aftergood & Damary-Homan, 2013). The other niches of the ecosystem are not measured. The habitats found in the leat, tail race and weir pool are providing new niches and thus increasing invertebrate diversity providing food for fauna higher up the food chain (Environment Agency, 2003). The invertebrate diversity also indicates that the turbines are not having a deleterious effect upon their abundance.

5.8 Limitations and problems

It could not be concluded that a Crossflow turbine is better than an Archimedes Screw. The different riparian environments at each of the sites meant it was not possible to compare the sites to each other. The mill at Hapsford is situated high upstream in woodland, the mill at Iford is in the lower reaches of the river in farmland. The different environs mean that the two cannot be compared.

At Tellisford both sampling points were downstream of the sewage treatment works so that the potential impact of this was consistent for both sets of data.

At each mill location the sampling sites were some distance from one another. However the riparian environment was the same for the upstream and downstream sites, any externalities that may affect the results are discussed e.g. cattle wading in the river at Tellisford is only applicable to the downstream sample. At Hapsford downstream sampling was fifty metres from where the tail race joined the river due to the water depth.

The abnormally wet weather in summer 2012 delayed sampling due to the high water level. This determined the timing of sampling in 2013. Invertebrate sampling should take place at the same time of year to avoid seasonal variation. Due to time constraints it was not possible to exactly match the timing of sampling to the previous two studies or to sample at other data points.

Tiplady (2006) and Elvey (2009) calculated ASPT over several months both before and after the MHP installation. When comparing data it was only possible to use the data points that corresponded with

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[4] Jaques Sisson, Technical Advisor, Natural Resources Wales.

the same time of year as data points in this study, to alleviate the variable of seasonality (Wheater *et al.,* 2012). The baseline in Tiplady (2006) was calculated at a time when the river flow had been temporarily changed possibly resulting in an artificially high result. Also the previous studies preserved the invertebrates in alcohol for identification in a laboratory. This was deemed not be beneficial to the ecosystem and for this study identification was done on location. However laboratory identification is more accurate and can be done to sub-species level resulting in greater accuracy than in this study.

The deep water in the river in 2012 restricted access to the upstream reaches at Iford, the only accessible and safe point was in a depleted reach which is not ideal but sampling this point in 2013 did illustrate the impact of an unimproved weir.

Aftergood & Damary-Homan is the follow on study to Elvey (2009). This report has yet to be published and was only available in mid August 2013. In any further research this study should be used for the comparison to historical data at Tellisford.

5.9 Conclusion

5.9.1 Conclusions from this study

The conclusions of this study only apply to these sites on the Somerset Frome. Other rivers, especially salmon rivers or rivers that are not restocked with fish will have different criteria to ensure good ecological status e.g. amount of water cresting the weir and depth of water in the depleted reach at low flow.

The River Frome is a highly modified river with many mills and weirs that have been present for many hundreds of years. The installation of MHP results in less water flowing in the depleted reach, but the other associated environs are improved. When assessing the ecological impact of MHP the EA only sample the depleted reach and they employ methods that assess invertebrates that prefer higher flows. This may result in a worse assessment of the ecological status of the river than is actually the case.

The installation of MHP on the River Frome has resulted in a more diverse invertebrate population. Eels are able to migrate up and downstream although may become impounded in the tail races at Hapsford and Tellisford. However for eels present in low numbers this is not problematical. At low flows there are issues for resident fish being unable to pass upstream over the weirs at Tellisford and Iford. The weir at Hapsford is currently impassable to resident fish. The timing of higher flows, re-allowing movement of fauna over the weir, may have different effects on different species depending on where they need to be in the river at specific times of year or it may have no effect. Some fish species are restocked by the local angling associations (Lewin Fryer, 2004) and so the need for genetic mixing between these fish populations is alleviated. The effect on other fish species and fishing in the area since the weir improvements it is not known.

5.9.2 Wider conclusions

Threats to aquatic fauna are many. MHP is a small threat in comparison to agricultural pollution (Kövecses & Marcogliese, 2005; Schäfer *et al.,* 2012; Beketov *et al.,* 2013) or climate change (Whitworth *et al.* 2012) but should still be considered and every effort, based on scientific evidence, should be made to protect all wildlife.

The European Eel (*Anguilla anguilla)* is classed as critically endangered (International Union for the Conservation of Nature, 2013), every individual is important. Eels are subject to many stressors that are contributing to their decline (Defra, 2010) and yet they are still on the menu around Europe, it seems illogical to put expensive and time consuming constraints on the owners of MHP schemes when eels can be fished with no restrictions (Gray, 2013).

Currently the EA use flow data to determine the amount of water that can be abstracted for use by MHP. As UK weather patterns change due to climate change (Met. Office, 2011) it may be increasingly difficult to apply a standard to each MHP scheme. Each installation should be considered on a case by case basis (Robson *et al*., 2011). This can already be demonstrated; the licence at Hapsford has resulted in less flow in the depleted reach than at Tellisford.

One of the biggest threats to river wildlife is climate change (Lake, 2000; Pang *et al*., 2010; Whitworth *et al*., 2012; Environment Agency, 2013a; Verdonschot, 2013). MHP could have a significant effect in lowering UK carbon emissions; Tellisford alone offsets 116 tonnes of carbon annually (Battersby, pers. comm., 2013b). In 2002 the potential electricity generating capacity in England was estimated to be 50 MW at low head sites (Paish, 2002). These sites are mostly in outlying areas at the end of the electricity distribution grid. Electricity generated at these sites can be distributed locally reducing transmission losses, alleviating the need to generate even more electricity centrally to compensate for these losses.

At low head MHP in lowland reaches the current guidelines require flow in the depleted reach that occurs 95% (Q95). The EA consultation ended in July 2013 and they have recommended significantly decreasing the proportion of water in the river can be used for hydropower. This reduces the amount of electricity generated, which would reduce the income received via the feed in tariff. The proposed option with the least impact on MHP would render projects financially unviable (Battersby, pers. comm., 2013a; Micro Hydro Association, 2013).

The EA must legally improve the ecological status of rivers. Under the Water Framework Directive many measurements are taken to determine this status. The lowest indicator is then used which can result in an unrepresentative appraisal (Cunningham, 2012). This would explain why the EA classify the lower reaches of the Somerset Frome as being of poor ecological status (Environment Agency, 2013d) when this study would indicate that this is not the case at the locations and times studied.

In the UK modern agriculture has a large impact on river ecology causing diffuse pollution from manure (Defra, 2008), veterinary medicines (Kövecses & Marcogliese, 2005; Boxall *et al.,* 2003), chemical fertilisers, pesticides (Defra, 2008; Schäfer *et al.,* 2012; Beketov *et al.,* 2013), sediment loading, water abstraction for irrigation (Richter *et al*. 1997), flooding and drought (Pang *et al*., 2010) . The costs associated to mitigate these effects are passed on to the general public e.g. the cost of removing agricultural pollution from drinking water is paid for in our water bills. If this cost was borne by farmers or the agrochemical companies the result would be higher food prices. Given the political sensitivity of this and the lobbying power of the National Farmers Union and the agrochemical industry, it is unlikely that a "polluter pays" policy will be enforced by the UK government. The EA is left in the frustrating position of having limited influence on the primary causes of ecological degradation in our rivers. The proposed new guidelines for water abstraction for hydropower will make MHP financially unviable to implement (Battersby, pers. comm., 2013a; Micro Hydro Association, 2013) with no evidence that they will improve the ecological status of UK rivers.

Each river and each MHP scheme has a diverse catchment, with unique flow characteristics and natural history. Each application to install MHP should be considered case by case (Robson *et al.,* 2011) applying current knowledge, based on scientific evidence at each site.

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Appendices

Appendix A

BMWP Scores for invertebrate families.

Common Name	Family	BMWP Score	Common Name	Family	BMWP Score
Flatworms	Planariidae	5	Dragonflies	Gomphidae	8
	Dendrocoelidae	5		Cordulegasteridae	8
Snails	Neritidae	6		Aeshnidae	8
	Viviparidae	6		Corduliidae	8
	Valvatidae	3		Libellulidae	8
	Hydrobiidae	3	Bugs	Mesoveliidae	5
	Lymnaeidae	3		Hydrometridae	5
	Physidae	3		Gerridae	5
	Planorbidae	3		Nepidae	5
Limpets and Mussels	Ancylidae	6		Naucoridae	5
	Unionidae	6		Aphelocheiridae	10
	Sphaeriidae	3		Notonectidae	5
Worms	Oligochaeta	1		Pleidae	5
Leeches	Piscicolidae	4		Corixidae	5
	Glossiphoniidae	3	Beetles	Haliplidae	5
	Hirudididae	3		Hygrobiidae	5
	Erpobdellidae	3		Dytiscidae	5
Crustaceans	Asellidae	3		Gyrinidae	5
	Corophiidae	6		Hydrophilidae	5
	Gammaridae	6		Clambidae	5
	Astacidae	8		Scirtidae	5
Mayflies	Siphlonuridae	10		Dryopidae	5
	Baetidae	4		Elmidae	5
	Heptageniidae	10		Chrysomelidae	5
	Leptophlebiidae	10		Curculionidae	5
	Ephemerellidae	10	Alderflies	Sialidae	4
	Potamanthidae	10	Caddisflies	Rhyacophilidae	7
	Ephemeridae	10		Philopotamidae	8
	Caenidae	7		Polycentropidae	7
Stoneflies	Taeniopterygidae	10		Psychomyiidae	8
	Nemouridae	7		Hydropsychidae	5
	Leuctridae	10		Hydroptilidae	6

	Capniidae	10		Phryganeidae	10
	Perlodidae	10		Limnephilidae	7
	Perlidae	10		Molannidae	10
	Chloroperlidae	10		Beraeidae	10
Damselflies	Platycnemidae	6		Odontoceridae	10
	Coenagriidae	6		Leptoceridae	10
	Lestidae	8		Goeridae	10
	Calopterygidae	8		Lepidostomatidae	10
Dragonflies	Gomphidae	8		Brachycentridae	10
	Cordulegasteridae	8		Sericostomatidae	10
	Aeshnidae	8	True flies	Tipulidae	5
	Corduliidae	8		Chironomidae	2
	Libellulidae	8		Simuliidae	5

Appendix B

Raw data Tiplady (2006)

Species	n	n/N	n/N²
Baetis scambus	4	0.001369	1.87524E-06
Baetis rhodani	90	0.030811	0.00094934
Bithynia tentaculata	15	0.005135	2.63706E-05
Caenis luctuosa	10	0.003423	1.17203E-05
Caenis rivulorum	4	0.001369	1.87524E-06
Erpodella octoculata	32	0.010955	0.000120015
Ephemera danica	10	0.003423	1.17203E-05
Gammarus pulex	38	0.013009	0.00016924
Lymnaea peregra	1	0.000342	1.17203E-07
Leuctra sp	14	0.004793	2.29717E-05
Pisidum subtruncatum	20	0.006847	4.6881E-05
Pisidum henslowanum	8	0.002739	7.50096E-06
Pisidum supinum	8	0.002739	7.50096E-06
Pisidium nitidum	5	0.001712	2.93006E-06
Sphaerium corneum	63	0.021568	0.000465177
Theodoxus fluviatilis	74	0.025334	0.000641801
Tubifex tubifex	36	0.012325	0.000151894
Seratalla ignita	493	0.168778	0.028485951
Elmis aenea	25	0.008559	7.32516E-05
Limnius volkmari	470	0.160904	0.025890033
Oulimnius tuberculatus	42	0.014379	0.000206745
Hydropsyche pellucidula	3	0.001027	1.05482E-06
Hydropsyche siltalai	16	0.005478	3.00038E-05
Simulium equinum(larvae	740	0.253338	0.064180091
Simulium ornatum(larvae	700	0.239644	0.057429226
N	2921	D	0.178935288
		1-D	0.821064712

ASPT = 6.3

Raw Data Elvey (2009)

Species	n 2007	n/N	n/N²	n 2009	n/N	n/N²
Theodoxus fluviatilis	16	0.0132	0.000175431	250	0.0843739	0.007118963
Bithynia tentaculata	14	0.0116	0.000134314	19	0.0064124	4.11191E-05
Lymnaea peregra				2	0.000675	4.55614E-07
Planorbis carinatus				1	0.0003375	1.13903E-07
Gyraulus albus				4	0.00135	1.82245E-06
Ancylus fluviatilis	8	0.0066	4.38577E-05	56	0.0188998	0.000357201
Sphaerium corneum	41	0.0339	0.001151951	90	0.0303746	0.000922618
Pisidium				20	0.0067499	4.55614E-05
Pisidium henslowanum	1	0.0008	6.85277E-07	56	0.0188998	0.000357201
Pisidium nitidum	34	0.0281	0.00079218	92	0.0310496	0.000964078
Pisidium subtruncatum	5	0.0041	1.71319E-05			
Oligochaeta	130	0.1076	0.011581181	130	0.0438745	0.001924968
Lumbricidae	5	0.0041	1.71319E-05			
Theromyzon tessulatum				1	0.0003375	1.13903E-07
Glossiphonia complanata				4	0.00135	1.82245E-06
Helobdella stagnalis				2	0.000675	4.55614E-07
Erpobdella octoculata	9	0.0075	5.55074E-05	49	0.0165373	0.000273482
Hydracarina				1	0.0003375	1.13903E-07
Asellus aquaticus	4	0.0033	1.09644E-05	1	0.0003375	1.13903E-07
Crangonyx pseudogracilis	4	0.0033	1.09644E-05			
Gammarus pulex	96	0.0795	0.006315512	129	0.043537	0.001895467
Orectochilus villosus				9	0.0030375	9.22618E-06
Elmis aenea	115	0.0952	0.009062788	353	0.119136	0.014193389
Limnius volckmari	407	0.3369	0.113515443	623	0.2102599	0.044209214
Oulimnius	8	0.0066	4.38577E-05	44	0.0148498	0.000220517
Oulimnius tuberculatus	24	0.0199	0.00039472	161	0.0543368	0.00295249
Rhyacophila	3	0.0025	6.16749E-06	24	0.0080999	6.56084E-05
Rhyacophila dorsalis	56	0.0464	0.002149029	65	0.0219372	0.000481242
Hydroptila	1	0.0008	6.85277E-07	2	0.000675	4.55614E-07
Hydropsyche	31	0.0257	0.000658551	30	0.0101249	0.000102513
Hydropsyche angustipenr	16	0.0132	0.000175431	96	0.0323996	0.001049734
Hydropsyche pellucidula	19	0.0157	0.000247385	92	0.0310496	0.000964078
Hydropsyche siltalai	16	0.0132	0.000175431	50	0.0168748	0.000284759
Chironomidae	145	0.12	0.014407948	507	0.1711104	0.029278756
N	1208	D	0.161144248	2963	D	0.10771765
		1-D	0.838855752		1-D	0.89228235

ASPT 5.8 6.2

Appendix C

Tellisford 2012																
species	family															
		BMWP	20cm	30cm	40cm	**n ds**	n/N	n/N²	BMWP	20cm	30cm	40cr	**n us**	n/N	n/N²	BMWP
Brachycercus harrsiella	Caenidae	7			2	**2**	0.013	2E-04	7							
Ephemera danica	ephemeridae	10	2	10		**12**	0.076	0.006	10			2	**2**	0.012	0.0001	10
Centroptilum luteolum	Baetidae	4			3	**3**	0.019	4E-04	4							
Caenis horaria	Caenidae	7	2	6		**8**	0.051	0.003		7	10	9	**26**	0.1566	0.0245	7
Leuctra sp	Leuctridae	10					0			1	1	4	**6**	0.0361	0.0013	10
Capnia bifrons	Capniidae	10					0			3		1	**4**	0.0241	0.0006	10
Amphinemura standfussi	Nemouridae	7					0				1		**1**	0.006	4E-05	7
Psychoda sp			3	4	5	**12**	0.076	0.006		2	2	3	**7**	0.0422	0.0018	
Heleinae sp			1		3	**4**	0.025	6E-04				2	**2**	0.012	0.0001	
Hydrobius fuscipes	Hydrophilidae	5		3	1	**4**	0.025	6E-04	5		1	1	**2**	0.012	0.0001	5
Helophorus aquaticus				1		**1**	0.006	4E-05								
Dysticus marginalis (larvae)	Dytiscidae	5		3	1	**4**	0.025	6E-04	5	3	4	4	**11**	0.0663	0.0044	5
Diplodontus despiciens			1		*1*	**2**	0.013	2E-04								
Gammarus pulex	Gammaridae	6		14	2	**16**	0.101	0.01	6	8	33	46	**87**	0.5241	0.2747	6
Sphaerium corneum	Sphaeriidae	3		8		**8**	0.051	0.003	3							
Viviparus fasciatus	Viviparidae	6		3		**3**	0.019	4E-04	6			1	**1**	0.006	4E-05	
Planaria torva	Planariidae	5	1	1		**2**	0.013	2E-04	5							
Haemopsis sanguisuga					2	**2**	0.013	2E-04								
Glossophonia concolor	Glossiphoniidae	3	1			**1**	0.006	4E-05	3			1	**1**	0.006	4E-05	3
Helobdella stagnalis	Glossiphoniidae	3					0				1		**1**	0.006	4E-05	
Tubifex tubifex	Tubificidae	1	16	34	24	**74**	0.468	0.219	1	1	6	8	**15**	0.0904	0.0082	1
			27	*87*	*44*				55	*25*	*59*	*82*				64
					N	**158**		0.25	ASPT 5			N	**166**		0.316	ASPT 6.4
simpson index ds	0.750360519															
simpson index us	0.683988968															

Hapsford 2012																
species	family	MWP	20cm	30cm	40cm	ds	n/N	n/N²	BMWP				us	n/N	n/N²	BMWP
										20cm	30cm	40cm				
Hepatagenia sulpurea	Heptageniidae	10	1	1	2	4	0.04	0.0016	10	2	1	3	6	0.075	0.0056	10
Brachycercus harrsiella	Caenidae	7	2		5	7	0.07	0.0049	7			1	1	0.013	0.0002	7
Ephemera danica	ephemeridae	10	3	2	3	8	0.08	0.0064	10	2			2	0.025	0.0006	10
Caenis horaria	Caenidae	7	1	1	1	3	0.03	0.0009		1	1	1	3	0.038	0.0014	
Leuctra sp	Leuctridae	10	1	3	2	6	0.06	0.0036	10							
Perlodes microcephala	Perlodidae	10		2		2	0.02	0.0004	10							
Psychoda sp	Psychodidae			1	1	2	0.02	0.0004				2	2	0.025	0.0006	
Thaumalea testacea	Thaumaleidae				1	1	0.01	0.0001								
Dysticus marginalis (larvae)	Dytiscidae	5		2	2	4	0.04	0.0016	5							
Limnius volkman (larvae)	Elmidae	5			1	1	0.01	0.0001	5							
Limnochares aquaticus	Limnocharidae									1			1	0.013	0.0002	
Gammarus pulex	Gammaridae	6	2	14	11	27	0.27	0.0729	6	5	20	34	59	0.738	0.5439	6
Pacifastacus leniusculus	Astacidae	8										1	1	0.013	0.0002	8
Valvata piscinalis	Valvatidae	3			4	4	0.04	0.0016	3							
Tubifex tubifex	Tubificidae	1	2	12	17	31	0.31	0.0961	1	2	1	2	5	0.063	0.0039	1
			12	*38*	*50*				67	*13*	*23*	*44*				42
					N	100	D	0.1906	ASPT 6.7			N	80	D	0.5566	ASPT 7
1-D ds	0.8094															
1-D us	0.4434375															

Iford 2012																
species	family	BMWP				ds	n/N	n/N²	BMWP				us	n/N	n/N²	BMWP
			20cm	30cm	40cm					20cm	30cm	40cm				
Rhyacophilia sp	rhyacophilidae	7	4	1	1	6	0.01504	0.0002	7							
Grammotaulius nigropunctata	Limnephilidae	7			1	1	0.00251	6E-06	7							
Hepatagenia sulpurea	Heptageniidae	10	1			1	0.00251	6E-06	10							
Brachycercus harrsiella	Caenidae	7	38	16	6	60	0.15038	0.0226	7	4	7	1	12	0.184615	0.034083	7
Ephemera danica	ephemeridae	10									1		1	0.015385	0.000237	10
Centroptilum luteolum	Baetidae	4	1			1	0.00251	6E-06	4							
Caenis horaria	Caenidae	7	41	26	9	76	0.19048	0.0363		2	1	1	4	0.061538	0.003787	
Psychoda sp	Psychodidae		16	6	1	23	0.05764	0.0033		4		1	5	0.076923	0.005917	
Dicranota sp	Pediciidae		137			137	0.34336	0.1179								
Helophorus aquaticus	Helophoridae				3	3	0.00752	6E-05				1	1	0.015385	0.000237	
Dysticus marginalis (larvae)	Dytiscidae	5	1		2	3	0.00752	6E-05	5	1	2		3	0.046154	0.00213	5
Limnius volkman (larvae)	Elmidae	5								1			1	0.015385	0.000237	5
Oulimnius sp (larvae)	Elmidae	5	1			1	0.00251	6E-06	5							
Arrenurus sp	Arrenuridae											1	1	0.015385	0.000237	
Gammarus pulex	Gammaridae	6	5	6	5	16	0.0401	0.0016	6							
Sphaerium corneum	Sphaeriidae	3	2		1	3	0.00752	6E-05	3							
Viviparus fasciatus	Viviparidae	6	4		10	14	0.03509	0.0012	6							
Ancylus fluviatlis	Planorbidae	3			2	2	0.00501	3E-05	3	2	4		6	0.092308	0.008521	3
Haemopsis sanguisuga	Haemopidae				2	2	0.00501	3E-05				1	1	0.015385	0.000237	
Helobdella stagnalis	Glossiphoniidae	3	1		2	3	0.00752	6E-05	3							
Dina lineata	Erpobdellidae	3			1	1	0.00251	6E-06	3							
Tubifex tubifex	Tubificidae	1	17	3	26	46	0.11529	0.0133	1	24	2	4	30	0.461538	0.213018	1
			269	*58*	*72*				70	*38*	*17*	*10*				31
		total			N	399	D	0.1968				N	65	D	0.268639	
									ASPT 5							ASPT 5.2
1-D ds	0.803223598															
1-D us	0.731360947															

Tellisford 2013																
species	family															
		BMWP	20cm	30cm	40cm	**ds**	n/N	n/N²	BMWP	20cm	30cm	40cr	**us**	n/N	n/N²	BMWP
Sericostoma sp	Sericostmoatida	10			1	**1**	0.011	1E-04	10			2	**2**	0.0116	0.0001	10
Anabolia sp	Limnephilidae	7	5	1	3	**9**	0.103	0.011	7							
Triaenodis bicolor	Leptoceridae	10		1		**1**	0.011	1E-04	10							
Brachycercus harrsiella	Caenidae	7	2	1	2	**5**	0.057	0.003	7	4	1	2	**7**	0.0407	0.0017	7
Ephemera danica	ephemeridae	10	3	5	2	**10**	0.115	0.013	10	7	9	10	**26**	0.1512	0.0229	10
Baetis sp	Baetidae	4		2		**2**	0.023	5E-04	4	2		5	**7**	0.0407	0.0017	4
Caenis horaria	Caenidae	7								2			**2**	0.0116	0.0001	7
Leuctra sp	Leuctridae	10	2		2	**4**	0.046	0.002	10	2	3		**5**	0.0291	0.0008	10
Culex pipiens				1		**1**	0.011	1E-04								
Psychoda sp			2	2	1	**5**	0.057	0.003		2	2	2	**6**	0.0349	0.0012	
Heleinae sp										2		2	**4**	0.0233	0.0005	
Hydrobius fuscipes	Hydrophilidae	5		2	1	**3**	0.034	0.001	5	2		1	**3**	0.0174	0.0003	5
Dysticus marginalis (larvae)	Dytiscidae	5								5	4		**9**	0.0523	0.0027	5
Hydrozetes lacustris			3	*1*	*3*	**7**	0.08	0.006								
Gammarus pulex	Gammaridae	6		3	3	**6**	0.069	0.005	6	32	22	12	**66**	0.3837	0.1472	6
Asellus aquaticus	Asellidae	3		2		**2**	0.023	5E-04	3							
Sphaerium corneum	Sphaeriidae	3	4	1	5	**10**	0.115	0.013	3			2	**2**	0.0116	0.0001	3
Planorbis albus	Planorbidae	3			1	**1**	0.011	1E-04	3							
Valvata piscinalis	Valvatidae	3			3	**3**	0.034	0.001	3							
Limnea sp	Lymnidae	3								6	1	1	**8**	0.0465	0.0022	3
Haemopsis sanguisuga					1	**1**	0.011	1E-04		1	1	1	**3**	0.0174	0.0003	
Polycelis felina	Planaridae	5		1		**1**	0.011	1E-04	5							
Tubifex tubifex	Oligochaeta	1	2	3	10	**15**	0.172	0.03	1	3	10	6	**19**	0.1105	0.0122	1
Eiseniella tetraedra	*Oligochaeta*	*1*							60	*1*	*2*		**3**	0.0174	0.0003	61
					N	**87**	D	0.091	ASPT 4.62			N	**172**	D	0.1944	ASPT 6.4
1-D ds	0.908970802															
1-D us	0.805570579															

Hapsford 2013																	
species	family	VP	20cm	30cm	40cm	ds	n/N	n/N²	BMWP				us	n/N	n/N²	BMWP	
										20cm	30cm	40cm					
Hepatagenia sulpu	Heptageniidae	10								2	2		4	0.13	0.018	10	
Brachycercus harrs	Caenidae	7			1	1	0.04	0.002	7								
Ephemera danica	ephemeridae	10	2	1	1	4	0.16	0.026	10								
Caenis horaria	Caenidae	7			1	1	0.04	0.002	7								
Leuctra sp	Leuctridae	10								4		3	7	0.23	0.054	10	
Psychoda sp	Psychodidae				2	2	0.08	0.006		1			1	0.03	0.001		
Dysticus marginali	Dytiscidae	5		2		2	0.08	0.006	5	2	2		4	0.13	0.018	5	
Culex pipiens					1	1	0.04	0.002									
Limnius volkman (l	Elmidae	5			1	1	0.04	0.002	5	1	1	1	3	0.1	0.01	5	
Chironomous sp	Chironomidae	2	3			3	0.12	0.014	2								
Gammarus pulex	Gammaridae	6	1	1	3	5	0.2	0.04	6	2	7	1	10	0.33	0.111	6	
Pacifastacus lenius	Astacidae	8		1		1	0.04	0.002	8							8	
Ancylus fluviatilis	Planorbidae	3		2	1	3	0.12	0.014	3								
Tubifex tubifex	Tubificidae	1		1		1	0.04	0.002	1		1		1	0.03	0.001	1	
									54							45	
					N	25	D	0.117	ASPT 5.4			N	30	D	0.213	ASPT6.43	
D-1 ds	0.8832																
D-1 us	0.786666667																

Iford 2013																	
species	family	BMWP				ds			BMWP				us			BMWP	
			20cm	30cm	40cm		n/N	n/N²		20cm	30cm	40cm		n/N	n/N²		
Isoperla sp	Perlodidae		3	2	6	11	0.054	0.0029									
Leuctra sp	leuctridae	10	6			6	0.029	0.0009	10								
Rhyacophilia sp	rhyacophilidae	7	1			1	0.005	2E-05	7								
Anabolia sp	Limnephilidae	7		2	5	7	0.034	0.0012	7		1		1	0.013	0.0002	7	
Tinodes waeneri	Phyraganidae	10		2	8	10	0.049	0.0024									
Mystacides longicornis	Phyraganidae	10		1	4	5	0.024	0.0006	10								
Athripsodes sp	Phyraganidae	10			1	1	0.005	2E-05									
Brachycercus harrsiella	Caenidae	7	1	3	1	5	0.024	0.0006	7		3	1	4	0.051	0.0026	7	
Ephemera danica	ephemeridae	10			8	8	0.039	0.0015	10		12	6	18	0.231	0.0533	10	
Baetis sp	Baetidae	4		1		1	0.005	2E-05	4	1	2		3	0.038	0.0015	4	
Psychoda sp	Psychodidae		5		3	8	0.039	0.0015									
Chironomous sp	Chironomidae	2	2	1	5	8	0.039	0.0015	2	2	6	7	15	0.192	0.037	2	
Culex pipiens				1	1	2	0.01	1E-04			1		1	0.013	0.0002		
Rhantus exoletus	Dytiscidae	5	1			1	0.005	2E-05	5								
Dysticus marginalis(larvae)	Dytiscidae	5	7	7	6	20	0.098	0.0095				1	1	0.013	0.0002	5	
Limnius volkman (larvae)	Elmidae	5							5	1			1	0.01	0.000	5	

														3	2		
Oulimnius sp(larvae)	Elmidae	5	1		1	2	0.01	1E-04									
Hydrobius fuscipes	hydrophilidae	5	4	4		8	0.039	0.0015	5								
Elmis amea	Elmidae	5			5	5	0.024	0.0006									
Arrenurus sp	Arrenuridae				1	1	0.005	2E-05									
Diplodontus sp				1	9	10	0.049	0.0024									
Gammarus pulex	Gammaridae	6	18	15	3	36	0.176	0.0308	6								
Limnea sp	Lymnaeidae	3	3	2	2	7	0.034	0.0012	3								
Ancylus fluviatlis	Planorbidae	3	7	9	7	23	0.112	0.0126	3		1		1	0.013	0.0002	3	
Haemopsis sanguisuga	Haemopidae		1		1	2	0.01	1E-04		1			1	0.013	0.0002	3	
Helobdella stagnalis	Glossiphoniidae	3			1	1	0.005	2E-05	3								
Glossophonia concolor	Glossiphoniidae	3		1	3	4	0.02	0.0004									
Tubifex tubifex	Oligochaeta	1		1	10	11	0.054	0.0029	1	11	14	7	32	0.41	0.1683	1	
Eiseniella tetraedra	Oligochaeta	1			1	1	0.005	2E-05	78							47	
		total			N	205	D	0.0716				N	78	D	0.2636		
									ASPT4.9							ASPT4.7	
1-D ds	0.928375967																
1-D us	0.736357659																