THE UNIVERSITY OF HULL

Impacts of water abstraction upon migratory fish species in the rivers Wye and Usk.

Being a thesis submitted for the degree of Master of Research

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by

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ABSTRACT

To assess the potential impact of increased abstraction on twaite shad (*Alosa fallax* (L.)) and Atlantic salmon (*Salmo salar* L.), the latter at two life stages (returning adults and smolts) - cameras were deployed in the river Wye from 3 May to 4 September 2013 and 22 April to 8 September 2013 in the river Usk. Visual images were continuously recorded and examined for the number, direction, and timing of fish movements and then compared against environmental factors (temperature, flow and tidal state) and the position of movements in relation to the camera array.

Shad were observed in the Usk between 08 May and 11 July and between 20 May and 11 July in the Wye. Migration was primarily influenced by both tide and flow with movements observed at temperatures above 12^{o}C in both rivers. Shad exhibited a crepuscular pattern with little movement overnight and actively avoided fast flows during their migration.

Adult salmon were recorded in both rivers throughout the whole study and migration seemed to be primarily influenced by both tide and flow once in fresh water. Movements were recorded at temperatures above 10^{o}C with migration predominantly at dawn. Salmon in the Usk showed no preference to position in the river whilst migrating, unlike the Wye where a clear preference to the outer camera position was possibly caused by a structure in the water causing a flow break.

Smolt migration was only visible in the Usk because a camera malfunction occurred in the Wye array in the first few months of deployment. Their migration was between 23 April and 22 May and was influenced primarily by flow and tide. Moving during the descending limb of the overall spring hydrograph, smolt migration occurred at temperatures above 10^{o}C with prominent movement occurring during daytime, contrary to the literature. Smolts showed a strong correlation to faster flows in their seaward migration being observed moving in the highest water velocity areas of the river detected on an Acoustic Doppler Current Profile (ADCP).

Flow was a primary factor in migration of these species and thus protecting the natural flow regime is essential to maintain and improve the conservation status of both species. Although it is assumed that abstraction would have a minimal effect on either river unless increased abstraction takes place during dry years which can increase the risk of barriers to migration by lowing the river levels further. This is supported by the 2012 egg surveys where no barriers to migration in the Wye were observed as eggs were found beyond each potential barrier. This study was particularly relevant as it was conducted during a dry year when flows were below average. In the Usk, low flows are highly likely to be significant particularly in relation to passage over major barriers such as the footings of Usk Town Bridge and Crickhowell Town Bridge. Lower flows will potentially increase the barrier effect by restricting the movements upstream of both salmon and shad. There is therefore potential for abstraction in the lower Usk to affect the spawning range of shad, in particular if abstraction from Prioress Mill reduces flow at Usk Town Bridge sufficiently to prevent passage. Thus a precautionary approach to abstraction is needed to support migration by protecting spring flows in low flow years during these vulnerable life stages.

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1 INTRODUCTION

The characteristics of flowing water are essential components of the environment of stream and river fishes across multiple spatial and temporal scales (Cowx *et al.* 2012; Milner *et al.* 2011, 2012a; 2012b). Superimposed on these multiple scales of influence are interactions between flow and other critical determinants of fish population performance, including physical factors such as temperature and water chemistry, and biotic factors such as predators and competitors (e.g. Bradford & Heinonen 2008; Murchie *et al.* 2008). Further relationships have been shown between river flow and fish diversity (Townsend *et al.* 1997; Muneepeerakul *et al.* 2008) exemplifying the need for the natural flow regime to be maintained to sustain the native populations.

On 23 October 2000 the European Union adopted the EU Water Framework Directive (WFD) legislation (Council Directive 2000/60/EC) which requires all EU member states to achieve Good Ecological Status (GES) in all surface waters (rivers, lakes, canals, wetlands, reservoirs, estuaries) and groundwater's by 2015, now extended to 2027. The WFD is essential due to the inconsistent management of water resources, a result of disassociated multiple sectors and authorities. The WFD therefore aims to unify authorities and stakeholders in an integrated catchment management approach (Acreman & Ferguson, 2010). The WFD has five categories to classify a water body: High, Good, Moderate, Poor and Bad. The categories are based on assessments of aquatic biota that directly indicate the environmental quality of the water body. Environmental quality is measured and assessed in numerous ways: Biologically (fish, macroinvertebrate, macrophyte and algae surveys), physio-chemically (water temperature and dissolved oxygen), hydromorphological (the physical structure of the water body) and chemically (in terms of pollution), and must meet the requirements set out in the WFD (Acreman & Ferguson, 2010). Good Ecological Potential (GEP) can be allocated instead of GES where water bodies have physical alterations such as dams, weirs, straightening and deepening, these are known as Heavily Modified Water Bodies (HMWB). These HMWB are given GEP status if it is believed that the ecological benefit and cost of restoring the water body to its natural predecessor will not outweigh the socio-economic importance of the water body, i.e. a main source of drinking water in a highly populated area.

The introduction of the WFD promoted better use of interdisciplinary science to assist in policy making (Acreman *et al.* 2014). Ecohydrology is one of these interdisciplinary sciences which combines riverine specialisms from hydrology and ecosystem sciences to provide guidance on an array of topics such as organism adaptions to water, impact of vegetation of flow and function, and eco-hydrological feedbacks. In this context, ecohydrology is used to assess the natural flow regime and the interaction it has between the migratory species shad and salmon (see section 2.3). One area highlighted by Acreman *et al.* (2014) for further assessment is water abstraction, the removal of water, either permanently or temporarily, from a water source (river, canal, lake or reservoir) for drinking water, irrigation, energy, recreation or flood control). Abstraction of water has been happening for centuries, but in recent years abstraction has become more prevalent largely as a result of the increased demand for water from an ever-increasing population (Acreman *et al.* 2008). This removal of water can alter the natural flow regime of a river and has been shown to have detrimental effects upon the native biota indirectly altering the community structure and river functioning (Wright and Berrie, 1987; Monk *et al.* 2012; Darty *et al.* 2014).

With increasing demand of water as a resource, abstraction levels are subject to statutory legislation and management (section 2.4), such as the Catchment Abstraction Management Strategy (CAMS), the Water Resource Assessment Management (RAM) framework and the Restoring Sustainable Abstraction (RSA) programme (1999), which review and monitor current abstraction licenses to assess abstraction limits, in addition to potential environmental problems caused. Such environments can, however, be protected through law and legislation by the designation of protected areas such as Sites of Special Scientific Interest (SSSIs), Special Areas of Conservation (SACs) and Special Protected Areas (SPAs). SSSIs are protected areas that are seen to be biologically and/or geologically significant and are designated by their relevant conservation statutory bodies (in this case NRW). SACs are protected sites designated under the EC Habitats Directive (Council Directive 92/43/EEC) designed to protect 189 habitat types and 788 species, outlined in Annex I & II. Finally, SPAs are designation under the European Union Directive to help protect the habitats and species of migratory and threatened birds. People/organisations wishing to work in these designated areas are legally required to carry out the Review of Consents (RoC) before any form of work (such as abstraction) shall be carried out upon them. The RoC evaluates the potential effects on the designated site(s) and provides mitigation measures with the aim to ensure that no deterioration towards the habitat and wildlife will ensue from either their development or activities.

In the rivers Wye and Usk, abstraction is prominent allowing a sufficient supply of water to both the immediate and surrounding areas, which acts as a major pressure in both rivers. These pressures can potentially have effects upon the resident and non-resident species such as (barbel (*Barbus barbus* (L.)), bleak (*Alburnus alburnus* (L.)), brown trout (*Salmo trutta* L.), carp (*Cyprinus carpio* L.), chub (*Squalius cephalus* (L.)), dace (*Leuciscus leuciscus* (L.)), eel (*Anguilla anguilla* (L.)), flounder (*Platichthys flesus* (L.)), grayling (*Thymallus thymallus* (L.)), gudgeon (*Gobio gobio* (L.)), minnow (*Phoxinus phoxinus* (L.)), mullet (*Liza ramada* (R.)), perch (*Perca fluviatilis* L.), pike (*Esox Lucius* L.), river lamprey (*Lampetra fluviatilis* (L.)), roach (*Rutilus rutilus* (L.)), sea lamprey (*Petromyzon marinus* L.) and stone loach (*Barbatula barbatula* (L.))) and non-fish species (common otter (*Lutra lutra* (L.)) and cormorant (*Phalacrocorax carbo* (L.)). However, as both rivers are categorised as SACs due to the flora and fauna that inhabits them (Table 2.1), they are subject to the RoC process when setting abstraction licences. Amongst the species that are designated features under Annex II of the SACs selection of the rivers Wye and Usk, are the protected anadromous fish species twaite shad (*Alosa fallax* (L.)), allis shad (*Alosa alosa* L.) and Atlantic salmon (*Salmo salar* L.), which are of particular importance due to their protected status. Shad are listed on Appendix III of the Bern Convention and on the IUCN Red List (IUCN, 2003). They are also listed on Annex II and V of the EC Habitats Directive and are priority species in the UK Biodiversity Action Plan (for shad ecology see section 4.1). Salmon is protected under the Salmon and Freshwater Fisheries Act 1975, Salmon Act 1986 and are listed on Appendix III of the Bern Convention and Annex II and V of the EC Habitats & Species Directive (EC Directive 92/43/EEC) (for salmon ecology please see section 5.1). Consequently, abstraction licences need to be dynamic and "environmentally friendly" by limiting water removal during key times of the year to allow for successful migration and subsequent spawning to take place.

Allis and twaite shad are two closely related, silver fish of the herring family. Within Wales, twaite shad is known to spawn in the middle reaches of the Wye, Usk, Tywi and Severn during the spring and spawn in the middle reaches (Noble *et al.* 2007). There are no recent records of allis shad on the Wye or Usk. As the last record was of one fish on the Wye in 1979, it is currently assumed that they are not present. Twaite shad has significant importance in both England and Wales as these are the most known northerly regions they travel for migration (Aprahamian *et al.* 2010). As such, precautions must be put in place to preserve the remaining populations and attempt to increase their abundance.

Atlantic salmon is found in many Welsh rivers, including the rivers Dee, Taff, Tywi, Wye, Usk. Salmon is an iconic species in the rivers Wye and Usk with, historically, the Wye being the most productive river in Wales (JNCC, 2001). This anadromous species predominantly migrate in late summer to spawning grounds in the head waters although it can be seen in early spring (known as spring-run fish). Both the rivers Wye and Usk are noted with high numbers (75% & 30-40% respectively) of multi sea winter salmon (MSW) with the Usk recording the highest egg deposition of any British river south of Cumbria (JNCC, 2001). These fish represent great importance to local economies creating business around the salmon migration, for example fishing and tourism, (WUF, 2012) and represent the fittest salmon stocks preserving their genetic integrity (Jonsson and Jonsson, 2011) Since the 1980s salmon populations have declined (Jonsson and Jonsson, 2011) which is problematic for the stocks of salmon in the Wye and Usk as they represent considerable importance in the United Kingdom (JNCC, 2001).

Alterations to the natural flow regime and river flow can have significant effects upon the survival of these respective species and one area that has received little attention within the Review of Consents (RoC) is the relationship between flows and migration of these anadromous species. This is of concern because flow regulation and abstraction can potentially adversely affect the survival of both shad and salmon during migration – an issue that has already been raised by The Wye and Usk Foundation (WUF) (see, WUF, 2012c). In response to the RoC by stakeholders, Dŵr Cymru Welsh Water (DCWW) and the Canal & River Trust established the 'Rivers Usk and Wye Abstraction Group' that included a large number of stakeholders, to investigate and understand the implications of abstraction on these catchments as well as provide the potential to improve the site-specific environmental data (whether via monitoring or through an evidence-based approach). It is hoped that this course of action will reduce the environmental impact of abstraction particularly as DCWW are the main abstractor in the rivers Wye and Usk and could risk substantially fines if found to be in breach of abstraction laws and legislation.

In view of their conservation status and importance to the Wye and Usk SAC status, there is a need to understand any potential impact of change in flow as a result of abstraction on shad and salmon populations.

1.1 Research aim and objectives

Aim

This research aims to determine if proposed abstraction regimes effect the migration of twaite shad, Atlantic salmon and other resident and non-resident species within the rivers Wye and Usk. The results will help inform baseline data for the establishment of abstraction licencing regimes as part of the DCWW Review of Consents (RoC).

Objectives

1. Using direct field observations recorded by underwater cameras, examine the movements (migrations) of all fish species in the rivers Wye and Usk that occurred between 14/05/2013–17/07/2013 and 28/04/2013–15/07/2013 respectively. This date represents the whole study period not just the observed migration windows.
2. Identify migration patterns of twaite shad and Atlantic salmon in association with potential environmental drivers (water temperature, river flow, tide, lunar cycle and diel cycle) in the rivers Wye and Usk.
3. Identify patterns of movements in other species that inhabit the rivers Wye and Usk.
4. Determine if abstraction will affect fish communities that both rivers support and to provide guidance on when abstraction should take place to minimise any ecological impact.
5. Provide empirical data to support and underpin decisions taken to develop abstraction management strategies as part of DCWW Review of Consents (RoC) with the results and conclusions of this research.

1.2 Structure of the thesis

The thesis structure and the corresponding development of the research are summarised in Figure 1.1. Chapter 1 provides context for the research project, highlighting the importance of the study, its importance to protected species and sets out the aim and objectives of the research. Chapter 2 provides a comprehensive overview of the rivers Wye and Usk and their ecological significance in addition to their WFD status and hydrology. Abstraction is comprehensively reviewed discussing the ecological effects of abstraction and the current legislation and management surrounding abstraction. In Chapter 3, the need for novel methodologies to address the research question is discussed and the methodological approach and site selection is outlined.

Organisation of the main research findings are outlined in Chapters 4, 5 and 6 and provide an overview of the results. The results for shad are presented first and subsequently for salmon and other species. For each, observations are set against the environmental drivers as previously mentioned and are discussed and evaluated. Chapter 6 provides a briefer overview of all other fish species (barbel (*Barbus barbus* (L.)), bleak (*Alburnus alburnus* (L.)), brown trout (*Salmo trutta* L.), carp (*Cyprinus carpio* L.), chub (*Squalius cephalus* (L.)), dace (*Leuciscus leuciscus* (L.)), eel (*Anguilla anguilla* (L.)), flounder (*Platichthys flesus* (L.)), grayling (*Thymallus thymallus* (L.)), gudgeon (*Gobio gobio* (L.)), minnow (*Phoxinus phoxinus* (L.)), mullet (*Liza ramada* (R.)), perch (*Perca fluviatilis* L.), pike (*Esox Lucius* L.), river lamprey (*Lampetra fluviatilis* (L.)), roach (*Rutilus rutilus* (L.)), sea lamprey (*Petromyzon marinus* L.) and stone loach (*Barbatula barbatula* (L.))) and non-fish species (common otter (*Lutra lutra* (L.)), cormorant (*Phalacrocorax carbo* (L.)) and a common frog (*Rana temporaria* L.)) observed during the data research. This is to provide context of how these other species can potentially be affected by the abstraction regime.

Drawing upon all the chapters, Chapter 7 discusses the results in relation to the objectives outlined and leads into the conclusions and draws upon the literature to provide recommendations for DCWW in future abstractions regimes and monitoring.

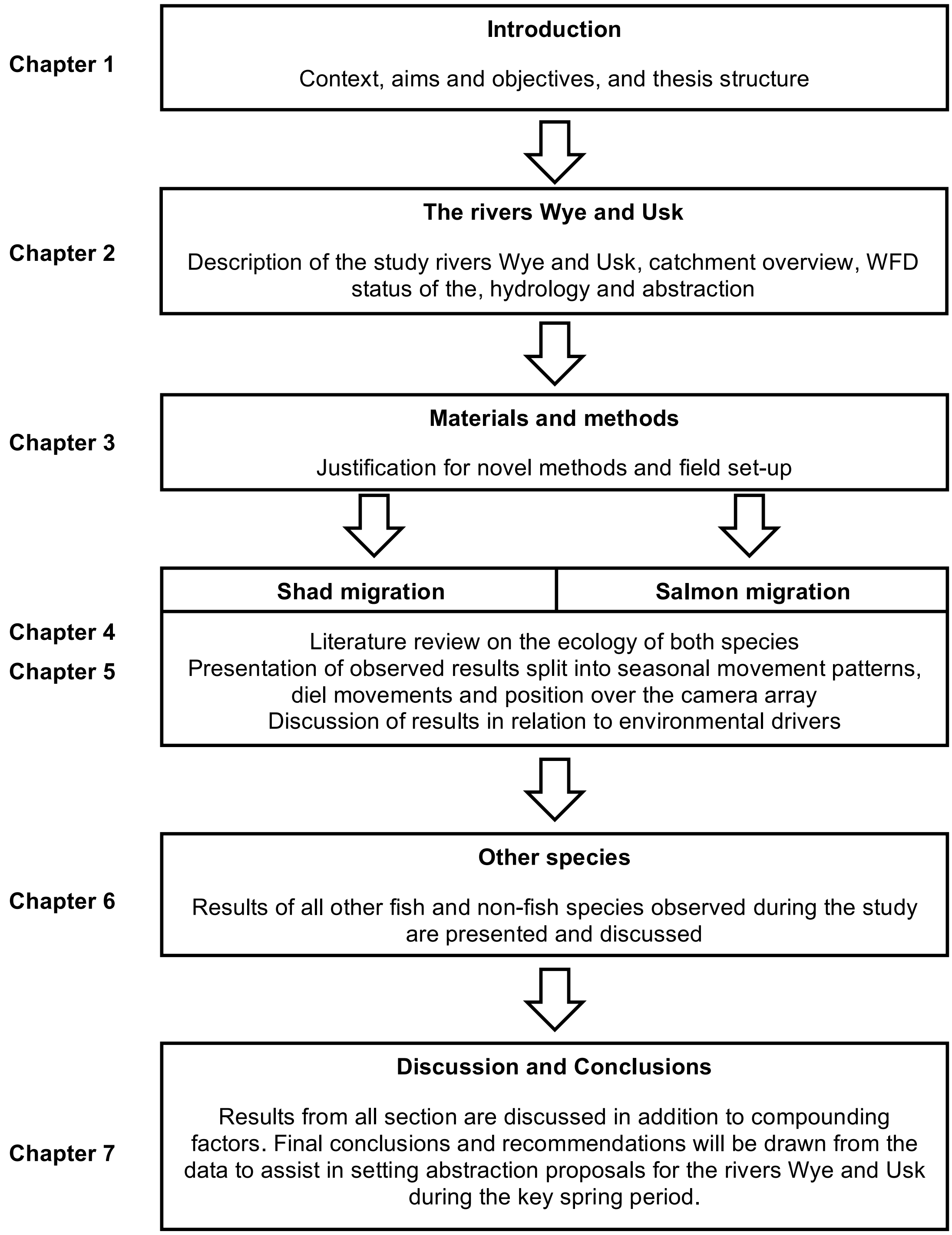

Figure 1.1 Schematic representation of the thesis structure.

2 THE RIVERS WYE AND USK

2.1 Description and catchment overview

2.1.1 River Wye

The River Wye (Figure 2.1) is the 5th largest river in the UK spanning 215 km with a catchment draining an area of 4136 km^2. Feeding into the larger Severn drainage basin, the Wye encompasses a total area of 11420 km^2 (Edwards and Brooker, 1982). The Wye's source is located on Plynlimon (SN789869), which is the highest peak of the Cambrian Mountains and feeds into the Severn estuary at Chepstow. The river has been used for navigation since the 14th Century and modern day navigation is still available to the public from Hay-on-Wye (Upper Wye) through to the tidal limit at Bigsweir (Lower Wye). Along the river's route, a section of the Wye (Redbrook to Chepstow) forms also forms a boundary between Wales and England.

The Wye is an important wildlife corridor as well as a migratory route for a number of species where the 12 tributaries of the Wye (including the rivers Lugg, Monnow, Trothy, and Llynfi) are used as spawning and nursery grounds for protected species (Table 2.1 discounting ranunculus). Due to the importance of these protected species, the Wye is a designated Special Area of Conservation (SAC) under the Habitats Directive (EC Directive 92/43/EEC) and in addition, has two Sites of Special Scientific Interest (SSSI). The two SSSIs are located at Upper Wye Gorge (SO560155) and the lower Wye (ST544912 to SO230429) and cover an area of 245.1 ha and 1404.8 ha respectively. They hold special interest attributable to high biodiversity in flora and fauna caused by the local geology and topography (CCW, 1996; CCW, 2001). The lower Wye in particular is noted to be, amongst a minority, an almost unmodified western eutrophic river in Europe (CCW, 1996). In addition to the Wye valley, the upper Wye has also been designated an Area of Outstanding Natural Beauty (AONBs).

2.1.2 River Usk

The River Usk (Figure 2.1) is one of the main rivers in Wales at 102 km in length. It spans from its source at Fan Brycheiniog (SN825217) at an elevation of 502 m, to the tidal limit at Newbridge-on-Usk, to the mouth (5 miles south) where it enters the Severn estuary at Newport (specifically Uskmouth). The Usk's catchment size is one quarter of that of the Wye, although, like the Wye, the Usk also drains into the Severn estuary. The River Usk has a rich history where, over the past millennium, it has played an integral part in Newport's development as a major port due to its prime location, ease of access and the rivers topology (large width and depth) (NCC, 2008). Both rivers drain into the Bristol Channel that is also an important SAC for both shad and salmon for their entry into their respective rivers.

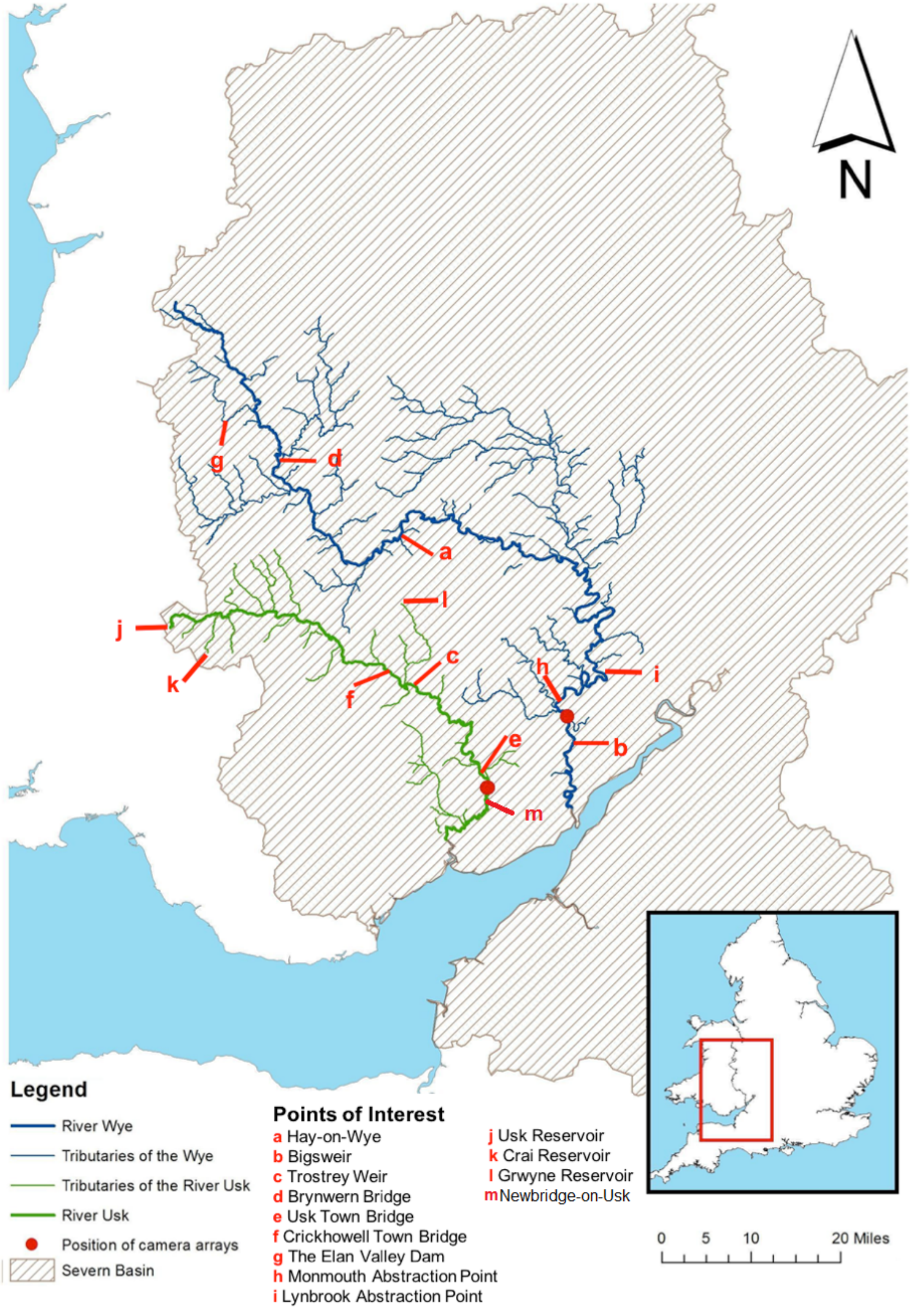

Figure 2.1 Location map of the River Wye & Usk including study site location and catchment area.

The River Usk, its 16 tributaries, estuary and surrounding catchment have all been designated as an SSSI as, like the Wye, an important migratory route and wildlife corridor for protected species (Table 2.1). Furthermore, the EU Habitats Directive has designated sections of the Usk an SAC (SO301113) to help conserve the species and populations for future generations in compliance with Natura 2000.

Table 2.1 Protected species in the rivers Wye and Usk listed under the annexes of the Habitats Directive that is important to this research.

Species	The Habitats Directive	Present in Wye and/or Usk
Floating vegetation of Ranunculus of plain, submountainous rivers	Annex I	Wye
Common otter (*Lutra lutra* (L.))	Annex II and IV	Both
Atlantic salmon (*Salmo salar* L.)	Annex II and V	Both
Twaite shad (*Alosa fallax* (L.))	Annex II and V	Both
Allis shad (*Alosa alosa* L.)	Annex II and V	Both
Sea lamprey (*Petromyzon marinus* L.)	Annex II	Both
River lamprey (*Lampetra fluviatilis* (L.))	Annex II and V	Both

Both rivers are subject to major anthropogenic pressures including urbanisation, industry, agriculture or water resource development (dams, abstraction and flow regulation). Furthermore, in addition to these major pressures, the rivers are subjected to recreational use from fishing, boating (canoes) and ramblers attracted to the area due to the AONB among others. These all act as external pressures upon the system and require regular habitat and hydrological maintenance to maintain these activities.

In the Wye there is a substantial network of weirs that historically have been used to aid navigation, in contrast the Usk only has one weir located at Trostrey. Over the years, weirs and other blockages, such as natural falls and debris, have been either removed or modified to allow for sufficient passage by fish using the rivers as part of their migration (WUF, 2012d), but, barriers still exist. On the Wye, there are currently no known barriers to migration although it must be noted that spawning of migratory species does not occur above Brywern Bridge (Figure 2.1), suggesting the bridge is a potential barrier to further upstream migration or that there is a lack of suitable spawning habitat further upstream. In the Usk there are known barriers to migration including the bridge footings at Usk Town Bridge and Crickhowell Town Bridge, respectively (Figure 2.1). It is therefore necessary for an equilibrium to be found between: recreation, water supply and ecology due to the local economy and livelihoods that rely upon the system. The prominent fear that these increases in anthropogenic stresses, forced upon the water resource from both water abstraction and impoundment, will become potential barriers to the migration of protected species highlights that this project is vital for their future survival. With particular reference to this study, this is thought to have already occurred in the Wye and Usk where the once native allis shad, owing to the number of physical barriers (weirs, debris) inhibiting its migration to spawning habitat, is thought to be extinct, like that of allis shad in the river Severn (M Aprahamian, 2014, pers. comm., 9 July 2014), increasing fears that twaite shad [and salmon] could soon follow suit.

2.2 WFD status of study rivers

EU Water Framework Directive (WFD)

Under the WFD, water bodies are required to achieve GES/GEP by 2027 (UKTAG, 2013). To help reach these targets statutory consultees - who are responsible for implementing the WFD (in this case NRW) - have to produce River Basin Management Plans (RBMP) to set realistic targets and goals ranging across all factors influencing the successful implementation of a WFD status. The 2011 WFD status of the rivers Wye and Usk are outlined in Appendix 1 and shows that many of the reaches assessed are not currently at the required GES/GEP needed by 2027 (Table 2.2 and Table 2.3). The River Wye has 136 reaches identified under the WFD of which 0 reaches are classed as high (Table 2.2). The River Usk has far fewer reaches at 39 in total, also with 0 reaches classed as high (Table 2.3). Both rivers have high proportions of reaches classified as moderate although most notably the Wye has numerous reaches already at GES in addition to 1 site classed as bad; something the Usk has none of. There are three main reasons why these rivers have not achieved GES/GEP in 2011: diffuse source agriculture; point source water industry sewage works; and most significantly to this research, physical alterations. The WFD failures for both rivers are shown in Figure 2.2 & Figure 2.3.

Table 2.2 2011 WFD status of all the reaches in the River Wye.

Current WFD status	Number of reaches at status
High	0
Good	47
Moderate	62
Poor	25
Bad	2

Table 2.3 2011 WFD status of all the reaches in the River Usk.

Current WFD status	Number of reaches at status
High	0
Good	9
Moderate	33
Poor	6
Bad	0

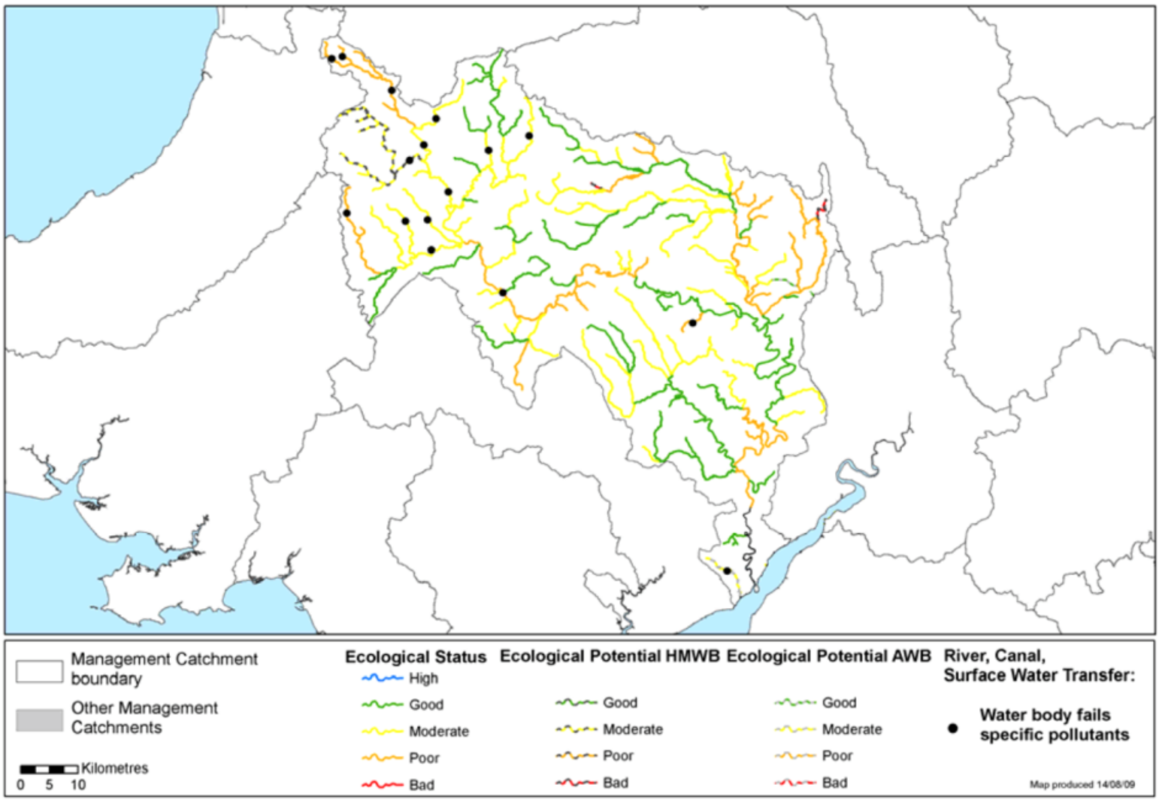

Figure 2.2 The 2009 status of waters in the Wye catchment under the WFD (EA, 2009)

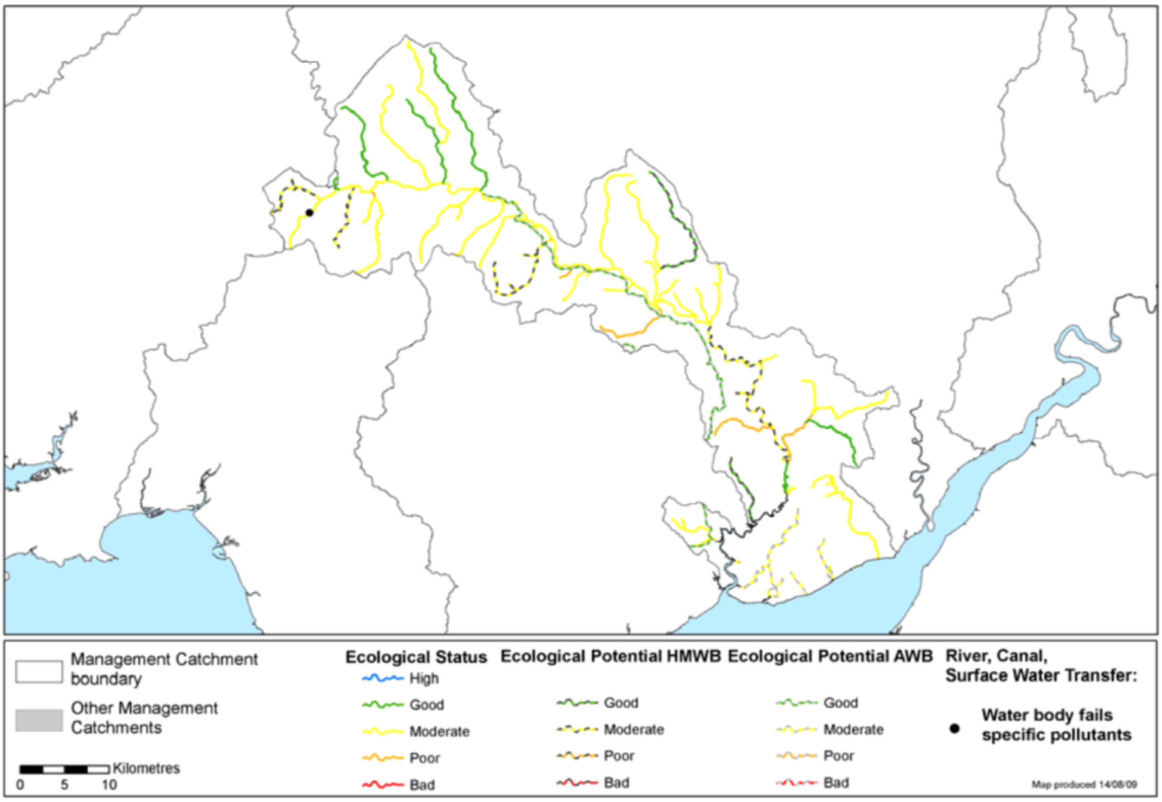

Figure 2.3 The 2009 status of waters in the Usk catchment under the WFD (EA, 2009)

2.3 Hydrology characteristics of the Rivers Wye and Usk

The characteristics of flowing water are essential for both fish and the overriding environment across multiple spatial and temporal scales. Flow variation determines energy intake and swimming costs for individual fish (Fausch 1984) and is a major cue for the upstream migration of adult anadromous fish (Jonsson and Jonsson, 2009). Flow modifications can have profound effects on the viability and sustainability of populations. Superimposed on these multiple scales of influence are interactions between flow and other critical determinants of fish population performance, including physical factors such as temperature and water chemistry, and biotic factors such as predators and competitors (Acreman *et al.* 2014).

Gauged river flow data has been recorded in both the rivers Wye and Usk from Redbrook (directly at the study site) and Chainbridge (7 miles from study site) respectively (NB: Llantrisant gauge station didn't have the historical data required for this analysis so the next closest station was choosen). Gauged river data are direct flow measurements from the river and are recorded remotely from gauge stations. The annual means of the gauge flow data from the past 34 years has been expressed in Figure 2.4. The gauged flow data shows irregularity over the 34-year period, however, there are specific peaks, caused by significant rainfall during the years of 2000 and 2008, and troughs caused by drought episodes during 2003 and 2010-11 respectively. As a consequence of the particularly dry years between 2010-2011, it is thought that these years may best represent the hydrology of the rivers during times of significant abstraction in low flow conditions. As a consequence, further hydrological discussion will concentrate on the time frame between 2008-11 as it is believed abstraction during these low flow conditions will cause ecological harm to the migrating fish species (Cowx *et al.* 2014).

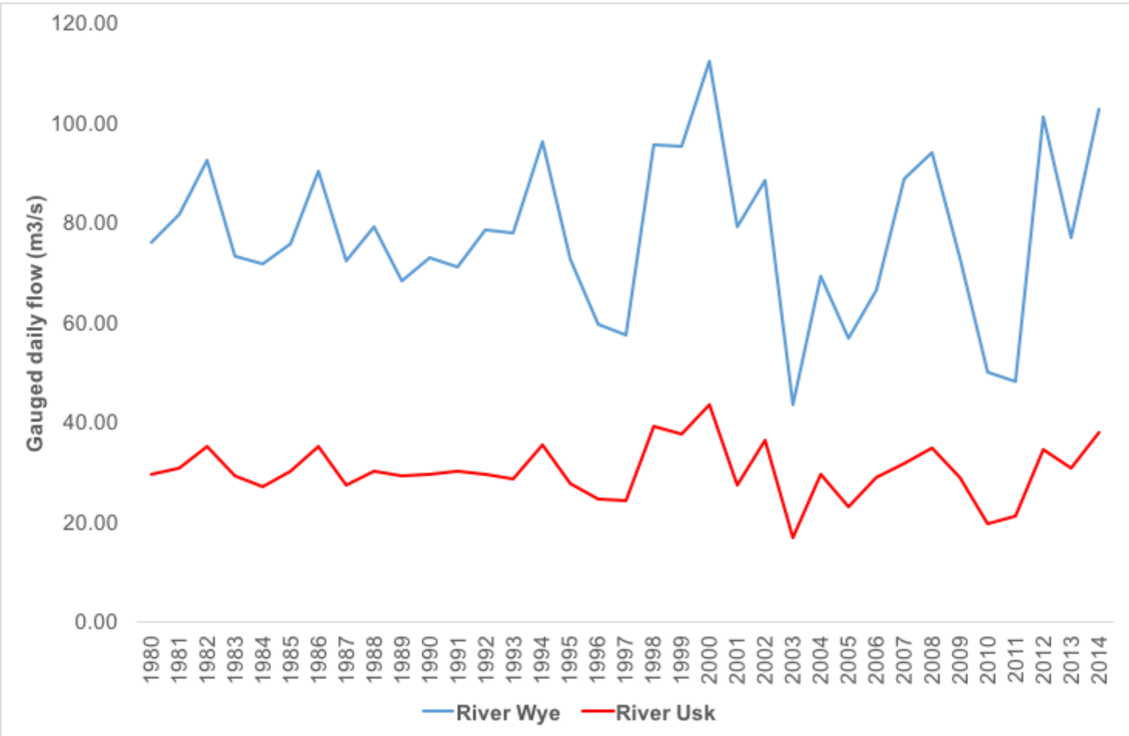

Figure 2.4 Annual mean of gauged daily flow of the rivers Wye and Usk between 1980 - 2014 (Source: National River Flow Archive, 2015)

Flow data used in further analysis was taken from gauge stations at both study sites (Llantrisant and Redbrook gaude stations) and takes into account both naturalised and modified flows. Naturalised flows adjust the upstream gauged river flow (direct measurements from the river) by taking into consideration the net effects of pressures such as reservoir releases and abstraction for supply, agriculture and specifically canal use in the Usk. Whereas modified flows is a raw reading of the flow data taken at the gauging station. The historical flow data of the Wye (Figure 2.5) and Usk (Figure 2.6) between the noted dry years of 2008 and 2011 suggest there is little evidence of substantial alteration in the flow regime during the spring period (March-June) when shad and most salmon are migrating (though it must be noted that the salmon migration cycle takes place all year round) to the Wye and Usk. The Wye, in comparison to the Usk, has higher flows with averages between 1000-7000 Ml/d compared to the average flows of the Usk ranging between 1000-4000 Ml/d, this is due to the catchment sizes of both rivers. The similarity in hydrographs is due to catchment topography, but the Wye could be described as being slightly flashier than the Usk due to the number of peaks during spate events.

This is confirmed by the spring only flow duration curves for these rivers (Figure 2.7 and Figure 2.8). The flow duration curves show the percentage of time that a flow is likely to equal or exceed a value of interest. In these flow duration curves, only values are shown between 80%-100% as their represent low flow levels which could cause ecological impact. Different models are ran (Base river v5.01, RoC river v5.01 and WUF Wye + RoC river v5.01) which uses naturalised flows and historic flows in order to model the likelihood of a flow reaching a particular point. Each model uses slightly different parameters which explains the difference in each model. However, the trends amongst the models remain the same. It must also be noted that normally a flow duration curve is on a logarithmic scale. However, it is important to know the specific flow values in order to help assess potential problems abstract may cause.

Flow modification during the spring period represents less than 10% of the naturalized flow and in dry years such as 2011 the flow in the Wye is even enhanced by the reservoir releases. Further, the probability of low flow events (below Q95) during the spring period is marginal and largely restricted to the June period. The scenario in the Usk is towards a greater probability of lower flows during the spring period compared with naturalised flows but it is unlikely to cause any problems with migration because flows during this period are generally high and there appears to be no impact detected on adult salmon catches one to three years later (Cowx, *et al.* 2014). In addition, as the main abstractions on the River Usk are at the lower end of the river, they affect flow over only a small proportion of the length of river that shad and salmon are migrating through.

It should be recognized that this analysis assumes that any changes in flow regime are the direct result of reservoir releases and abstraction. However, there is a fundamental problem with such assessment because it can be difficult to tease out the effects of water abstraction from change in flow regime caused by climate change, given that spring periods have become fundamentally drier in recent years (Cowx, *et al.* 2014).

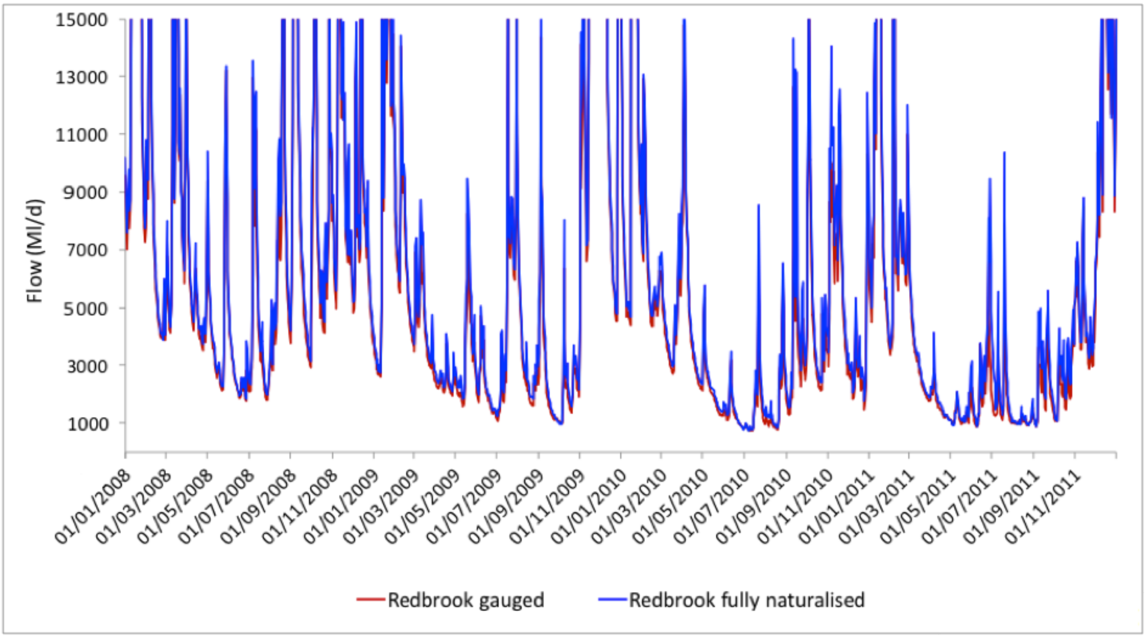

Figure 2.5 Gauged and naturalised flow regimes for the River Wye at Redbrook for the period 1 January 2008 – 31 December 2011 (Cowx, *et al.* 2014).

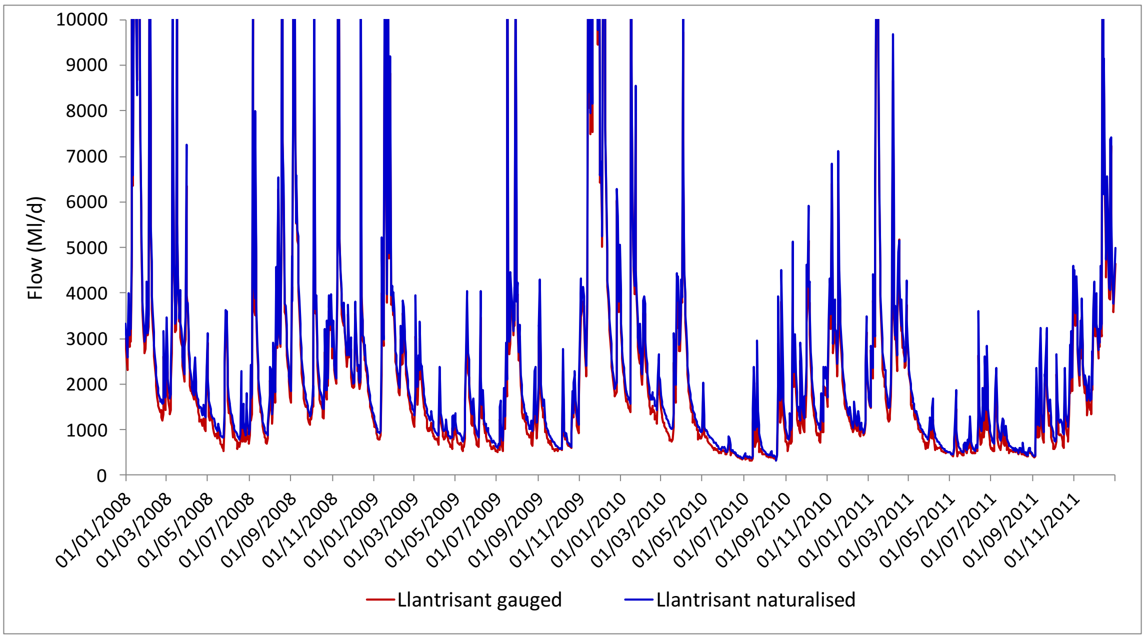

Figure 2.6 Gauged and naturalised flow regimes for the River Usk at Llantrisant for the period 1 January 2008 – 31 December 2011. (Cowx, *et al.* 2014).

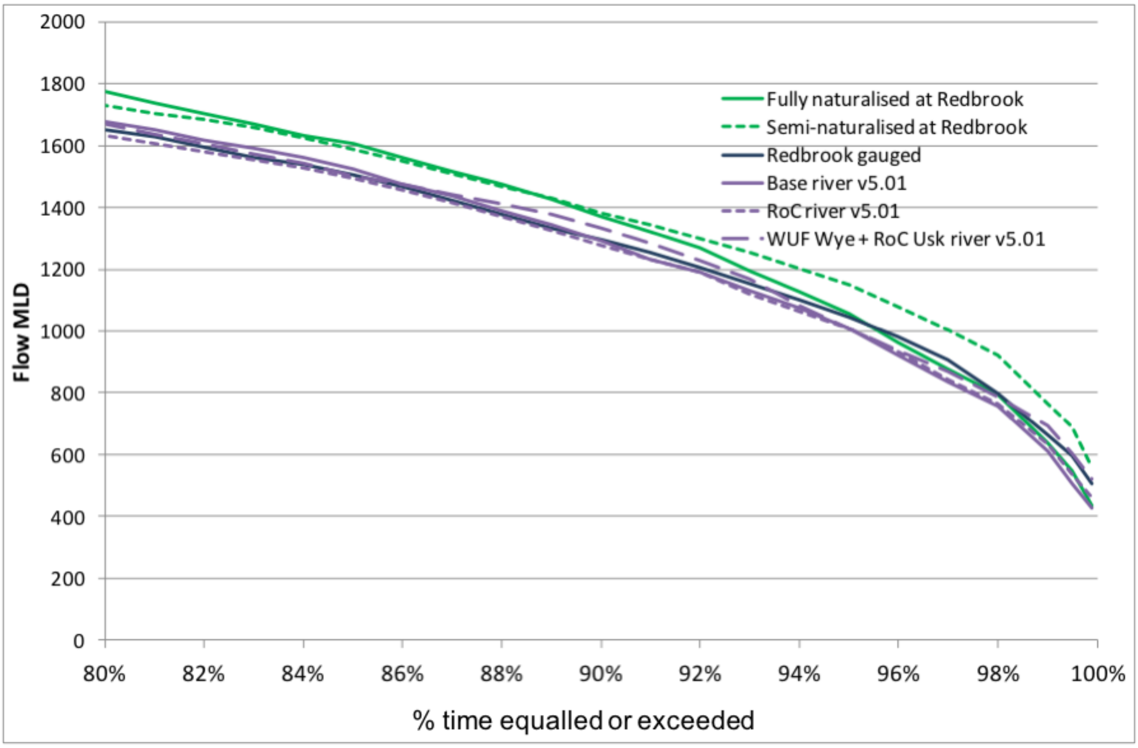

Figure 2.7 Spring Flow Duration Curve for River Wye at Redbrook, 1973-2008 (Cowx, *et al.* 2014).

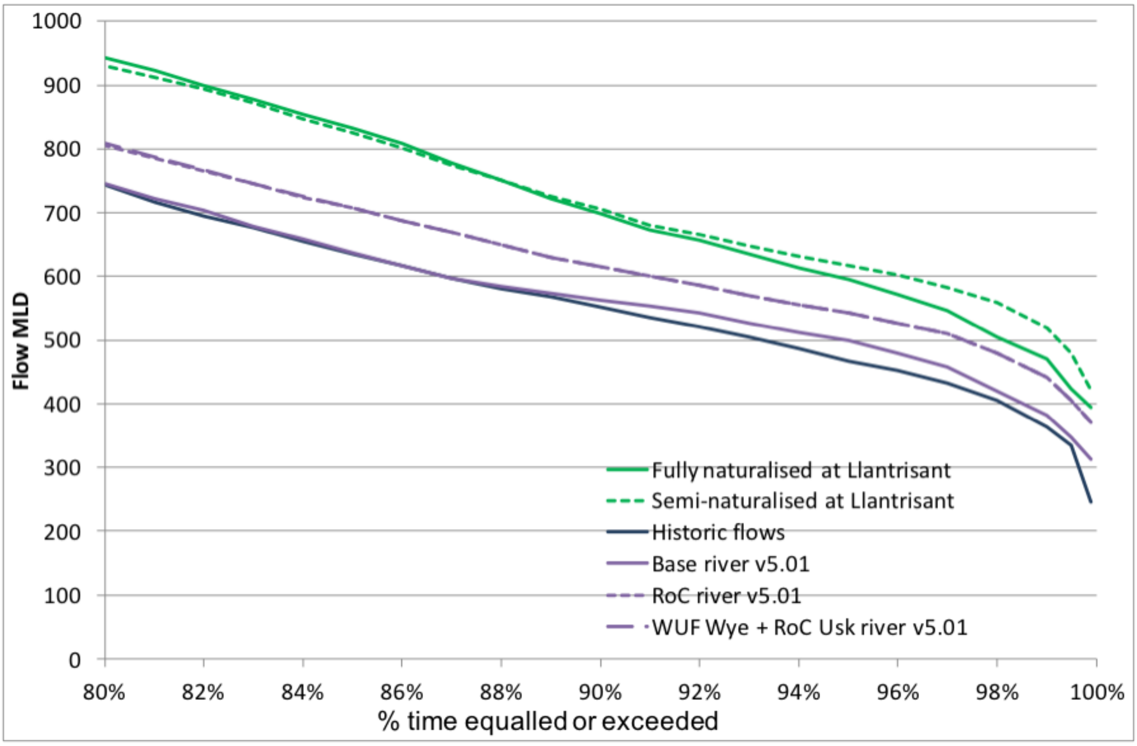

Figure 2.8 Spring Flow Duration Curve for River Usk at Llantrisant, 1973-2008 (Cowx, *et al.* 2014).

2.4 Abstraction in the Rivers Wye and Usk

Water abstraction is the permanent or temporary removal of water from a water source (river, canal, lake or reservoir) for a purpose. Abstracted water in the UK is most predominantly used for drinking water and supporting industry (Acreman *et al*. 2008), although it is also used, amongst other purposes, for irrigation and recreational use. Abstraction limits are controlled by licenses provided by the relevant environmental authorities (in this case NRW) and are subject to review when assessing any potential damage to the ecosystem (Acerman & Dunbar, 2003; 2004). In the rivers Wye and Usk there are numerous abstraction points which take and supply water for multiple uses. The Elan valley dam complex on the Wye is the primary source of water abstraction and pumps a steady supply to Birmingham for public drinking water (Figure 2.1). Additional abstraction points on the Wye are found at Monmouth and Lydbrook, noting that abstraction for irrigation and agricultural purposes happens at numerous points along the whole course of the Wye (WUF, 2012c) (Figure 2.1).

The Usk, unlike the Wye, has multiple reservoirs for mass water storage for later use. The Usk and Crai reservoirs store water for use outside of the river, Grwyne reservoir stores water for release back into the river when flows need to be adjusted to meet the natural flow regime, and Talybont and Llandegfedd is used to supply water to SE Wales (WUF, 2012c) (Figure 2.1). Like the Wye, there are also multiple smaller points of abstraction used for irrigation and agricultural purposes along its course.

With the rise in population and increase in demand for water, fears are growing that the abstraction rates will rise to meet future higher demands (Acreman *et al*. 2008; Dunbar *et al*. 2004). With increased water abstraction the rivers may become over abstracted and cause significant environmental damage. The term ‘over abstraction’ refers removing more water than the river can tolerate and thus reducing both river and aquifer levels to unacceptable conditions. Over abstraction can cause major ecological problems through alterations in hydrology and river morphology if not managed correctly, these are:

- Alterations in the natural flow regime which, is used by many species to promote migration in both salmonids and course fish (Cowx *et al*. 2012)
- Alterations in river chemistry by increasing water temperature and pH and decreasing dissolved oxygen.
- Increased sediment deposition, in particular interstitial sediment fines that degrade the physical area by eliminating spawning habitat (i.e. salmon redds) and increasing the damage to aquatic biota (Kemp *et al.* 2011).
- Changes in hydrology, morphology and chemistry which cause a shift in aquatic flora and fauna increasing the chance of non-native species to inhabit the area. This is due to the native biota evolving and adapting in parallel with the natural river morphology and hydrology to inhabit these reaches. For example, body shape, body size and feeding behaviour (Cowx *et al*. 2004; Monk *et al*. 2012).

- Increased sediment deposition, in particular fines, degrade the physical habitat eliminating spawning habitats (i.e. salmon redds) reducing population size (Kemp *et al.* 2011).
- Decreased river depth increases the propensity of impassable barriers to both lateral and vertical migration preventing biota reaching their spawning grounds (Nunn & Cowx, 2012; Bolland *et al*. 2012).
- Lack of connectivity to the floodplains for both refugia in high flows and spawning habitat (Bolland *et al*. 2012).
- Reduced river depth and flow increases the chance for the river to become eutrophic or dry out.
- Lack of access to spawning habitats which become available during high flows (Cowx *et al*. 2004).
- Increased risk of entrainment where during low flows, eggs, juveniles and small fish are all at risk of being sucked into the abstraction points and killed.
- Decreased ecological status as set out by the WFD.

Over abstraction can therefore be detrimental to an ecosystem. By significantly reducing river levels in the Wye and Usk through further abstraction, WUF (2012c) postulated that weirs will actively become barriers to migration. Such inhibition of migration of the protected species within both the rivers – shad, salmon and sea lamprey (Table 2.1) – would result in neither river meeting the requirements set out by the WFD and RoC.

2.4.1 Abstraction Legislation and Management

Catchment Abstraction Management Strategy (CAMS) was developed in 2001 by the Environment Agency (EA) to assess water abstraction on a catchment to catchment basis. This catchment approach calculates appropriate water levels for abstraction, the water levels needed to maintain a healthy environment and if required, can be used to control excess water for further abstraction. Ongoing data collection during the CAMS process is used to review and update the abstraction licences to maintain a GES or GEP under the WFD. This data is disseminated publicly in an attempt to engage the stakeholders and licensees and promote fair and transparent policy making. To obtain and set the abstraction limits for each current and future licensee, Environmental Flow Indicators (EFIs) are used to allocate a baseline flow level to support the biota. EFIs are worked out by assessing historical and current river flow, rainfall and abstraction data to produce a safe minimum flow level for a river during all water resource activities. If the river flow is found to be below the EFIs it is deemed to degrade the WFD status of said river and further abstraction will be halted until the EFIs flow is maintained. Furthermore, if an application is made for an abstraction licence, CAMS will be able to show if the applicant's level of abstraction will maintain or drop below the EFIs baseline flow.

Due to the sedimentary nature of lower devonian bedrock (mudstone, siltstone and sandstone), the rivers Wye and Usk fall under the branches of "Hard limestone and sandstone; low- medium altitude; some oligotrophic hard rock" and "salmon spawning & nursery (not chalk rivers)" within the EA guidelines (Table 2.4).

Table 2.4 Flow standards for UK river types for supporting good ecological status given as the percentage allowable abstraction of natural flow (EA, 2013)

River Type	Flow > Q95		Flow < Q95	
	Mar - Jun	**Jul - Feb**	**Mar - Jun**	**Jul - Feb**
Predominantly clay. South East England, East Anglia and Cheshire plain	25%	30%	15%	20%
Chalk catchments; predominantly gravel beds; base-rich	15%	20%	10%	15%
Hard limestone and sandstone; low-medium altitude; some oligotrophic hard rock	20%	25%	15%	20%
Non-calcareous shales; pebble bedrock; Oligomeso-trophic; Stream order 1 and 2 bed rock and boulder; ultra-oligo trophic torrential	15%	20%	10%	15%
	Oct - Apr	**May - Sept**	**Oct - Apr**	**May - Sept**
Salmon spawning & nursery (not chalk rivers)	15%	20%	10%	15%

Further work by the UK Technical Advisory Group (UKTAG) has recommended refinement amongst abstraction limits at different river flows (Table 2.5 and Table 2.6).

Table 2.5 Recommended revisions to the "moderate" standards for river flows (UKTAG, 2013) (River Types are outlined in Appendix 3).

	Permitted maximum abstraction per day as a proportion of natural flows			
	At daily flows (Qn) from Qn60 up to Qn5		At daily flows (Qn) greater than Qn90 and less than Qn60	
River Type	Existing Standards	**Recommended revision**	Existing standards	**Recommended revision**
A1	60% of Qn	70% of Qn	50 - 55 % of Qn	The proportion of Qn determined by the linear increase from 50% at Qn90 to 70% at Qn60
A2 (downstream), B1, B2, C1, D1	55% of Qn	70% of Qn	45 - 50 % of Qn	The proportion of Qn determined by the linear increase from 45% at Qn90 to 70% at Qn60
A2 (headwaters), C2, D2	50% of Qn	70% of Qn	40 - 45 % of Qn	The proportion of Qn determined by the linear increase from 40% at Qn90 to 70% at Qn60
No changes are recommended to the existing standards for daily flows from Qn95 and up to Qn90 and for daily flows less than Qn95.				

Table 2.6 Recommended revisions to the "poor" standards for river flows (UKTAG, 2013) (River Types are outlined in Appendix 3).

	Permitted maximum abstraction per day as a proportion of natural flows	
	At daily flows (Qn) from Qn90 up to Qn5	
River Type	Existing Standards	**Recommended revision**
A1	75 - 85% of Qn	Qn less 25% of Q90
A2 (downstream), B1, B2, C1, D1	70 - 80% of Qn	Qn less 30% of Q90
A2 (headwaters), C2, D2	65 - 75% of Qn	Qn less 35% of Q90
No changes are recommended to the existing standards for daily flows from Qn95 and up to Qn90 and for daily flows less than Qn95.		

The Water Resource Assessment Management (RAM) framework is incorporated into the application and development of CAMS and is an integrated approach to resource assessment, planning and management that allows for a widely applicable management style for a catchment focusing on river flows (AMEC, 2012). The outcome of results from the RAM framework is incorporated within CAMS to set abstraction licensing strategies for the catchment.

The RAM framework assesses the water use within a catchment by differentiating between natural and modified river flows (both positive and negative) to find the natural flow duration curve. The natural flow duration curve is used to work out the natural flow regime by assessing the catchment and environment sensitivity to changes in the flow regime. Anthropogenic flows include water abstraction from surface and ground waters, as well as pumping from industries such as sewage treatment works or flow releases from reservoirs. The ability to distinguish between these two types of flows enable accurate assessment of available water for abstraction from a catchment when plotted against a rivers mean flow. To establish sustainable water abstraction and to improve decision making, 'Low Flows 2000' – an advance modelling program – was written to estimate the water availability within a catchment (Holmes *et al.* 2005). This powerful model can estimate a river's flow duration curve on a nationwide scale. Furthermore, Low Flows 2000 accounts for changes in seasonal and annual variations based upon the catchment's geographical area, climatic variations and hydrogeology. Due to its interdisciplinary nature, the RAM framework integrates specialisms from multiple areas including hydrology, ecology, fisheries, water management and water resources (AMEC, 2012). This integration of multiple specialisms is advocated by the WFD.

The Review of Consents (RoC) - The Conservation of Habitats and Species Regulations 2010 requires authorities to review existing decisions and consents in accordance with regulation 63. The aim of the Review of Consents (RoC) is to ensure consistency amongst European wide authorities (CCW, 2012) and to assist in supplementing information that is already available.

This review process is a requirement for authorities under Article 6(1) and 6(2) of the EC Habitat Directive 1992 and evaluates potential effects on the designated Special Protected Areas (SPAs), Special Areas of Conservation (SACs) and Sites of Special Scientific Interest (SSSIs) (CCW, 2012). The review aims to ensure that no potential deterioration of features, and/or habitat, at these internationally important sites, from either development or activities, will be caused by requiring legal consent before such development or activities can begin. Authorities are defined in Regulation 7 in the Habitats Directive and those defined are known as "competent local authorities". These competent local authorities are responsible for issuing and reviewing the consents and reviewing the potential impacts under the Natura 2000 network for future generations (CCW, 2012). Local authorities are required to liaise with the larger statutory consultee – in this case NRW – due to their expert knowledge before any consent(s) can be approved for developments or activities. All individuals and companies wishing to apply for consent must go through the review process where they are required to produce a document outlining their development/activity, identifying which specific consent is required and determining the level of effect this development/activity will cause to the environment. Local authorities are also required to review their own permissions, consents and reviews to determine and identify if there has been any change in impacts.

The Restoring Sustainable Abstraction (RSA) programme (1999) is used to identify sites that might be at risk from abstraction and work with the license holders to mitigate the damage caused by abstraction. RSA can highlight potential conflicts between river flow and abstraction within a catchment and prioritises resolutions to alleviate the problem. NRW (2014) outlines these resolutions as:

- Moving the point(s) of abstraction on the river.
- Finding alternative means to make water abstraction more sustainable and less environmentally harmful forcing licensees to use these methods where appropriate.
- Preventing over abstraction by only permitting suitable levels of abstraction.
- Applying clauses to the licensee's contracts to dictate when levels of abstraction must be lowered to reduce the environmental and ecological damage, i.e. during periods of animal migration.
- Engaging in stakeholder participation to solve potential issues within the catchment.
- Undertaking habitat restoration to restore the natural physical processes.

Where ecological derogation has occurred, licenses can, and will, be changed either voluntarily or forcefully to meet the requirements set out in the WFD. It is hoped that the use of RSA will help with the UK's objectives under the WFD by pushing for GES or GEP where appropriate.

3 MATERIALS AND METHODS

A protocol to assess the conservation status of shad in SAC rivers was developed under the 'LIFE in UK Rivers' project (Hillman *et al.* 2003). The protocol uses a number of attributes to assess the status including egg surveys, juvenile netting surveys, and adult counter data. This can be supplemented where available from commercial catch data and entrainment surveys at power stations and water intakes. Unfortunately, pursuing the protocol is resource intensive and problematic in large rivers such as the Wye and Usk and the outputs are not necessarily robust (Noble *et al.* 2007).

Shad are noted for being very physiological sensitive species, especially when migrating into freshwater. Previous studies have tried to catch, tag and release twaite and allis shad (Acolas *et al.* 2004; Alexandrino *et al.* 2005) but, as shad are very delicate fish, they lose scales to touch easily and this loss in condition has resulted in mortality among tagged fish (Aprahamian, *et al*. 2003). Furthermore, shad have also been observed to have an extremely high sensitivity to sound frequencies, with studies showing that the American shad (*Alosa sapidissima* W.) can respond to frequencies as high as 120 kHz (Mann *et al*. 1998). In comparison, salmon studies have long used invasive tracking methods such as radio tracking sometimes requiring field surgery (Solomon, 1999) to monitor their freshwater phase of migration. Although this methodology is acceptable for salmon, the use of radio tracking for shad is not appropriate due to their morphological sensitivity. Both injury and death could be caused in the tagging process and due to both species being protected under Annex II and V of the Habitats Directive, it was thought that a non-intrusive method would be the best course of action.

An example of a non-invasive methodology that has been used to monitor fish migrations is the use of sonar equipment, for example Dual-frequency identification sonar (DIDSON) and Adaptive Resolution Imaging Sonar (ARIS), which use ultrasound technology. Both of these systems can monitor fish movement even in turbid environments. DIDSON and ARIS work by sending a sonar signal which when received back can produce real time, near video quality data at a range of 30 m and in some models to a depth of 300 m. Both the DIDSON and ARIS have been used successfully within fisheries management where both have been used in Welsh rivers (including the Wye) to monitor multiple fish species including salmon migrations (Clabburn, 2014 pers comm). However, although this method would be ideal for salmon, due to the shad's sensitivity to sound these methods cannot be used in conjunction with their monitoring. Gregory and Clabburn (2003) studied the effect of ultrasound using a DIDSON on shad migration using underwater camera arrays to record their data in the river Wye. Their research found that shad displayed clear avoidance behaviour to the 200 kHz DIDSON deeming the use of ultrasound ineffective in monitoring shad.

As such, methodologies must be used and trialled to assess and understand the factors that may influence the migration and recruitment of shad and salmon without association to mortality or inhibiting migration. Gregory and Clabburn (2003) used underwater camera arrays to assess the behaviour of fish whilst the DIDSON unit was turned on and it was thought that underwater cameras could thus be used to monitor both shad and salmon, in addition to any other species, as the experimental set up was not limited to single species.

Numerous studies have successfully used underwater cameras for remote sensing (Gregory & Clabburn, 2003; Watson *et al.* 2005; Cappo *et al.* 2006; Jan *et al.* 2007; Ebner 2009, Larsen *et al.* 2009 and Booma *et al.* 2014). Many of these studies are based in marine systems monitoring biota of coral reefs, although with particular reference to this study, Gregory & Clabburn (2003) successfully monitored migration of shad in the River Wye.

The use of underwater cameras is fast becoming a cheap alternative to the usual remote sensing techniques (Booma *et al.* 2014) and modern advances are allowing for computer algorithms to identify and process the video footage removing the human processing element (Larsen *et al.* 2009 and Booma *et al.* 2014).

Therefore, underwater cameras were selected for the research based on five reasons:

1. Underwater cameras are a non-invasive methodology that would remove the potential loss in condition and/or mortality associated with tagging fish.
2. Will not inhibit the migration of shad and salmon nor the resident species.
3. Be able to have a real time collection of data.
4. Recent studies have shown underwater cameras to be a cheap and successful remote sensing tool.
5. Underwater cameras are not limited to a specific fish species and thus able to monitor every fish species.

3.1 Field set-up

Three sets of four underwater cameras (Figure 3.1) were set in an elongated array approximately ¼, ½ and ¾ of the way across each river channel and were deployed in the lower reaches of both the rivers Wye at Redbrook Gauging Station (SO52738 11069) and on the Usk at Llantrisant Pumping Station (ST38676 97196) (Figure 2.1 & Figure 3.2). These locations were chosen due to readily available power from gauging and pumping station to power the camera arrays in addition to the homogeneous topography of the riverbed. The cameras were deployed from 22 April to 8 September 2013 on the Usk and 3 May to 4 September 2013 on the Wye, and were aimed horizontal to the riverbed and perpendicular to the river flow across the width of the river as described by Gregory & Clabburn (2003). The later deployment in the Wye compared with the Usk was the result of the need to obtain indemnity for using Redbrook gauging station to power the camera array.

Figure 3.1 a) Left - Setup of camera arrays deployed in the lower Wye and Usk; b) Right - Camera and infrared light coated with algal growth.

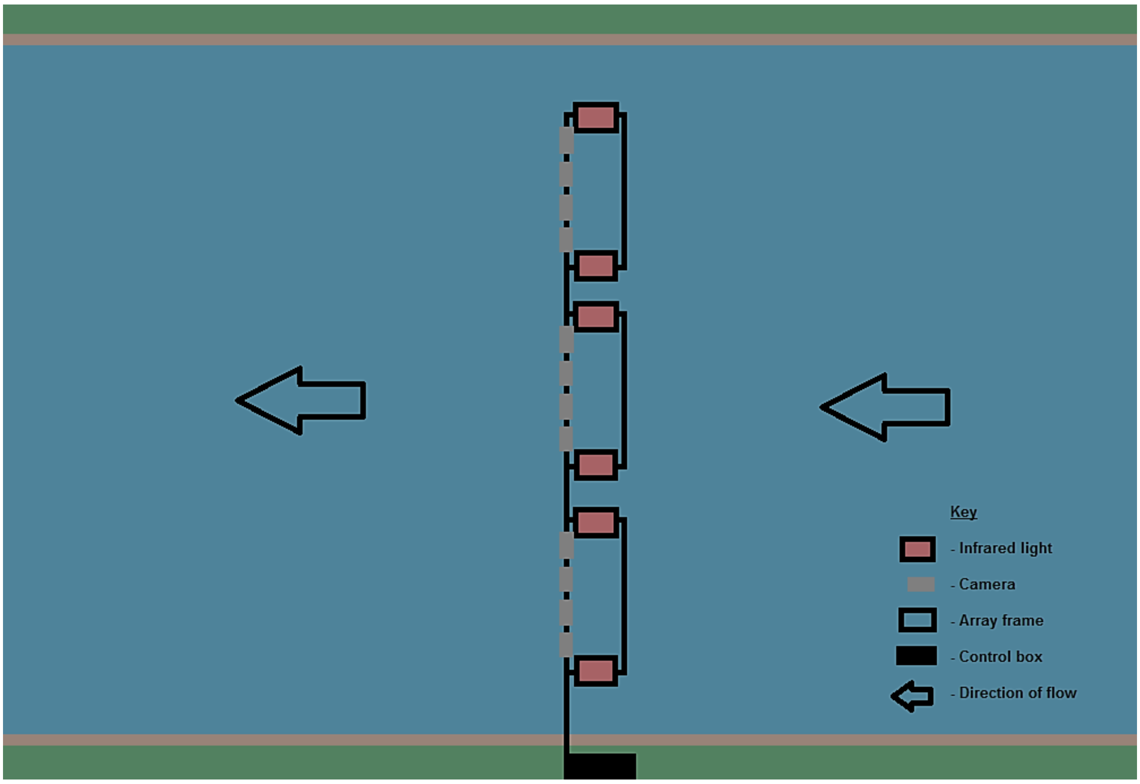

Figure 3.2 Cross section diagram of experimental set up

The three experimental arrays consisted of 12 high definition underwater cameras and six large infrared lights to enable imaging throughout the 24-hour cycle (Figure 3.1 & Figure 3.2). All cameras were connected to a main control box that controlled the power input and recording of data onto two terabyte hard drives. Video footage was continuously recorded and hard drives were swapped to download the data approximately every two weeks. The images were examined in the laboratory on the TimeSpace™ software called "PCLink 200" which allowed the speed of the footage to be manipulated for processing. The number, direction and timing of all fish movements were noted in Microsoft Excel™ for further analysis where the movements were plotted against known environmental factors: lunar cycle, temperature, flow and maximum tide height.

Figure 3.3 Images of shad recorded at the Llantrisant camera array on the River Usk.

Although images of fish were usually sufficient to identify species and count numbers and direction of movement (see Figure 3.3 for examples), viewing images under turbid high flow conditions made visualization of the images difficult due to a reduced field of view. Several technical problems were also encountered with an electronic fault causing loss of data for short periods. These were mainly computer gliches and failure of storage on the hard drives causing corrupt data files. The camera lens and infrared lights also quickly coated with algae and fine sediment (Figure 3.1b) meaning the arrays required cleaning approximately every two weeks during the recording period. Occasionally, when adverse weather conditions prevailed, it was not possible to enter the river to clean the arrays, thus making it more difficult to visualise the images, especially in the River Wye, which it is deeper than that of the Usk.

The aim of this study was to use the camera analysis to contribute to defining abstraction patterns and quantities on the rivers Wye and Usk to accommodate all species and life stages.

4 SHAD MIGRATION

Shad are an anadromous species when during the early spring period (April-June) are seen migrating into freshwaters to reach their spawning grounds. Their migration is perceived to be controlled by multiple environmental drivers:

- River flow;
- Tidal phases;
- Lunar cycle;
- Temperature (Aprahamian *et al.* 2003)

As part of the Wye and Usk RoC process the use of underwater camera arrays were deployed in both rivers to assess their migration. The camera arrays were deployed in the Usk on the 28 April and the 14 May in the Wye. The arrays in the Wye and Usk were subsequently removed on the 11 and 12 September, although the recording of data ended on the 14 and 15 July respectively. The subsequent days of no migration in the recordings were deemed to be adequate to conclude that migration had ended thus the rest of the footage was not assessed.

It is hoped the migration of shad will be captured by using underwater cameras and to ascertain the key environmental drivers to their migration to help set abstraction licencing that will minimise ecology damage.

This section describes the outputs of the experimental fisheries camera monitoring surveys carried out in the rivers Wye and Usk in 2013 with the objective to inform the review of abstraction regimes. It is hypothesised that the migration exhibited will mimic that of the literature where temperature is the overriding factor to the onset of migration followed by the multiple temporal drivers.

4.1 Shad ecology

Twaite shad and allis shad are two closely related anadromous species of the herring family Clupeidae. They have streamlined bodies covered with large, distinctive silvery scales, forming a toothed edge under the belly. The adults live in coastal waters and estuaries but migrate into fresh waters to spawn. Both species are listed on Appendix III of the Bern Convention and on the IUCN Red List (IUCN, 2003). They are also listed on Annex II and V of the EC Habitats Directive, and the Wye and Usk are designated SACs as a means of contributing to the favourable conservation status for the two species across the EU area. Allis shad is also protected through Schedule 5 of the Wildlife and Countryside Act 1981 (as amended) and both are priority species in the UK Biodiversity Action Plan. Allis shad is a qualifying feature for both SACs but not a primary reason for site selection in this study.

Species separation is difficult due to close similarities in the morphological characteristics. Allis shad is larger with a maximum body size of 830 mm (Sabatié, 1993) than Twaite shad with a maximum size of 568 mm (Manyukas, 1989). Nevertheless, due to overlaps in potential length between the two species, separation can be difficult. Accurate species separation can be achieved through the counting of gill rakers on the first gill arch: Twaite shad have between 35-60 and allis shad have between 80-155 (Sabatié et al. 2000; Aprahamian *et al.* 2003).

During the marine phase of their life cycle, both shad species are located around the catchments they use for reproduction during their freshwater phase (Taverny, 1991). Both twaite shad and allis shad have a preference for water depths between 10-20 m although depths have been recorded to as much as 110 m in twaite shad and 150 m in allis shad (Taverny, 1991). The depths that each species are found are positively correlated with both age and size (Taverny & Elie, 2001).

Within Wales, twaite shad is known to spawn in the rivers Wye, Usk, Tywi and Severn. As the last record of allis shad in the rivers Wye and Usk was of one fish on the Wye in 1979, it is currently assumed that they are not present in either river. It is thought that the decline maybe associated with the construction of physical barriers inhibiting migration to their spawning habitat (M Aprahamian, 2014, pers. comm., 9 July). Though this is not confirmed, it has been confirmed that the decline and ultimate extinction of allis shad in the river Severn was due to barriers to migration (M Aprahamian, 2014, pers. comm., 9 July).

Migration for allis shad occurs between May and July and is seen predominantly during the day with little movement overnight. Temperature appears to be the main driver for the onset of migration and begins once temperatures reach 10-12^{o}C (Aprahamian *et al.* 2003). Earlier migrations are shown within populations in the southern range due to the associated increase in temperature in accordance with latitude. Furthermore, temperature effects movements upstream with little movement below 11^{o}C, (Boisneau *et al.* 1985). This is believed to be a response to swimming speeds becoming inhibited. It has also been shown that shad move in conjunction with the tides with larger catches on spring tides (Mennesson-Boisneau *et al.* 1999). This has further been shown by Aprahamian (1988) who noted that increased numbers of shad were associated with neap tides. Once in fresh water the migration process is seen in waves, which relate to tidal state (Boisneau *et al.* 1985), although no relationship in their migration is seen with flow unless levels exceed a mean velocity of 721 m^3s^{-1} where it is deemed to inhibit their migration.

Migration in twaite shad begins in spring, between April and May when shad are seen to enter the estuary of their respective rivers. They spawn between May and July with peak spawning occurring in mid-June (Claridge & Gardner 1978; Aprahamian, 1985, 1988), but also as late as July. Aprahamian & Aprahamian (2001) showed, with significance to this study, that twaite shad enters the Severn Estuary in April for the start of the freshwater phase of their spawning migration. Like allis shad, the main factor influencing their migration is temperature with 10-12^{o}C is necessary for upstream movement (Claridge & Gardner 1978; Aprahamian 1985, 1988). Tidal state again influences their migration with twaite shad observed to move upstream in waves related to the tide, there is usually a higher proportion of males at the start of the migration (Claridge & Gardner 1978; Aprahamian 1981). Twaite shad appear to move up estuaries on spring tides (Bracken & Kennedy 1967, Aprahamian 1982) and movement decreases as tidal height declines (Mennesson-Boisneau *et al*. 1999). Shad move predominantly during daylight hours (05:00-20:00), where it is noted that their movements are near the bottom of the river to avoid high flows (Clabburn, 2002), presumably to save energy.

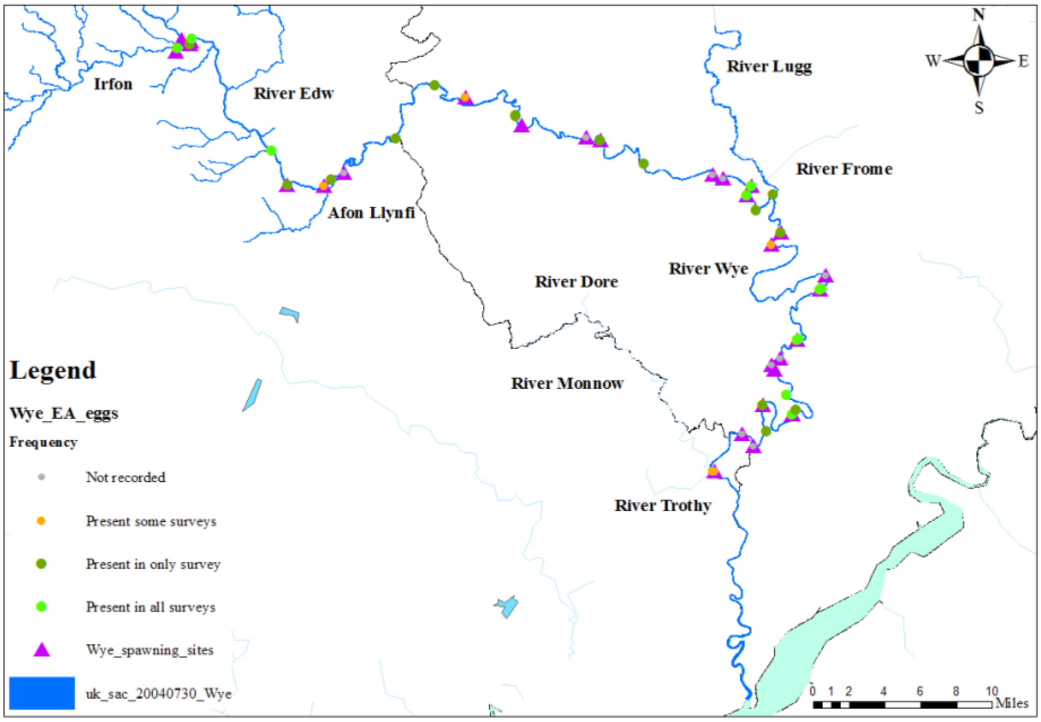

Figure 4.1 Known distribution of shad spawning in the River Wye from EA egg survey data and spawning sites reported by Aprahamian (1999) and Noble *et al.* (2007).

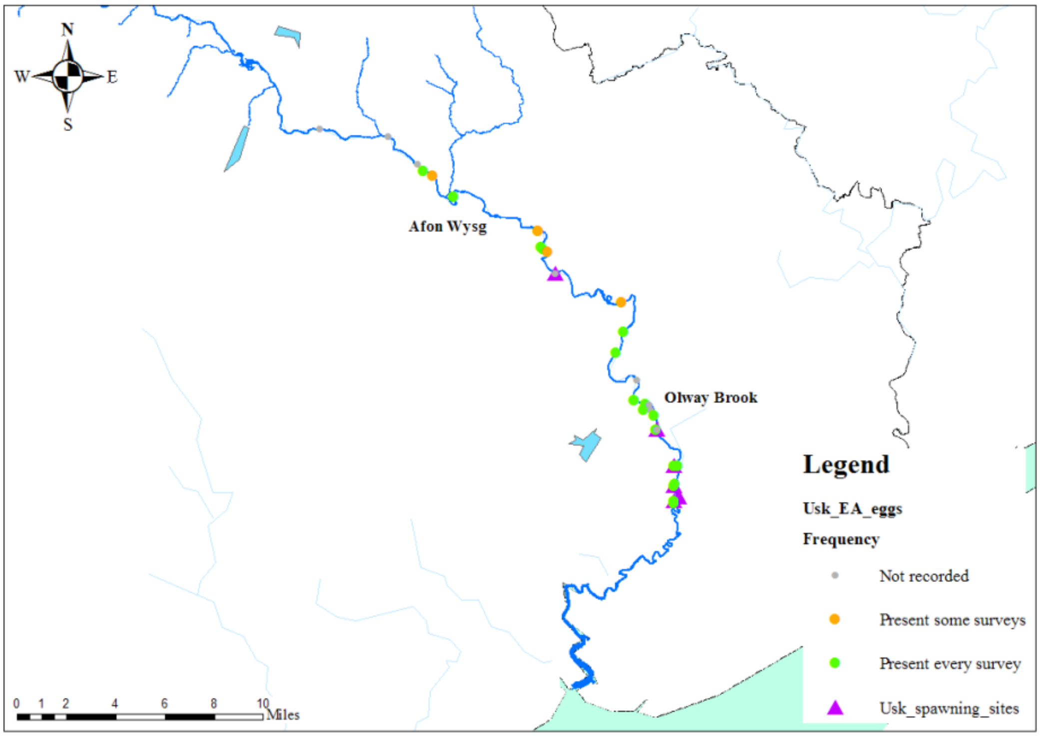

Figure 4.2 Known distribution of shad spawning in the River Usk from EA egg survey data and spawning sites reported by Aprahamian (1999) and Noble *et al.* (2007).

Shad are known to migrate up to 100 km from estuaries to find suitable spawning sites. Noble *et al.* (2007) found that populations of twaite shad in the Wye spawn as far as Builth Wells (Figure 4.1), with the vast majority of spawning sites on the main body of the Wye itself rather than its respective tributaries. Twaite shad predominantly spawn between Newbridge-on-Wye and Hay-on Wye (Figure 4.1) although spawning of twaite shad has been observed further upstream, although no records support this. Shad have been seen migrating as far as Brywern Bridge suggesting that this is their upstream limit. This could also indicate that a potential barrier to further migration is present or that no suitable spawning habitat exists beyond this reach

In the Usk, twaite shad spawning takes place primarily downstream of Trostrey (Figure 4.2). No spawning or nursery grounds were observed upstream of Crickhowell Bridge, suggesting, that this is their upstream limit. This could also imply that there is a barrier to further migration or that there is no suitable spawning habitat beyond this reach. The lower limit is the Llantrisant intake with the predominant distribution range found between Trostrey and Llantrisant (Figure 4.2) where the spawning conditions are more favourable for shad with a gradient of 2 m/km. The weir at Prioress Mill (Rhadyr) was also likely to have been a barrier in the past but has since been removed by DCWW.

The construction of barriers is thought to be the primary factor driving the declining population of shad in the UK. Abiotic and biotic factors have shown to have a drastic effect on water quality, in particular dissolved oxygen, as shad require substantial levels to maintain their populations. Shad are also highly temperature sensitive, where temperature is seen to initiate their migration. Furthermore, Aprahamian *et al.* (1998) showed a relationship between recruitment (year class strength) and higher temperatures, where it is also thought that flow could be a contributing factor. Aprahamian & Aprahamian (2001) found that good recruitment was related to higher mean water temperatures between June-August and the latitude of the north wall of the Gulf Stream in August. This has been further illustrated through historical catch records from fishing traps, known as putchers, in the Severn estuary where catch per unit effort (CPUE) increased after warmer summers (Aprahamian *et al.* 1998). These trends were reflected in the number of juveniles entrained on intake structures, as reported by Henderson (2003) from the Hinkley Point ‘B’ Nuclear power station. These datasets indicate that very high levels of recruitment are seen in warmer years (1989 and 1990), with other strong periods of recruitment around 1984 to 1985 and 1995 to 1996. The numbers of juveniles recorded from 1997 to 2002 have, with the exception of 1999, been relatively low, indicating poor recruitment during this period as a result of the cooler temperatures.

The genetic structure of twaite shad shows isolation-by-distance with similar DNA structure found within a population’s geographical location. Jolly *et al.* (2012) showed that breeding populations of a river can migrate to neighbouring rivers within their native estuary exhibiting mixing. This is found in the study area where the populations of the Wye, Usk and Severn are all of the same stock. Although hybridization between twaite shad and allis shad is possible, there have been no confirmed cases found within this study area supporting the increased belief that the allis shad species is now extinct within this region (Aprahamian *et al.* 2003).

4.2 Results

Due to the difficulty in visual separation of twaite and allis shad, from here on out both species will be known as “shad” unless stated where the vernacular nomenclature (twaite shad and allis shad) will be used. However, the presence of allis shad in this study is highly unlikely as they are thought to be extinct, as a consequence it is assumed that all fish observed are twaite shad.

4.2.1 Seasonal movement patterns

The numbers of shad moving up- and downstream in the rivers Wye and Usk were counted during each 24-hour period during the migration window (20 May-11 July and 08 May-11 July, respectively) and compared with known environmental drivers of migration (namely tidal height, water temperature and flow) (Figure 4.5 - Figure 4.4). Due to camera malfunctions, high turbidity and algal growth on the infra-red lights and camera lenses, there were difficulties with the recording process. These problems were exacerbated in the Wye because the river is deeper, resulting in less visibility during rain fall events by increasing suspended sediment concentration concentrations of sediment and thus the ability to accurately process the images. The increased water flows between 25 June-04 July also preventing access to both camera arrays to clean the lenses. Furthermore, the camera field of view couldn’t span the whole stretch of the river due to the limited length of light that the infrared lights produced. These sources of error are graphically displayed during the days of difficulty to explain the gaps in data, although it must be noted that fish could still be seen if they were in close proximity to the camera and thus counts of fish were still recorded during these times where possible (Figure 4.3 & Figure 4.4).

The first record of shad migrating upstream in the Wye was the 20 May 2013, 12 days later than the Usk. Unfortunately, a malfunction of the software recording system corrupted the image files preventing observations during this period; this issue was identified and fixed by May 14th. Consequently, it is therefore possible that initial migration of shad may have been earlier, in parallel with the observations seen in the Usk (08 May). Shad numbers migrating in the Wye increased to an initial peak on 21 May and 22 May with 218 and 296 individuals respectively (Figure 4.3). During this first migration, period (20 May-28 May) 875 shad were seen to move upstream with only 47 shad moving downstream.

The first record of shad migrating upstream in the Usk was on 08 May 2013 with 48 individuals observed. Subsequent high flows and turbidity resulted in decreased observations until 18 May 2013 when numbers increased to peak on 21 May, and then decrease again to lower numbers about 10 days later Figure 4.4). During this period shad moved both up (1202) and downstream (781), suggesting that they may mill around the camera array; although an overall net upstream migration was observed. In both rivers shad were observed with peaks in upstream migration in early and late June (07/06-21/06 in the Usk and 03/06-19/06 in the Wye) and peaks in downstream migration observed in late June and early July (19/06-22/06 in the Usk and 22/06-05/07 in the Wye). The last shad were observed on 11 July in both rivers (Figure 4.3 & Figure 4.4), which suggests that the migration timeframe in both rivers is similar and would also suggest the initial migration was unfortunately missed in the Wye.

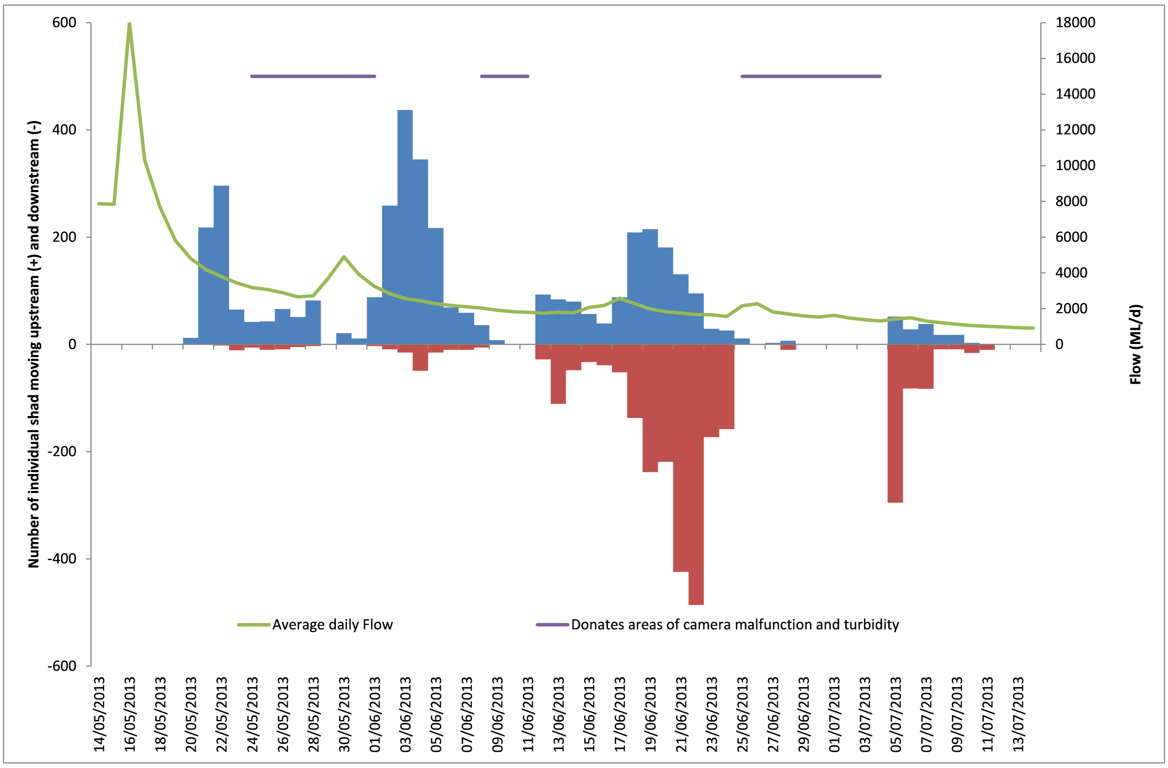

Figure 4.3 Up (blue) and downstream (red) movements of shad in the River Wye in relation to flow. Purple line denotes areas of camera malfunction or high turbidity.

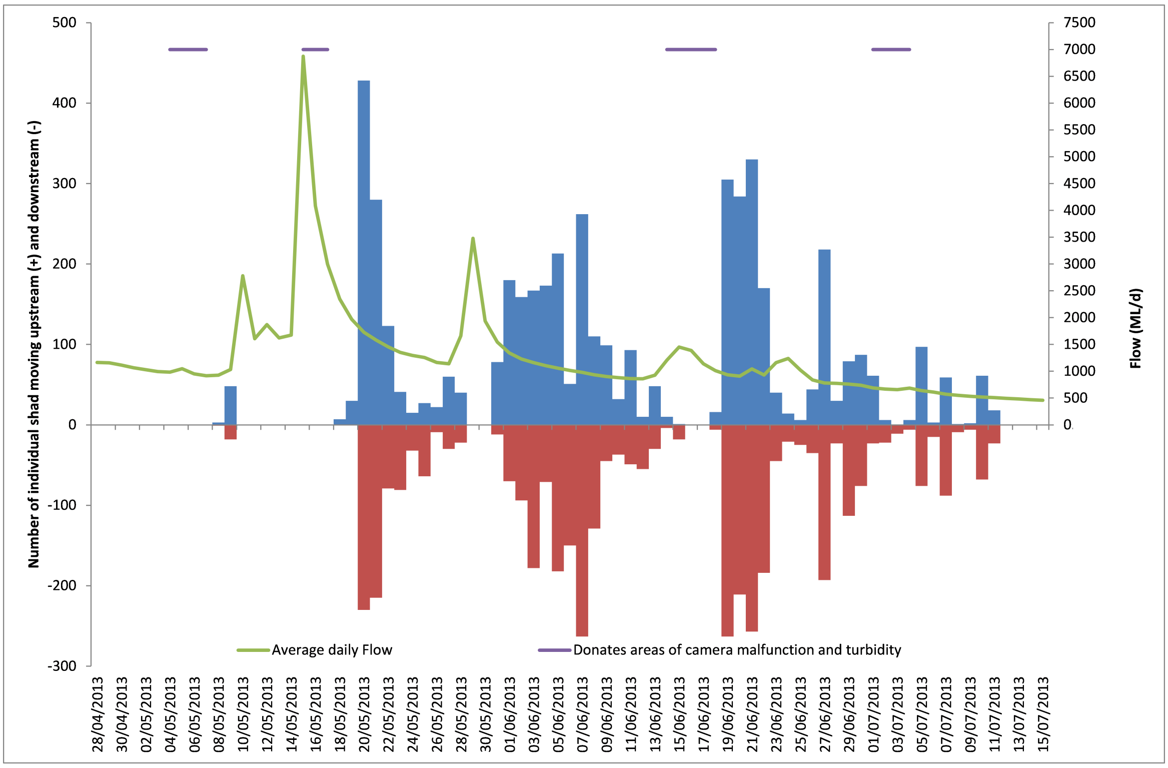

Figure 4.4 Up (blue) and downstream (red) movements of shad in the River Usk in relation to flow. Purple line denotes areas of camera malfunction or high turbidity.

Data shows that there also appears to be a trend with flow (Figure 4.3 and Figure 4.4). In the Usk, shad were observed first on the 08 May, however, during the spate event (10 May-17 May) no shad were observed moving until 17 May (Figure 4.4). Although there is no data available before 14 May in the Wye, no shad were observed migrating until 20 May, which is well after the same spate event in the Usk (Figure 4.3). During the course of the study there were numerous high flow events when shad numbers declined suggesting that this increase in flow/velocity affects shad migration (Figure 4.3 and Figure 4.4). In particular, shad appear to halt their migration to avoid high flow events and stopped migrating upstream until flow levels were below 2000 Ml/d in the Usk and below 5000 Ml/d in the Wye. However, the lack of observed shad could also be due to decreased visibility as a result of increased levels of suspended sediment. Although, this is unlikely as other species were recorded during this period and the use of infra-red lights allowed light to be reflected off of the fish scales back to the camera showing that fish are in the areas (something which wasn't seen during this event).

Prior to peaks in their migration, shad appear to be specifically influenced by tidal state (Figure 4.5 and Figure 4.6) with peaks in migration on both rivers at the bi-monthly tidal cycle between spring and neap tides caused by the full moons (8 May and 21 June). Numbers also increased at the beginning of the neap tide cycle in early June. However, due to an algal build up and unforeseen circumstances that prevented entering the river to clean the camera arrays in the Wye (Figure 4.3), the final period of the second full moon was not possible to interrogate. The results, however, show that the main timing of migration corresponds with the lunar and tidal cycles around the two full moons of spring. It must be noted that the cameras were positioned above the tidal limit (Bigsweir and Newbridge-on-Usk on the Wye and Usk respectively; Figure 2.1) and as such, rivers levels were not affected by tide. Consequently, all assumptions on tide are based upon the tide height downstream of the cameras influencing the movements of shad past the camera arrays.

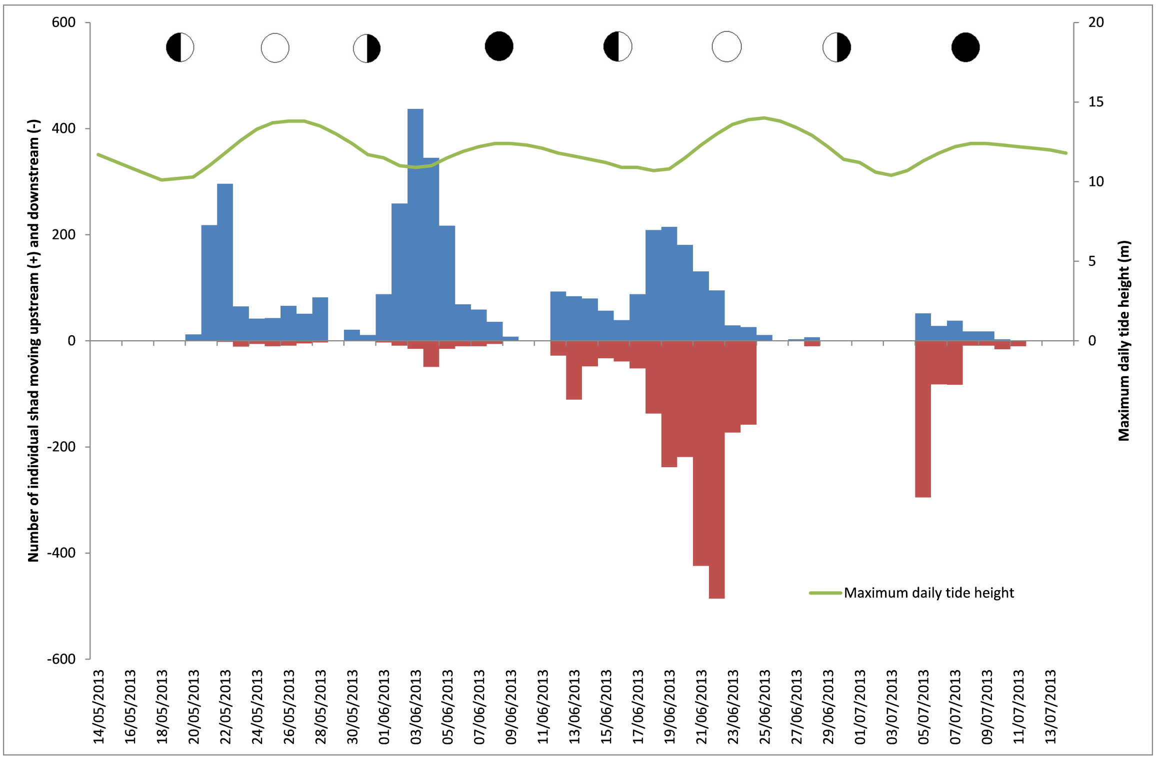

Figure 4.5 Up (blue) and downstream (red) movements of shad in the River Wye in relation to tide height and lunar cycle.

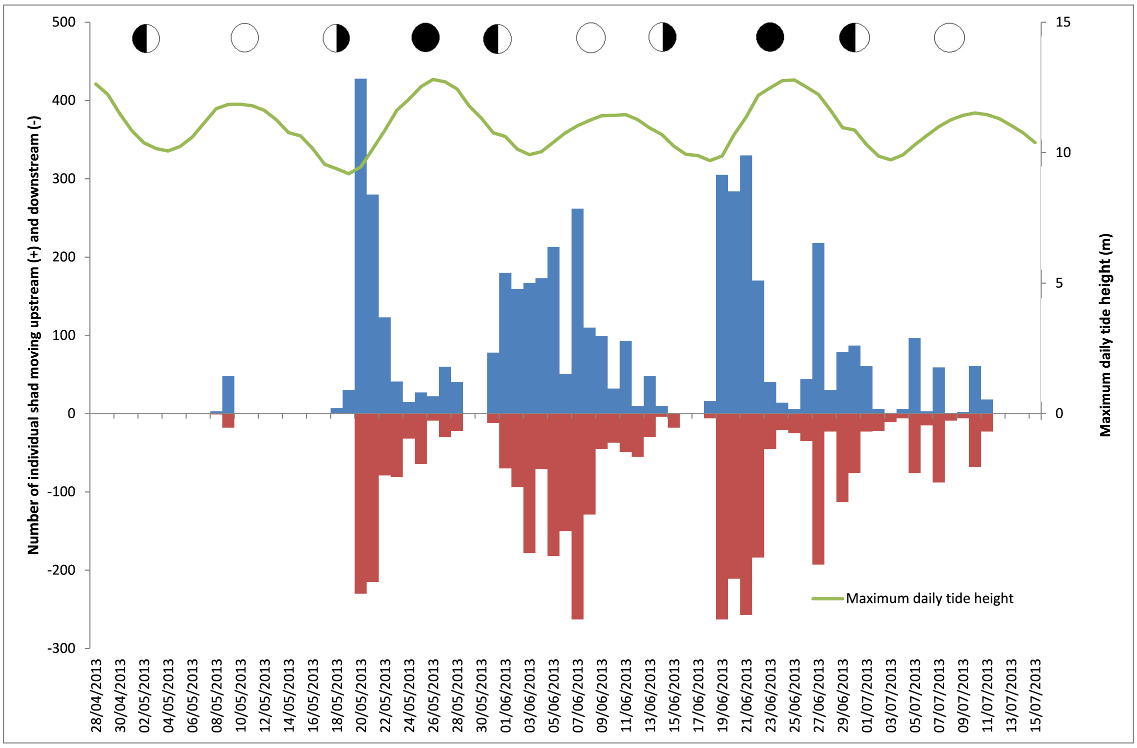

Figure 4.6 Up (blue) and downstream (red) movements of shad in the River Usk in relation to tide height and lunar cycle.

In both rivers, temperature data was gained from NRW taken from both study sites (Redbrook and Wye) from temperature loggers, which allows direct comparisons between the temperature and observed movements captured as they are in the same spatial area. The initial upstream migration was observed at temperatures greater than 11°C (Figure 4.7 and Figure 4.8). After the initial immigration of shad into the system, water temperatures rose steadily between 12 and 19°C throughout June in both rivers (Figure 4.7 and Figure 4.8). As temperatures rose past 20°C, shad numbers decreased, although this timing coincides with the outmigration from the system. Due to the steady rise in the temperature with no sudden variations, no relationships can therefore be drawn from the data.

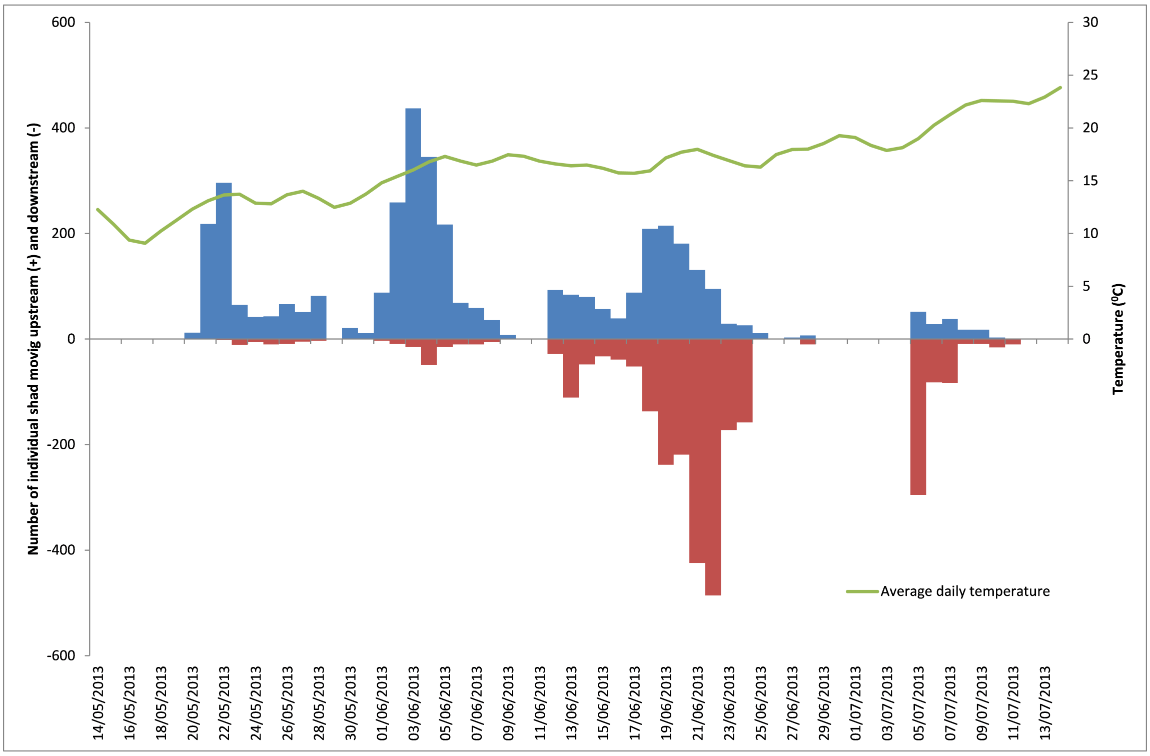

Figure 4.7 Up (blue) and downstream (red) movements of shad in the River Wye in relation to temperature.

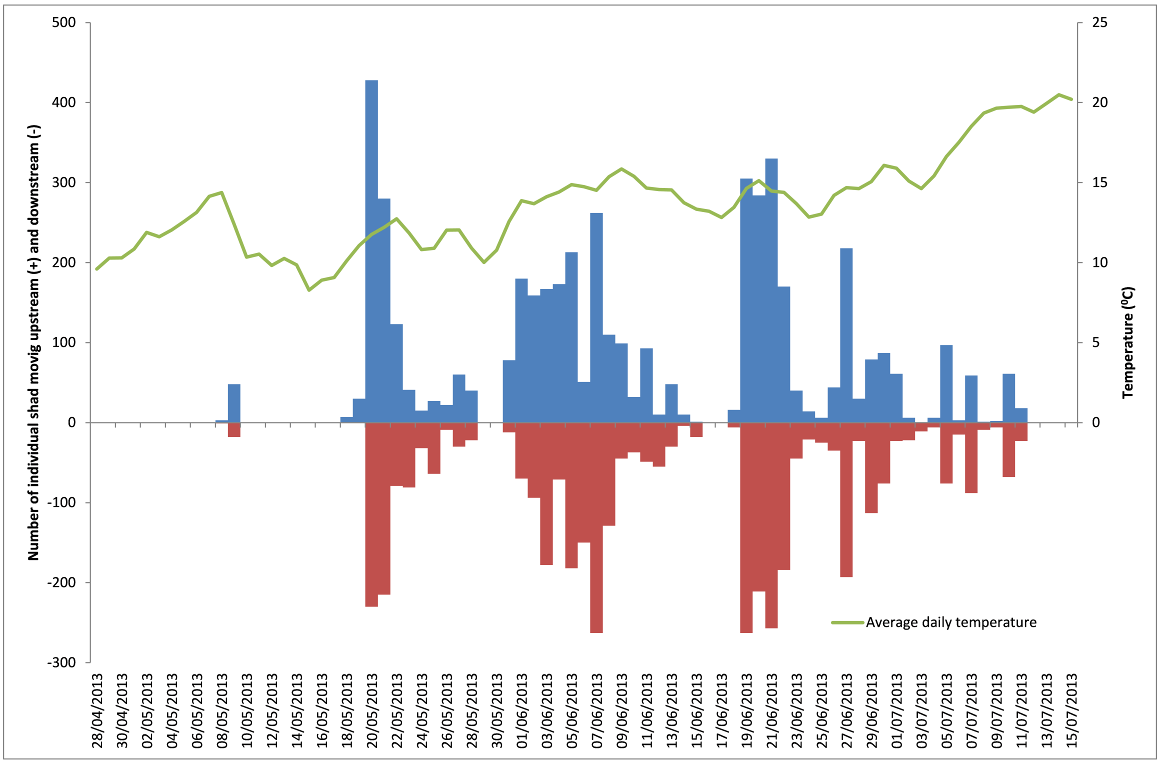

Figure 4.8 Up (blue) and downstream (red) movements of shad in the River Usk in relation to temperature.

Net migration in both rivers was calculated by subtracting downstream movements from the upstream movements. In the Wye (Figure 4.9), net migration showed a clear shift from net upstream to downstream movements on 18 June. Whereas in the Usk (Figure 4.10), there are no clear shifts from shad migrating to and from spawning grounds. This could point to two factors: 1. the spawning grounds are in close proximity to the camera array set up at Llantrisant, or 2. shad were milling around the camera array until more favourable migration conditions were met.

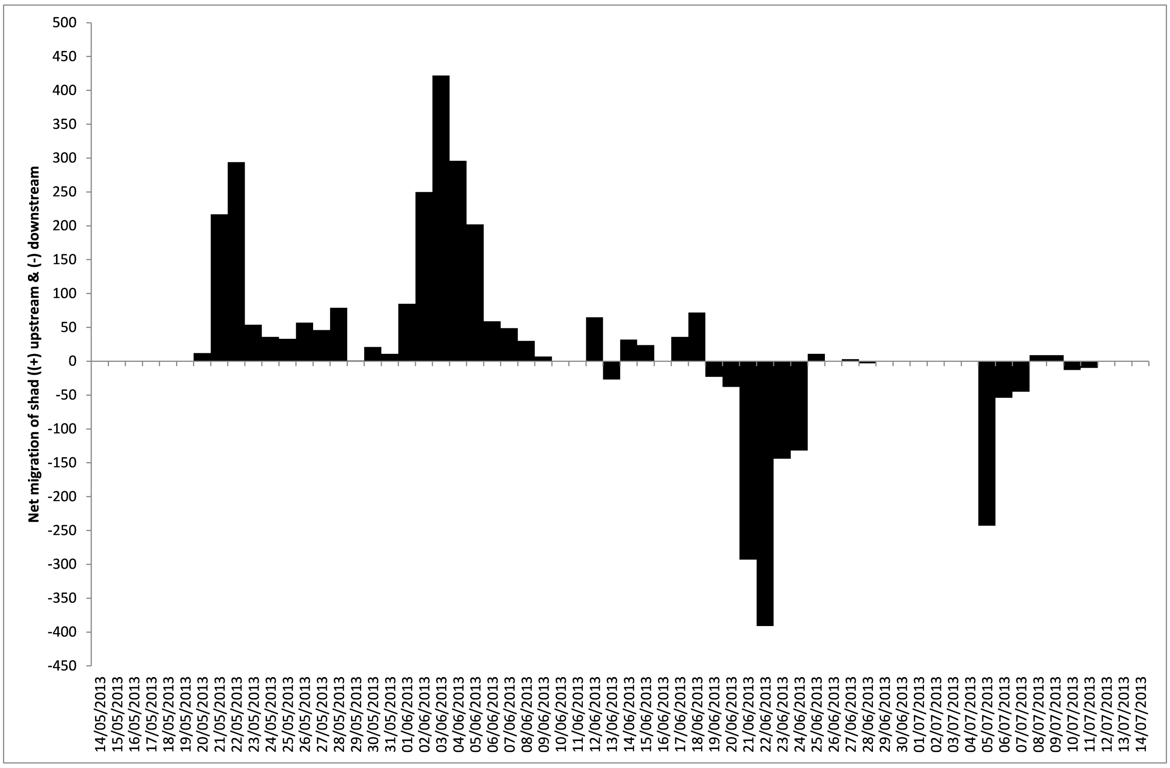

Figure 4.9 Net migration of shad in the River Wye

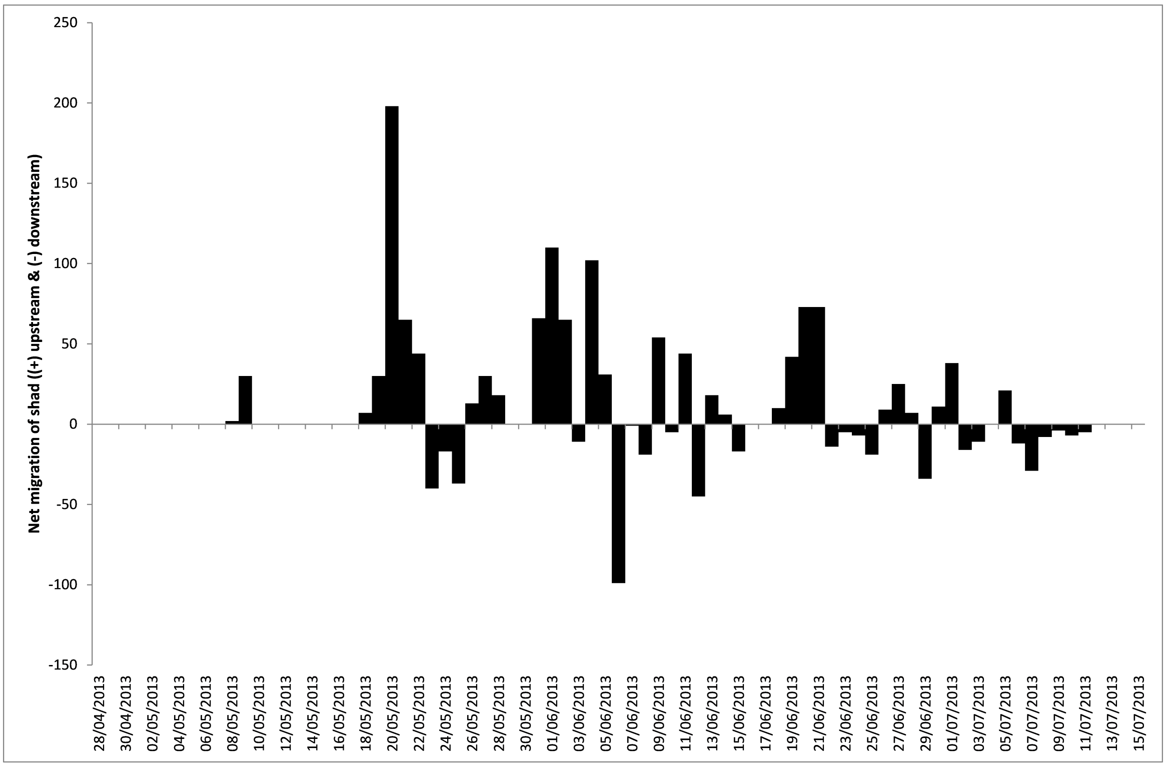

Figure 4.10 Net migration of shad in the River Usk.

4.2.2 Diel movements

Due to each fish movement being noted against time and date throughout the study, it was possible to calculate the diel movements of shad. Data for figures Figure 4.11 and 4.12 combine both upstream and downstream movements, whereas figures 4.13 and 4.14 compare the differences between upstream and downstream movement.

Data from the Wye (Figure 4.11) show shad move predominantly during the day between 05:00-20:00, when migration numbers appear to peak between 12:00-18:00, with very little movement overnight. In the Usk (Figure 4.12) migration is, in comparison to the Wye, an hour later predominantly between 06:00-21:00, although smaller numbers are seen to migrate from 04:00. Migration in the Usk appears to be more prevalent at dawn and dusk with large peaks between 06:00-08:00 and 19:00-21:00 when three unexplained peaks during the day. Like the Wye there is little movement during the night and on both rivers shad move between the hours of dawn and dusk.

Total numbers of shad migrating both up- and downstream were recorded in both rivers to compare any changes in diel movements between both phases in migration. The River Wye showed a rise in upstream migration (Figure 4.13) at 05:00 although migration was predominantly between 13:00-20:00. Downstream migration (Figure 4.13) earlier with most fish seen between 10:00-18:00, with two smaller peaks at 05:00 and 20:00. In the Usk both upstream and downstream migration (Figure 4.14) showed an erratic daytime pattern with peaks throughout the day, which was probably milling behaviour discussed previously. Up- and downstream migration phases take place within the daylight period with large numbers during the dawn and dusk periods and little movement overnight.

As discussed previously there is a lack of net migration trends in the Usk (Figure 4.10). Consequently, the split in the phases between net upstream and downstream migration was not identifiable. This inability to identify the shift from the upstream to downstream phase of shad migration means that no comparisons can be made regarding the potential change in their diel patterns.

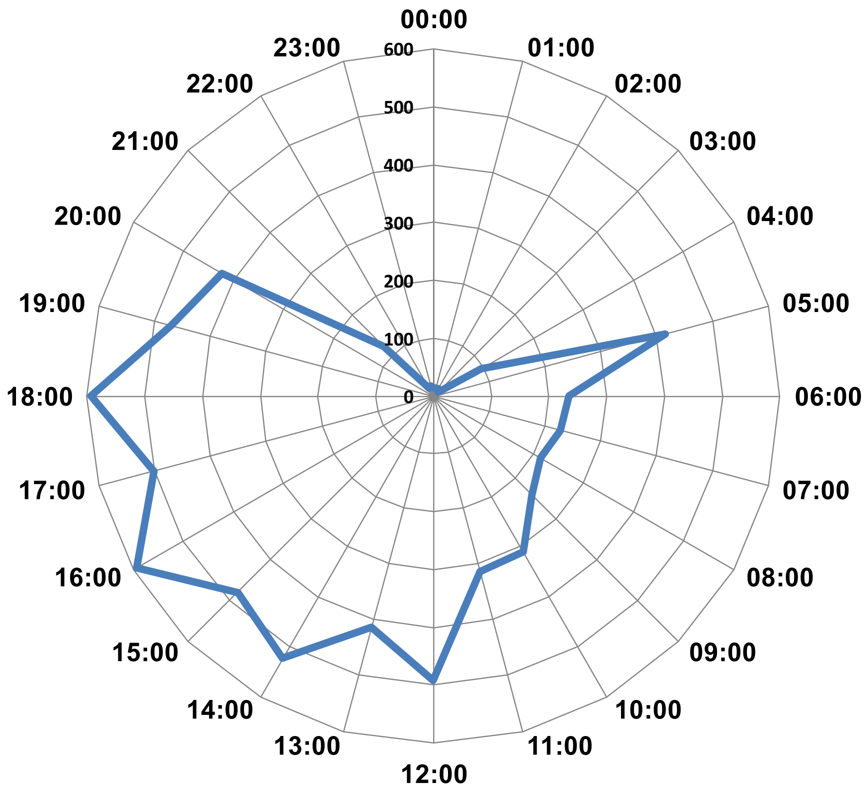

Figure 4.11 Diel movements of Shad in the Wye.

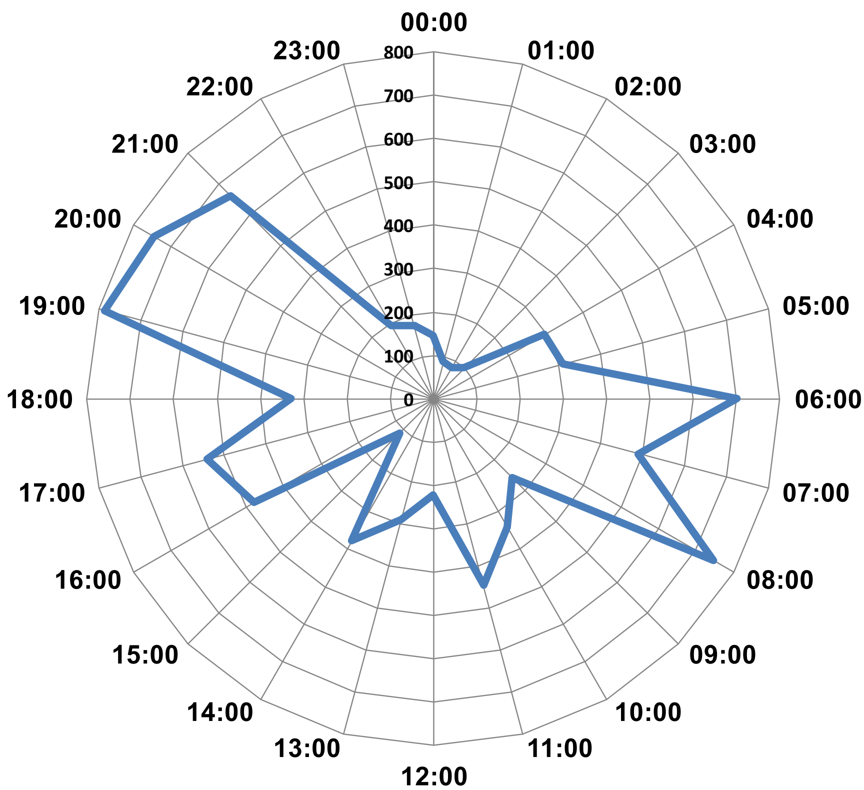

Figure 4.12 Diel movements of Shad in the Usk.

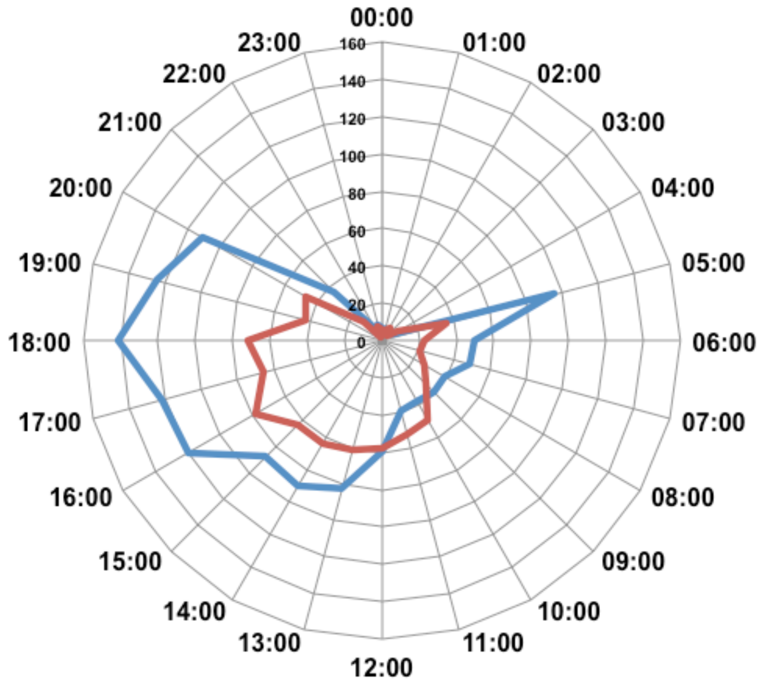

Figure 4.13 Up (blue) and downstream (red) total diel migration of shad in the River Wye.

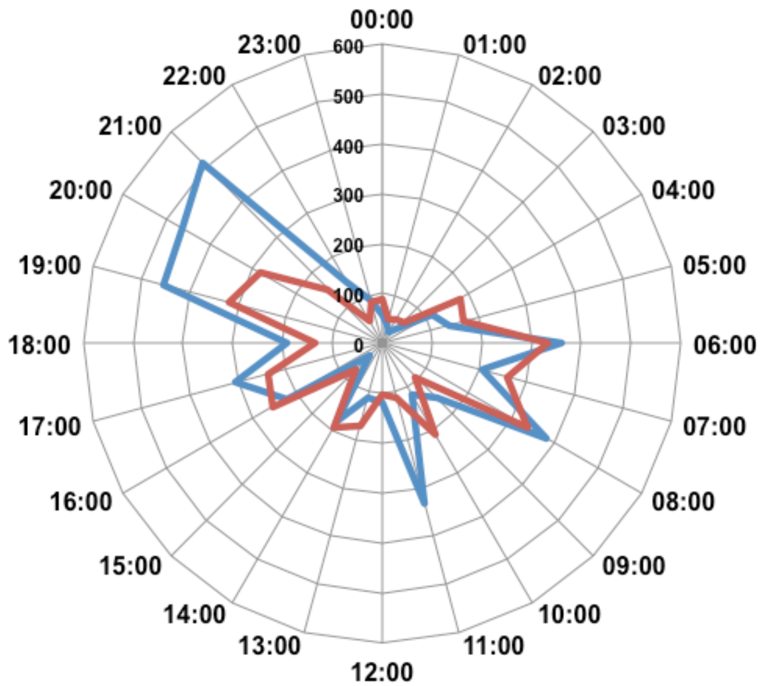

Figure 4.14 Up (blue) and downstream (red) total diel migration of shad in the River Usk.

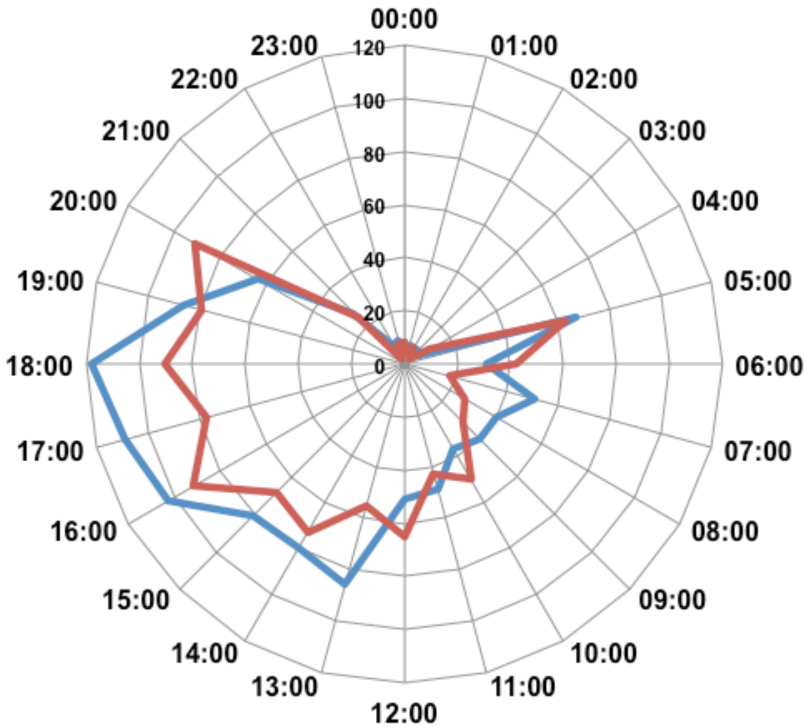

Figure 4.15 Up (blue) and downstream (red) diel migrations of shad during the net upstream phase of migration (20/05-18/06) and downstream phase of migration (19/06-14/07) in the river Wye.

However, this pattern can be assessed in the Wye. As discussed previously, the River Wye shows the noticeable shift from the upstream to downstream phase of shad migration (Figure 4.9). This split was seen between 18 June-19 June, which suggests that the migration timeframe is almost exactly equal for both phases. Data from these periods in the Wye allows further analysis upon the timing of movements of shad during both their upstream and downstream phases of migration (Figure 4.15).

During the net upstream phase (Figure 4.15), shad showed a strong preference for daytime movements (05:00-20:00) with most fish moving between 13:00-19:00, and little movement overnight (21:00-04:00). Downstream net migration followed a similar pattern with migration mainly between 05:00-20:00, although migration was predominately between 10:00-20:00. Again little migration occurred overnight, but there was an unexplained peak at 05:00 which wasn't isolated to one event.

4.2.3 Position over the camera array

Along with noting species and direction of migration against time, the specific camera at which the fish moved over the array was also noted (Figure 4.16 and Figure 4.17). In the River Wye (Figure 4.16), shad appeared to preferable each of the end cameras (4, 8 and 12) on each array, which recorded 390, 1054 and 3608 individuals respectively with the largest number in camera 12 (Figure 4.18). There is also a peak over camera 11 although this is most likely accountable to the shoal sizes of shad encompassing an area of two cameras. In the River Usk (Figure 4.17), the same trends were observed with camera 12 capturing 3105 individuals and the last cameras in the other arrays (4 and 8) the highest numbers of individuals of the 4-camera block with 1121 and 1642, respectively (Figure 4.18).

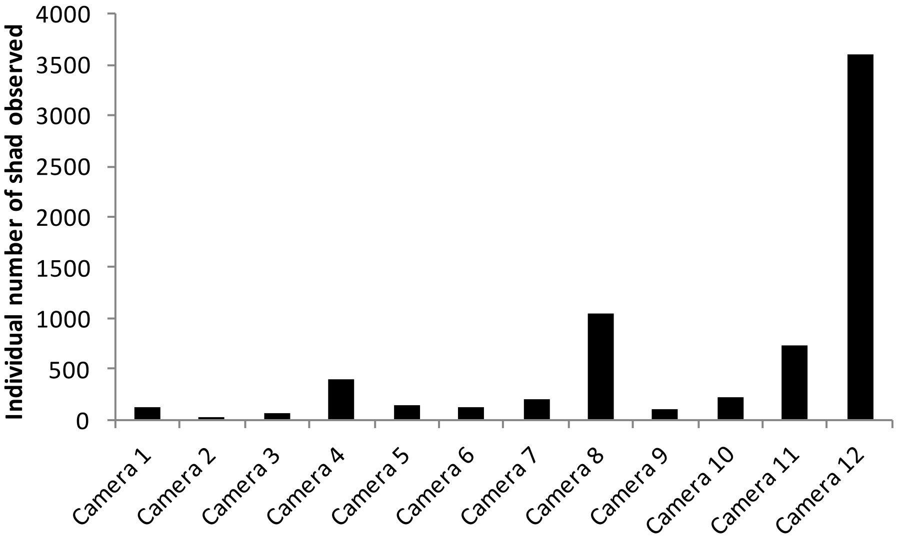

Figure 4.16 Position of shad movements across the camera array in the River Wye.

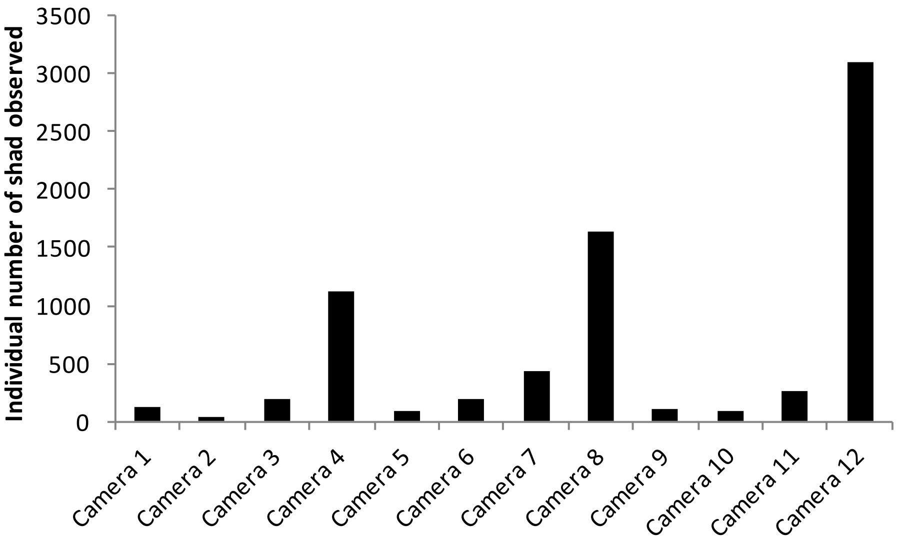

Figure 4.17 Position of shad movements across the camera array in the River Usk

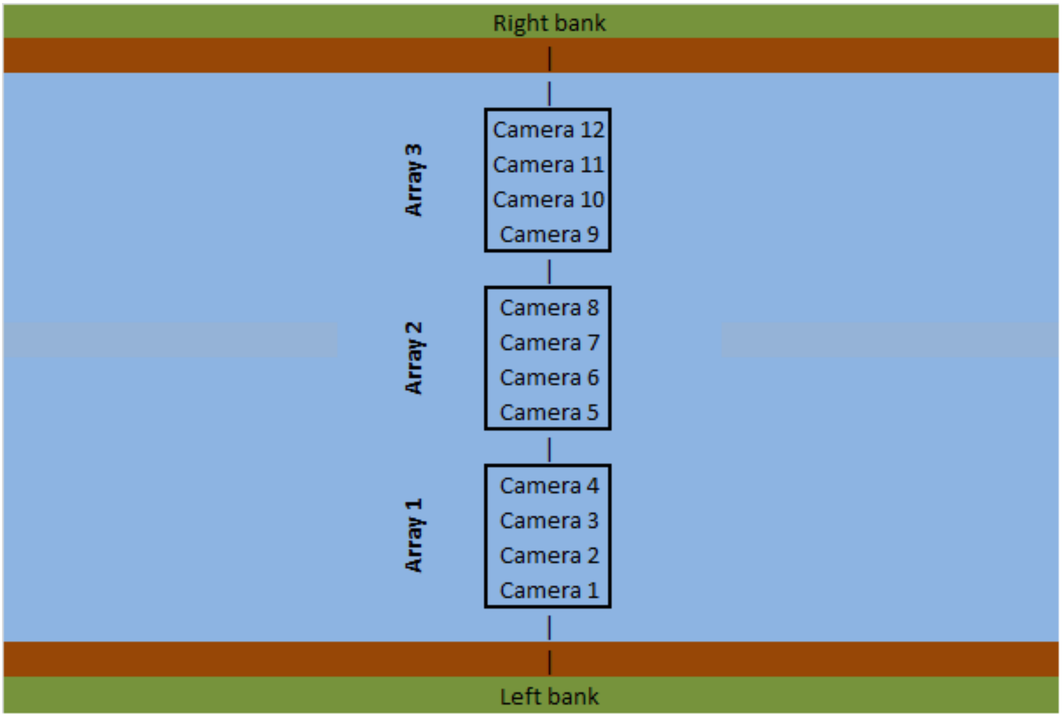

Figure 4.18 Graphical representation of camera positions in both study rivers

To explain this spatial behaviour, an Acoustic Doppler Current Profiler (ADCP) (Figure 4.19) was used to profile the river at the River Usk study site. With the three arrays set up at roughly the 25, 20 and 15m track points on the ADCP profile, the velocity profile was found to differ between each array. With the velocity of the river decreasing from the left bank, it can be assumed that the increased numbers seen closer to the middle/right bank (cameras 8 and 12) was to avoid these higher flows. Unfortunately, no ADCP profile was taken of the site used on the River Wye so this explanation cannot be confirmed.

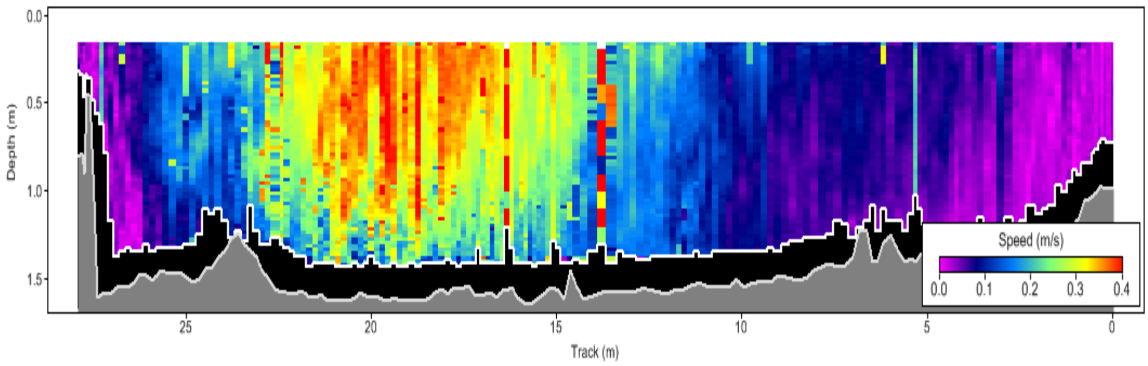

Figure 4.19 ADCP cross-sectional water velocity profile at position of camera array at Llantrisant on the River Usk. Left bank (and hence intake and camera) is on the left side of the graph.

There is, however, no obvious justification for the quantity of shad passing along the outside cameras of each array (from the riverbank) and in particular camera 12 (Figure 4.16 and Figure 4.17). The camera arrays were identical in construction (Figure 3.1) and the riverbed is homogeneous in topography (Figure 4.19).

4.3 Discussion

Migration of shad in the rivers Wye and Usk was observed and provided vital information for future management strategies. The observed migration window in the Usk was 08 May – 11 July and it is believed that this could be the end of migration as no individuals were seen 10 days prior to the start of the first observation or 4 days subsequent of the final observation. In the Wye the window was observed between 20 May – 11 July, with no individuals seen 6 days prior to the start of migration or 4 days subsequent of the end. The days of no migration either side of the window were deemed adequate to assume that migration had begun and ended. It must be noted that these periods may not represent the exact start and end of migration as fish could have been missed in either phase of migration due to high turbidity, camera malfunction, biofouling or fish migrating out of sight of the cameras.

In the Wye, migration was observed 12 days later due to a fault with the camera arrays and then, when fixed, footage began during a spate event. During this spate event, no shad were seen in either river. It is therefore assumed that due to migration in both rivers concluding on 11 July and taking place within close geographical proximity (Severn basin), migration did start earlier in the Wye – as shown in the Usk - although it was not observed. The timing of migration is consistent with the literature (Claridge & Gardner 1978; Aprahamian, 1985, 1988; Gregory and Clabburn, 2003) and the visual sightings supplied by the WUF (Appendix 3). The observations supplied, although generally associated with the upper reaches of the rivers, suggest the predominant time for shad movement was at the end of May and the beginning of June. In the Usk the timings are also consistent with angler catch records and observations in upper Llangybi beat (Appendix 2). Although there were no shad observed or caught by anglers in the upper Llangybi beat in 2013, independent reports to DCWW indicated shoals of shad around Usk Town Bridge on 2 June 2013 (Cowx *et al.* 2014) and one rod-caught twaite shad on the lower Monkswood beat on 13 June 2013.

With significance to this study, Aprahamian (1981, 1982 and 2003) found shad populations in the rivers of the Severn estuary started their migration in late April/May, peaked in June and ended in July. although migration in this study was not observed in April, shad are known to mill until favourable conditions for migration are met (Aprahamian, 2003). Water temperature has been shown to influence shad migration (Claridge & Gardner 1978; Aprahamian 1985, 1989; Guillard & Colon 2000; Aprahamian & Aprahamian, 2001; Aprahamian, *et al.* 2010; Gregory & Clabburn 2003). Aprahamian *et al.* (2010) showed that immigration into the Severn estuary coincided with temperatures ranging between 10.6 and 12.3^{o}C. This was also seen in other estuaries in the south of the United Kingdom where migrations start earlier (Aprahamian *et al.* 2010). This is consistent with the results where shad movements were seen above 10.6^{o}C in both rivers. Evidence currently suggests that rising water temperature is not a cue to the onset of upstream migration into the freshwater system. Therefore, the seven-day delay between reaching the temperature threshold and the first observed shad migration could be in conjunction with the lunar and tidal cycles of that time of the year. Temperatures during the study were constant which will help the successful development of eggs as incubation takes up to 10 days. Furthermore, higher water temperatures are suggested to be the underlying factor driving recruitment success (Aprahamian *et al.* 2003, 2010), indicating that 2013 will have high recruitment levels. Additionally, as temperatures were fairly consistent and, as stated previously shad migrated in waves, there is no evidence that temperature is a further trigger during their freshwater migration.

Aprahamian (1981) found that tidal state is the primary factor that begins and drives the freshwater phase of migration. This is consistent with the data where shad in the Usk were seen to begin migration on the rising limb of a full moon tide (Figure 4.6). Furthermore, the change in net migration on the Wye (Figure 4.9) was seen just prior to the second full moon coinciding with the predicted end of the spawning cycle (Aprahamian, 1989) and the potential cue to emigrate out of the system. The period of the second waning moon was, however, not possible to process in the Wye (Figure 4.3), although it was expected to show a peak in the number of shad migrating downstream as the migration window is comparable in both rivers and the literature.

Boisneau *et al.* (1985) and Aprahamian *et al.* (2003) found no relationship between flow and the cue of migration. Flows, however, have been shown to inhibit migration when they reach high levels (mean = 721 m^3s^{-1}) causing shad to seek refugia. Agreeing with the literature, this study has shown that shad halt their upstream migration during high flow events and even stop during the spate event (10-17 May) until flow levels returned below 2000 Ml/d in the Usk and below 5000 Ml/d in the Wye. This same trend was also shown by Gregory and Clabburn (2003) on the River Wye who found that migration only started when flows had fallen to 4320 Ml/d with numbers subsequently decreasing during high flow events (8640 Ml/d). It is therefore probable that higher flows are actively avoided by shad which stay in the estuary or riverine refugia until the flows subside as a behaviour strategy to save essential energy for migration and spawning.

No net migration was observed in the Usk with multiple peaks both up- and downstream. In contrast, a clear split in net migration was found on the Wye between 18-19 June, coinciding with the second full moon (Aprahamian, 1989) and the expected spawning of shad (Claridge & Gardner, 1978; Aprahamian, 1989). The Wye is therefore thought to be a fair reflection of the expected net migration of shad. The lack of net uni-directional migration in the Usk, suggest that shad were exhibiting milling behaviour (Figure 4.10). This can be accountable to two reasons: 1. the areas in which the cameras are positioned in the Usk (ST38676 97196) are used as an area of refugia from high flow events and potential predation, 2. The location of the cameras is within the principal spawning area, as found by Aprahamian (1989) and Noble *et al.* (2007) (Figure 4.2). The second hypothesis is the most likely as only 4 large flow events were observed in the Usk, and the behaviour was seen outside of these events. It can therefore be assumed that large numbers of shad spawn around the Llantrisnt site thus shifting rapidly between up- and downstream migration.

Previous studies have found some evidence of diel variation in movements of shad, although they are primarily seen during the day (Travade *et al.* 1998; Gregory & Clabburn, 2003; Aprahamian *et al.* 2003). Gregory & Clabburn (2003). They found that shad shoals in the Wye moved predominantly during the day (05:00-20:00) in a crepuscular pattern. These observations are consistent with this study where diel patterns of observed shad were predominately crepuscular (05:00-20:00).

Shad also showed preference to the position in which they migrated past the camera arrays. There is no justification for the quantity of shad passing along the outside cameras of each array (from the river bank) and in particular camera 12 (Figure 4.16 and Figure 4.17). The camera arrays were identical in construction (Figure 3.1) and the river bed is homogeneous in topography (Figure 4.19).

This behaviour, as stated previously, is probably linked to river flow and velocity. Shad are known to migrate upstream in the lower half of the water column close to the river bed, where water velocity is lowest. It has also been shown that during downstream migration, shad use the middle to upper part of the water column where water velocities are greatest (Clabburn, 2002). These findings indicate that velocity plays a vital role in the energetics used in the migration of shad and as such it is more likely that the behavioural response is in reaction to changes in flow dynamics within the water body. The ADCP profile in the Usk showed that the velocity of the river decreases from the left bank and as such it can be assumed that the increased numbers seen closer to the middle/right bank (cameras 8 and 12) is in response to lower velocities.

It is therefore likely that the shad positioning is the result of both river velocity and avoidance behaviour. It must be noted, however, that this conclusion is based only on the River Usk over a one-year data set. As such, it is recommended that further spatial and temporal studies are carried out to either isolate the cause or assess what other factors are involved.

5 SALMON MIGRATION

Salmon are seen as a key and iconic species, and within Wales salmon is of importance particular in the rivers Wye and Usk where it supports local economies and livelihoods. Furthermore, with its importance to the designation of the rivers Wye and Usk SAC, it is important to monitor their migrations. Salmon have numerous life stages that can be affected by alterations in flow. These are: the anadromous migrations of adults to return to their natal streams to spawn, the spawning of salmon, egg development, development of both the alevins and parr's and the out migration of smolts from their respective rivers. All of these life stages are crucial to the future survival and recruitment of the species and why flow regulation and abstraction is of concern as they can potentially adversely affect survival and dispersal.

The relationships between adult salmon migration and flows in the rivers Wye and Usk have been explored through the Wye and Usk Foundation (WUF) flow migration model (WUF, 2013) and the AMEC assessments of salmon migration patterns derived from rod catch and counter data (Cowx *et al.* 2013, 2014). There is considerable variation in temporal patterns of upstream movement. Factors believed to influence upstream movement include:

- the physiological readiness of the fish to spawn;
- river flow;
- water discolouration;
- water temperature; and
- tidal state and estuarine conditions (Milner *et al.* 2012a).

However, one area that has received little attention is the relationship between flows and the smolt life stage. This is of concern because flow regulation and abstraction can potentially adversely affect the survival and dispersal of smolts as they out-migrate from rivers, an issue raised by WUF regarding the Review of Consents for the rivers Wye and Usk. This arises because it is considered that "*low spring flows reduce the downstream migration of smolts"* (G. Mawle, Technical Meeting 11 July 2012) and thus reduction in spate flows in April and May through abstraction may adversely affect smolt migration. A review of the current literature on smolts by Cowx *et al.* (2014) indicated that most smolts out-migrate during the descending limb of the overall spring hydrograph, and flow is a co-trigger initiating migration along with temperature and day length. Onset of the smolt run is positively correlated with river water temperature; a rise in water temperature above 10°C being the main proximate environmental cue.

As part of the Wye and Usk RoC process the use of underwater camera arrays were deployed in both rivers to primarily assess the migration of shad, although were later used to assess salmon migration due to the quality of the outputs.

In the context of this study, data will focus on two life stages of the salmon: the anadromous migrations of adults to return to their natal streams to spawn and the out migration of smolts from their respective rivers. As migration of salmon at both life stages is subject to multiple temporal factors in both upstream and downstream movement, it is hoped the migration of salmon at both of these life stages will be captured by using underwater cameras and to explore the effects of multiple factors on their respective migration.

This section describes the outputs of the experimental fisheries camera monitoring surveys carried out in the rivers Wye and Usk in 2013 with the objective to inform the review of abstraction regimes. It is hypothesised that the migration exhibited will mimic that of the literature where temperature is the overriding factor to the onset of migration followed by the multiple temporal drivers. The objective is to understand the relationships between salmon at both life stages against key environmental drivers to their migration to help set abstraction licencing that will minimise ecology damage.

5.1 Salmon ecology

Atlantic salmon is an anadromous species spending a proportion of its life in the marine environment, feeding until they return to fresh water to spawn (Figure 5.1). Atlantic salmon spawn in fresh water between autumn and winter in fast flowing streams or rivers. Spawning sites are chosen based upon channel morphology although it is noted that salmon prefer deeper areas where fast flows are still sufficient (Jonsson and Jonsson, 2011). However, the effects of abstraction and hydrological flow alterations can adversely affect the migrations of both adult salmon and parr. These affects are summarised in Table 5.1 and are discussed in detail with respect to juvenile and smolt life stages in the following sections.

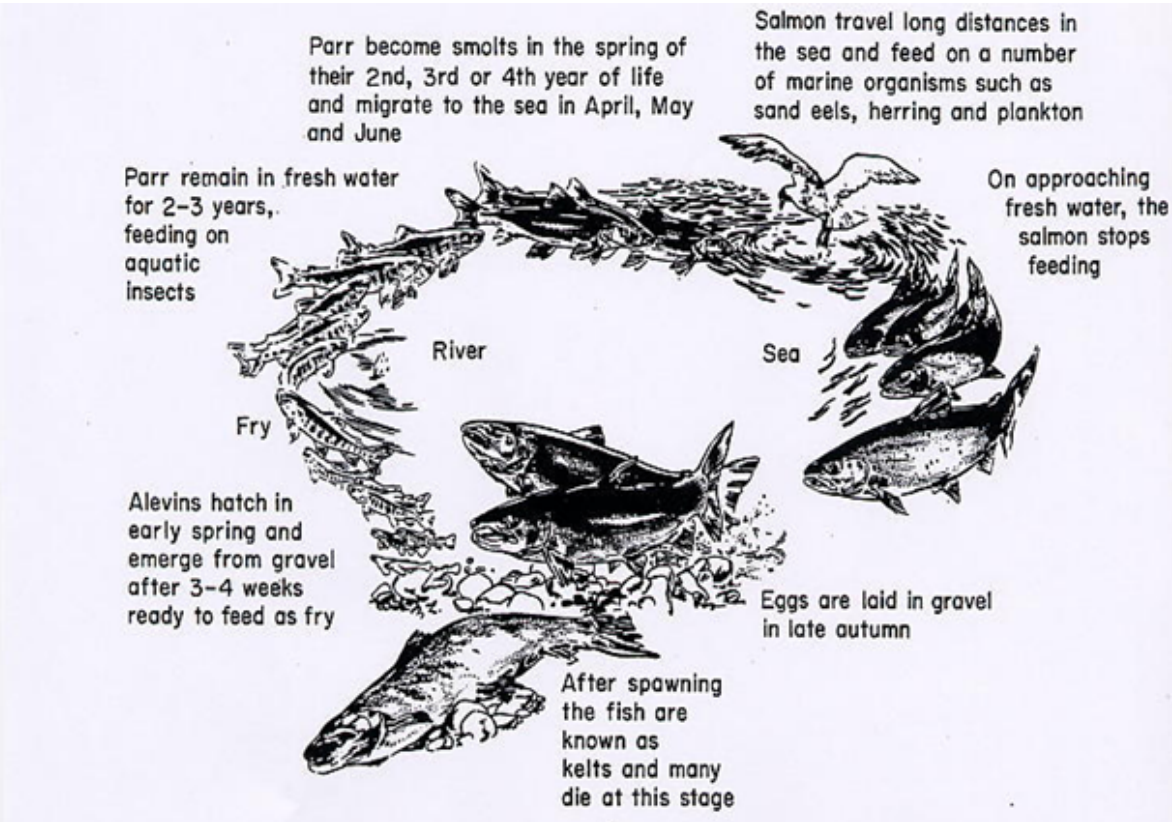

Figure 5.1 Simplified life cycle of the Atlantic salmon (*salmo salar*) (Mills and Graesser, 1992).

Table 5.1 Summary of general potential impacts of abstraction and hydrological alteration in rivers and streams on different life stages of salmon (adapted from Nislow & Armstrong, 2012).

	Alevins	Parr	Smolts	Adults
Spring	Lower or higher survival	Lower growth; stronger negative effects with increasing temperature; reduced shelter availability if bed-mobilizing flows are eliminated	Migratory delay, desmolting, reduced survival	Impede upstream migration
Summer	Lower growth; low prey, high density	Lower growth; stronger negative effects with increasing temperature	n/a	Impede upstream migration
Autumn	n/a	Lower growth; stronger negative effects with increasing temperature; inhibition of pre-spawning movements for residents	n/a	Impede upstream migration
Winter	n/a	Positive to negligible effects on growth; increasing positive effects with increasing temperature	n/a	n/a

5.1.1 Smolts

Parr undergo a transformation process where behaviour and physiology change to prepare them for seaward migration (Nilsen *et al.* 2003). This process is known as smoltification or smolting. Smoltification varies amongst populations due to specific environmental conditions and genetics. The size at smoltification depends upon both growth rate and age, although it is accepted that once body length reaches approximately 15 cm parr undergo transformations to become smolts (Jonsson and Jonsson, 2011). Not only is there a morphological transformation, but there are changes in: salinity tolerance, visual pigments, buoyancy, metabolism and behaviour (Jonsson and Jonsson, 2011) to prepare them for life at sea. The most noticeable change in smoltification is in colouration where they lose their cryptic parr marks in favour of a silvery colour to gain camouflage from mid water and surface predators such as piscivorous birds – in particular cormorants – and pelagic fishes. The colouration change occurs from deposition of guanine and hypoxanthine crystals in the skin which are located beneath the scales and deep in the dermis itself (Jonsson and Jonsson, 2011). It is thought that the colouration is not only an adaptation of predator protection but also for water equilibrium in a hyper-osmotic environment (Hoar, 1988). The morphology of the fish changes with an increased, slimmer body and a more pointed snout, which is meant to assist with migration in becoming more streamlined (Hoar, 1988). Salmon's ability to process different wavelengths of light alters during smoltification. During the alevin to parr life stage their eyes can process high wavelengths of light up to 650nm, although during smoltification (Jonsson and Jonsson, 2011)., they lose the ability to process this wavelength as their retinas lose the ultraviolet-sensitive (UVS) cone receptors through the switching of visual pigments (Jonsson and Jonsson, 2011). These changes are linked to the differences between the marine and aquatic environments where marine fish are sensitive to wavelengths of 450-550 nm (Boeuf, 1993). Buoyancy and metabolism in smolts also increases, in addition to their hypo-osmoregulatory ability with increased Na+ and K+-ATPase found within chloride cells in their gills and intestines (Spencer *et al.* 2010). These adaptations increase as the fish begin smoltification and decrease the closer it gets to migration.

Morphological changes during smoltification are controlled internally (endogenous) by hormones (thyroxin, cortisol, growth hormone, growth factor I and insulin) that promote the preparatory development of seaward migration (McCormick, 2009). The smoltification process itself is controlled by temperature, which donates the rate of change within the aquatic environment, and photoperiod which indicates the time of year (Zydlewski *et al.* 2005). Photoperiod is the primary 'zeitgeber' (migration cue) which controls the different aspects of smoltification as day length is used as a timer to identify the seasons. Migration itself is dependent upon water temperature and is thought to be the primary factor (Hoar, 1988). Water temperature affects the time of seaward migration and is accountable for annual variation (McCormick, 2002). Zydlewski *et al.* (2005) showed that smoltification and migration takes place over a shorter period when temperatures were warmer; although it must be noted that temperatures above 15^{o}C inhibit smoltification. Furthermore, it is shown that survival rates for smolts are lower in cold early summers (surface water temperature <9°C) than in those with an average surface water temperature (9-11.9°C), and lower again, although not significantly, in warm early summers (SST greater than or equal to 12°C) (Cowx *et al.* 2014).

As previously mentioned, smoltification behavioural changes cause parr to rise off the bottom and move downstream with the current. This movement into high water columns is in response to locating other smolts, where they take on schooling behaviour rather than their previous epibenthic and territorial lifestyles (Hoar, 1988). Mortality during this stage can strongly influence population dynamics and production, since there is little evidence of density-dependent compensation associated with the marine life stage (Jonsson *et al.* 1998). Furthermore, as smolts gather out of tributaries and backwaters to join the main body of water to begin their seaward migration, they are subject to the full range of stresses from environmental alterations within river systems, including flow alteration, predation and environmental degradation.

Smolts face downstream (negative rheotaxis) to be transported with the natural flow regime to save energy, although it must be noted that they move a few hundred meters at a time before holding and beginning downstream movement again (Jonsson and Jonsson, 2011). Movement is seen predominantly at night when temperatures are below 12^{o}C, although natural (moon light) or artificial light (street lights) decreases the downstream migration (Jonsson and Jonsson, 2011). Smolts, however, become more active during daylight once water temperatures increase above 13^{o}C (Ibbotson *et al.* 2006). Their diel movement is thought to be a strategy to increase food intake from invertebrate drift, or as mentioned previously, to reduce the risk of predation from piscivores (Jonsson and Jonsson, 2011). Smolt migration to sea is in spring and is normally seen May when migration downstream predominantly takes place over a two-week period in early-mid May. Outmigration can be seen earlier than this if the temperature is too high and the river level is too low in a mechanism to avoid higher temperatures. Migration can be extended in complex systems where there are barriers to migration (Byrne *et al.* 2003). This extension of time can increase the mortality already associated with migration in both the river and estuary systems, primarily from predation (Riemen *et al.* 1991). As pointed out previously, temperatures at 15^{o}C or above inhibit smoltification and therefore increase delays in migration which will cause a loss of physiological and behavioural characteristics. Water flow has been shown to be the primary mode of transport for smolts where they actively seek the main current, although with a preference to be close to the river bed (Hansen & Jonsson, 1985). It has also shown that the higher the water flow the faster the rate of migration out of a system and this is directly related to the rivers velocity and impacts upon the speed of descent (Smith *et al.* 2002).

Temperature is seen to be the main environmental cue where smolts are characteristically seen to migrate out of the rivers when the sea surface temperature is above 8^{o}C (Hvidsten *et al.* 1998) and the river water temperature is above 10°C (Moore, 1997). Other cues include tidal state and river flows, where it has been observed that smolts move on high and ebbing tides (Davidsen *et al.* 2009) and on the descending limb of the spring hydrograph (McCormick *et al.* 1998). There is also a weaker relationship between the decreasing river discharge in the spring and the onset of the smolt migration (Hvidsten *et al*. 1995), although it is thought that it could be a result of genetic differences and local adaptions.

This affinity to the natural flow regime means that smolts are susceptible to flow alteration. Barriers to migration are a source of substantial smolt mortality (McCormick et al. 1998; Marschall *et al.* 2011; Gauld *et al.* 2013) and abstraction during their migration can delay downstream movements (Budy *et al.* 2002; Svendsen *et al.* 2011). Variation in the lateral and longitudinal patterns of river flow has a strong influence on the ability of smolts to pass potential barriers, including depleted reaches generated by abstraction (Cowx *et al.* 2014). Furthermore, with an increase in variable spring temperatures, the migration window for smolts may become shorter and as such it is important that flows during this migration window are sufficient to support rapid migration (McCormick et al. 1998).

5.1.2 Adult salmon

When Atlantic salmon migrate out to sea they feed primarily in the North Norwegian Sea and off the coast of Greenland where they mature ready for spawning (Holm *et al.* 2003). After 1-4 years and growths in multiple orders of magnitudes, salmon experience strong homing behaviours to locate their natal streams for spawning (Harden-Jones, 1968). The migration from sea to river can take up to 9 months due to the vast distances salmon are required to travel (Hansen, *et al.* 1993), this is thought to be a life strategy to conserve energy for spawning. Migration among salmon is under genetic control, although they are also influenced by environmental factors such as temperature and flow (Northcote, 1992).

Although there are many hypotheses, it is still unknown what factors are used by salmon to navigate to their natal streams successfully. The use of sunlight as a visual cue was postulated by Hasler and Schwassmann (1960) who thought salmon used the sun as a reference point to guide them to their natal stream. Although fish can view natural light sources such as the sun, moon and stars, it is now accepted that it is their ability to sense the polarised light emitted from these sources which assists with their movements. This was shown by Smith (1985), who demonstrated that salmon would still migrate at night and under cloud cover.

Salmon are known to migrate all year round, although salmon appear in estuaries during April to begin the freshwater phase of their migration. These fish are known as "spring salmon" due to the overlap with their migration and the season. Once in fresh water, salmon halt feeding for spawning that occurs between October-January.

Tidal phases influence salmon to leave the estuaries and begin migration up the river where salmon move in the same direction as the tidal currents with upstream movements on rising tides and downstream during the ebb tides (Brawn, 1982; Aprahamian *et al,* 1998). Salmon halt their migrations when they meet with unfavourable conditions (i.e. flow and temperature) and they can lie in deep pools until conditions improve. The freshwater migration phase of salmon is therefore influenced by water flow and is thought to be an adaptation to increase chances of successful migration and predator avoidance (Tetzlaff *et al.* 2005). High flows can decrease predation from visual predators due to increased cover. This cover comes from increased turbidity, surface turbulence and deeper water. However, extreme high flows can also impede migration causing salmon to seek refugia.

It has also been shown that returning spawners (multi-sea-winter salmon) and thus larger fish, stay in the estuary for longer periods until the flow conditions are correct for their migration (approximately 10 $m3s^{-1}$.), in contrast to one-sea-winter salmon which require less water flow of 1 $m3s^{-1}$ to successfully migrate (Jonsson and Jonsson, 2011). Cowx *et al.* (2013) go on to define specific flows stating that salmon require 30 to 50% of the average daily flow (ADF) in the lower and middle reaches of rivers (50 to 70% for large spring salmon) and >70% ADF in the headstreams. The requirements are defined as discharge per metre river width. Upstream movement begins when flows reach 0.08 $m^3s^{-1}m^{-1}$, peaks at 0.2 $m^3s^{-1}m^{-1}$, and reduces at higher flows.

Tetzlaff *et al*. (2008) hypothesised that constantly reduced flows in rivers will likely decrease population abundance, size at maturity, and the time of freshwater migration due to a decreased level of spawning females entering rivers at non-optimal flow regimes for migration and the subsequent degradation of juvenile habitat reducing its use for the following spring.

Temperature is another key trigger in the freshwater phase of migration with the initial migration taking place between 8-15°C. The need for oxygen is increased for salmon within higher river temperatures due to the energetic cost involved in migration (Salinger and Anderson, 2006), although an equilibrium is required as the ability to pass potential barriers declines with a decrease in temperature (Jensen *et al.* 1998). The ease with which these barriers can be passed varies with river flow where some falls are surmounted by leaping. Salmon can leap up to 3.7 m, although the conditions required are complex. The fish generally leap from near the crest of a standing wave at the foot of the fall with a pool depth of at least 1.25 times the height of the fall. It is likely that leaping ability, as with swimming speed, will vary with temperature. Salmon migration has been shown to have a phenotypic plasticity to temperature as they are reported to peak at mean monthly sea and river temperatures during spring, where salmon are seen to begin their migration earlier when the water temperature is higher and later when lower (Dahl *et al.* 2004). Salmon movement is inhibited at both low (5-6°C) and high (22°C) temperatures ceasing entirely between 22°C and 25°C, where these temperatures become lethal (Jensen *et al*. 1986; Gowans *et al*. 1999).

The impact of day length upon migration is population dependent as each river is diverse (Jonsson and Jonsson, 2011). These differences are due to the river's topography and the time taken to reach the optimum habitat in their native stream.

5.2 Results

Unfortunately, smolts (Figure 5.2) could not be observed on the River Wye due to the later deployment of the camera arrays and the previously mentioned camera malfunction between 03 and 14 May. This malfunction was not noticed until the migration was over and no subsequent smolts were observed in the days after the cameras were fixed.

Figure 5.2 Image of smolts recorded at the Llantrisant camera array on the River Usk.

5.2.1 Seasonal movement patterns

5.2.1.1 Adults

The numbers of salmon moving up- and downstream in the rivers Wye and Usk were counted daily during the study period (20 May-11 July and 08 May-11 July respectively) and compared with known environmental drivers of migration (namely tidal height, water temperature and flow) (Figure 5.4-Figure 5.5). The camera set up used to formulate the data as in this chapter is the same as that in chapter 4 and data was captured at the same time. Due to camera malfunctions, high turbidity and algal growth on the infrared lights and camera lenses, there were difficulties with the recording process. With a deeper water body, these problems were exacerbated in the Wye, decreasing the levels of light and thus the ability to process the images accurately. The increased water flows between 25 June and 04 July also resulted in unforeseen circumstances preventing access to both rivers to clean the camera arrays. These sources of error are graphically displayed during the days of difficulty to explain the gaps in data, although it must be noted that fish could still be seen if they were in close proximity to the camera and thus counts of fish were still recorded during these times where possible (Figure 5.3 and Figure 5.4). Furthermore, as the cameras were set up primarily to observe shad migration, the time the cameras were deployed does not coincide with the observed salmon migration. It is therefore highly possible that salmon were missed on both rivers before the cameras were installed and during times of malfunction, and after the cameras were removed.

The first record of salmon migrating upstream was 28 April 2013 in the Usk (when the cameras were first turned on) and 21 May in the Wye (due to the camera malfunction) although these do not represent the first salmon in their migration. The issues with the cameras were identified and fixed by the 14 May. The number of salmon migrating in the Wye was stable with an initial peak on 28 and 29 May with 11 and 10 individuals, respectively (Figure 5.3). During the study period (14 May – 14 July), 240 salmon were recorded moving upstream and 69 salmon moving downstream. In comparison, numbers in the Usk initially peak at nine on 09 May but numbers subsequently fell due to high flows and turbidity (Figure 5.4). Salmon numbers again decreased between 14 June and 18 June as a consequence of increased flow. Numbers increased to a second peak on 08 July with 13 individuals observed. During this second peak (05 July-11 July) 53 salmon were moving upstream and 34 downstream, coinciding with a rise in temperature (Figure 5.8). During the observation window, a total of 174 salmon migrated upstream and 107 downstream (107). Figure 5.4

Numbers of salmon migrating in both the Wye and Usk decreased with increased flow. In the Wye (Figure 5.3) during the a large spate event (15-18 May) there was a significant drop in the number of salmon migrating. Furthermore, after this spate event (≈18000 Ml/d) numbers of salmon migrating rose with two peaks on 28-29 May and 03-05 June with 21 and 45 individuals, respectively. However, it must be noted that this rise and fall in numbers could be attributed to the difficulty in processing the footage during times of high flows and is a fault in the experimental design. In comparison, the Usk saw an increased number of salmon decrease during the same spate event, with numbers decreasing during high flows only to increase after a flow event (Figure 5.4).

It appears that peaks in migration occur after spates, although this was not seen in either river at the end of July when there were notable numbers of salmon moving; therefore, multiple factors influencing migration must be involved.

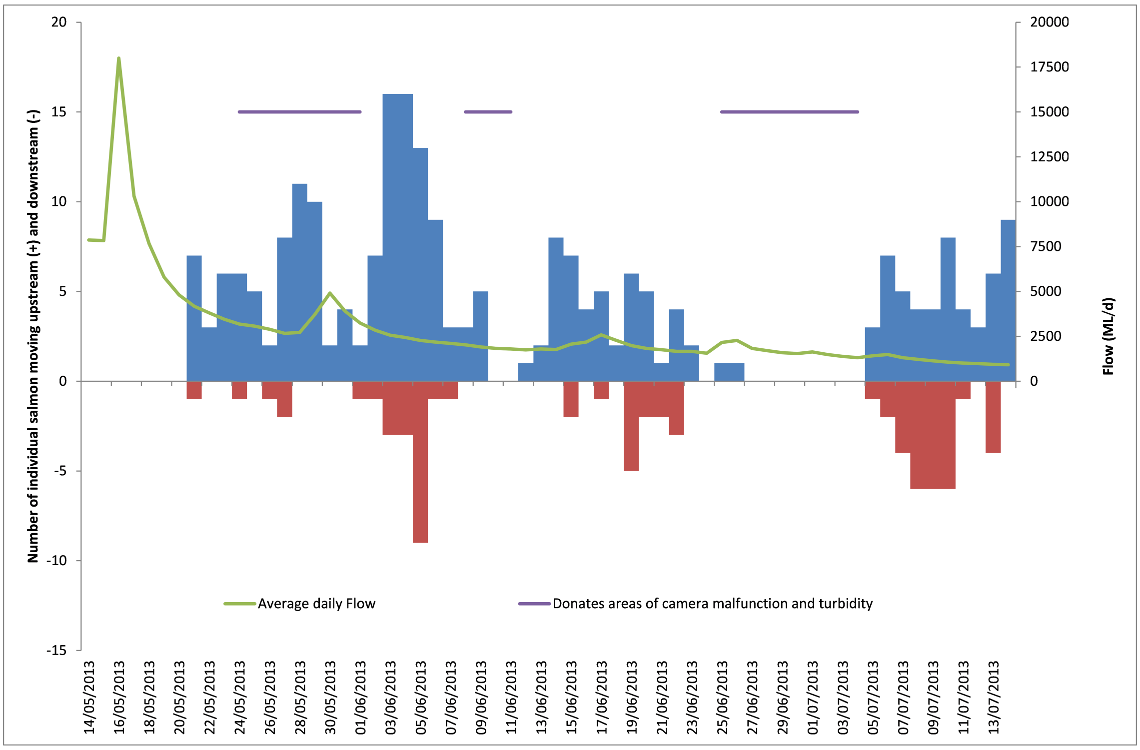

Figure 5.3 Up (blue) and downstream (red) movements of salmon in the River Wye in relation to flow. Purple line denotes areas of camera malfunction or high turbidity.

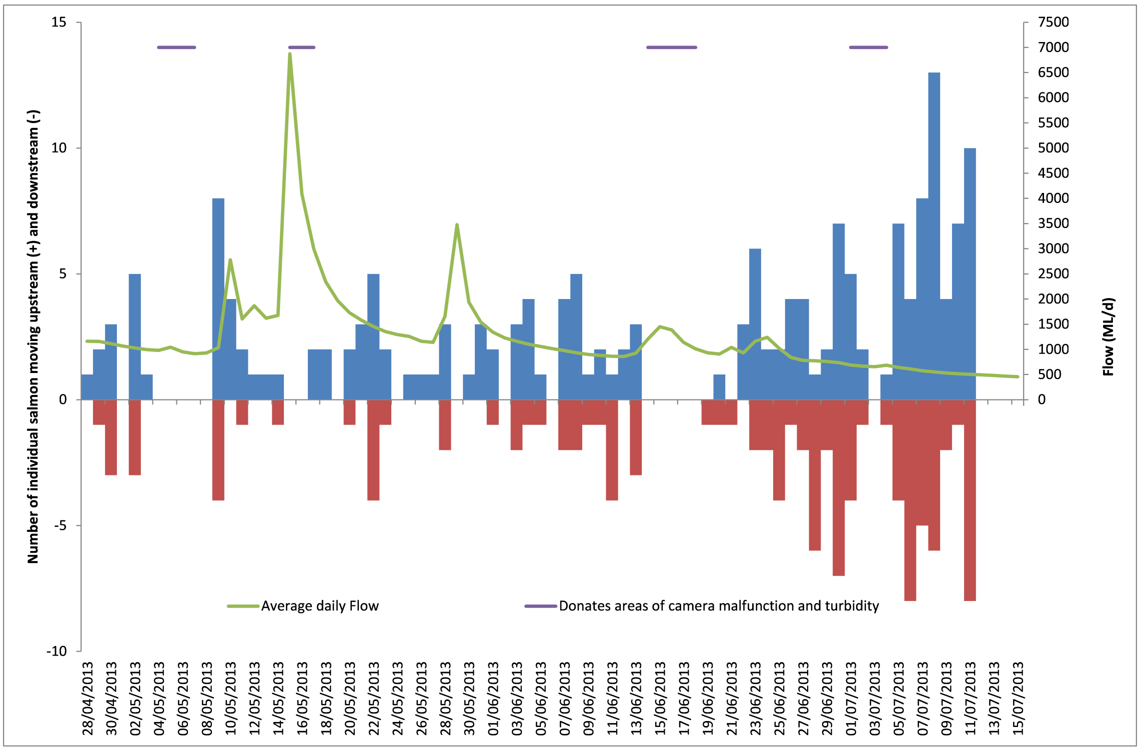

Figure 5.4 Up (blue) and downstream (red) movements of salmon in the River Usk in relation to flow. Purple line denotes areas of camera malfunction or high turbidity.

Tidal state also appears to influence the movements of salmon into freshwater (Figure 5.5 and (Figure 5.6). In both rivers salmon appear, to migrate in waves in relation to the tidal state. This is shown through separations between different groups of salmon in relation to tidal phases. In general, salmon were observed migrating upstream and downstream, associated with the rise and fall of the tides (Figure 5.5 and (Figure 5.6), although an overall net upstream migration was observed during the total observed period. Although, as with the shad, it must be noted that the cameras are above the tidal limit (Figure 2.1), so it is assumed that the tides effect the salmons entry into freshwater and not whilst passing the camera arrays.

In the Wye, the numbers of observed salmon peaked twice, before and after a spate event (28-29 May and 03-05 June) (Figure 5.3). The first migration peak coincided with a full moon event, when the mass of the migration occurs on the rising limb of the tide or at the maximum tide height (Figure 5.5). There is no clear decrease in salmon during the falling limb, although migration was seen in waves linked to tide influence on their migration.

Like in the Wye, the peaks observed in the Usk were seen on the rising limb of the tide with numbers reducing on the falling limb of the tide. The two main peaks in the salmon migration (09 May and 08 July) occurred before a full moon and the full moon event on the rising limb (Figure 5.6). It can be speculated that a second peak during the second full moon may have occurred, although this data was unable to be processed due to the problems previously outlined.

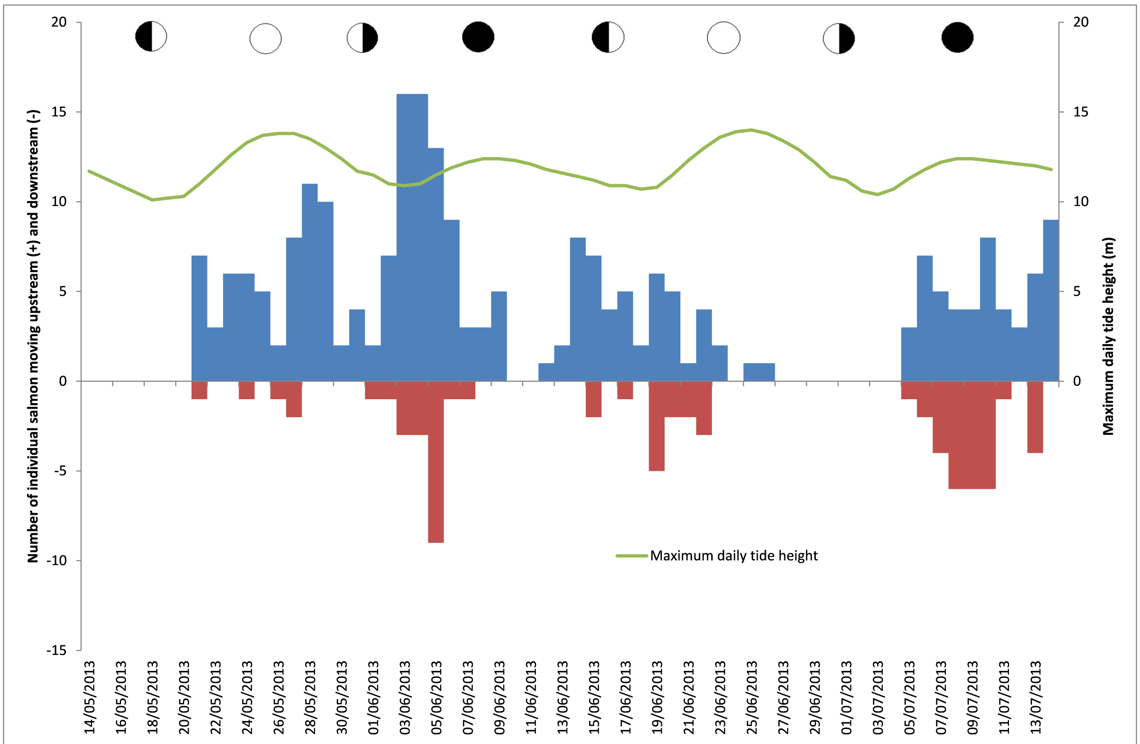

Figure 5.5 Up (blue) and downstream (red) movements of salmon in the River Wye in relation to tide height and lunar cycle.

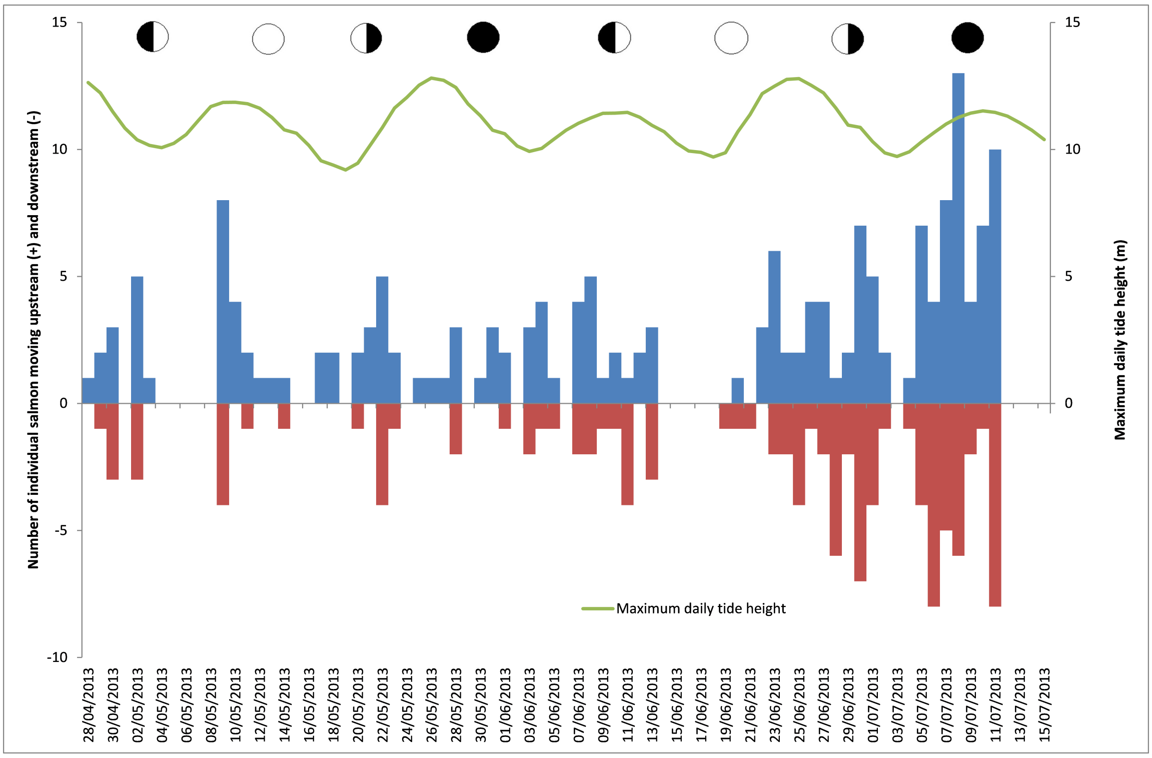

Figure 5.6 Up (blue) and downstream (red) movements of salmon in the River Usk in relation to tide height and lunar cycle.

There also appears to be no direct relationship between salmon movements and temperature in both the rivers Wye and Usk (Figure 5.7 and Figure 5.8). In the Usk (Figure 5.8) there was a sudden rise in temperature to 14.3°C from the start of the survey until 08 May, which coincided with the beginning of the large spate event. During this period, no salmon were observed in the Usk and it is possible that these salmon were holding up in deeper water area awaiting optimal environmental conditions to move upstream. After this event the temperature steadily increased to 19.7°C on 11 July when the last fish were recorded before the cameras were turned off.

In the Wye, the first salmon was seen on the 21 May at a temperature of 13.1˚C. The temperature, like the Usk, steadily rose through the survey period to 23.8˚C when the last fish was seen on 14 July. The number of salmon rose to an initial peak between 03 and 05 June when the temperatures ranged between 16-17˚C. There were no observed high or low temperature events on the Wye as the lead up to the spate event was missed due to the later camera deployment, thus no relationships can be distinguished in the Wye in relation to temperature and salmon movements.

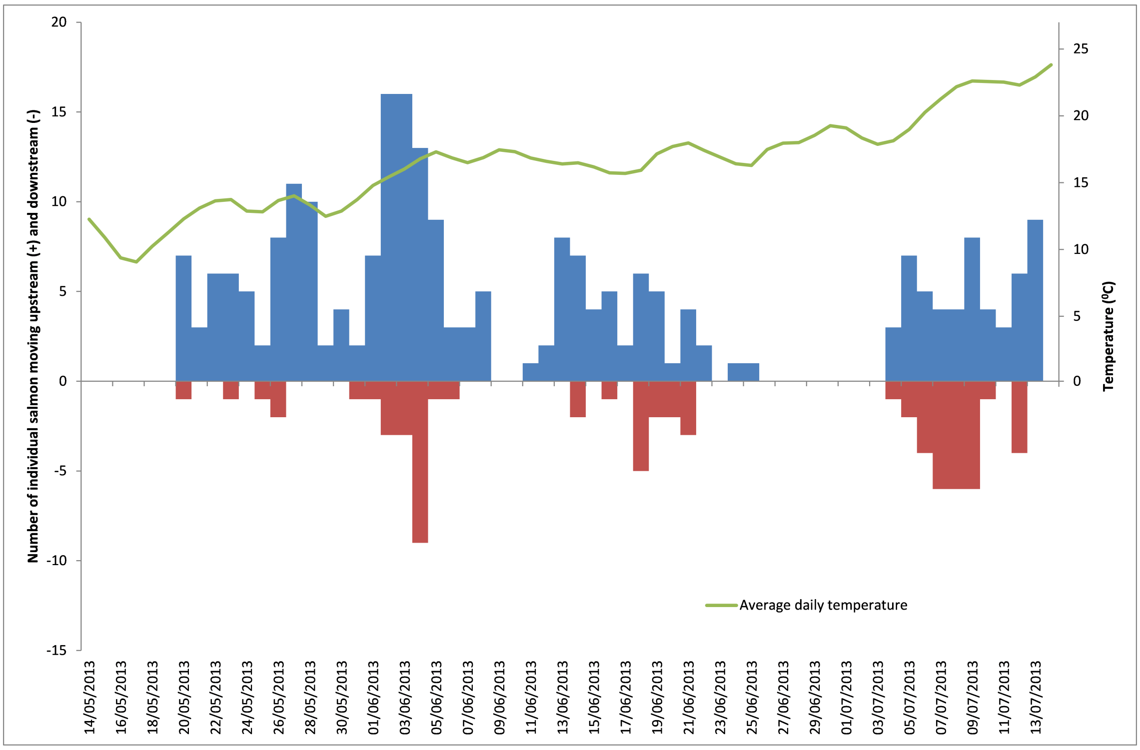

Figure 5.7 Up (blue) and downstream (red) movements of salmon in the River Wye in relation to temperature.

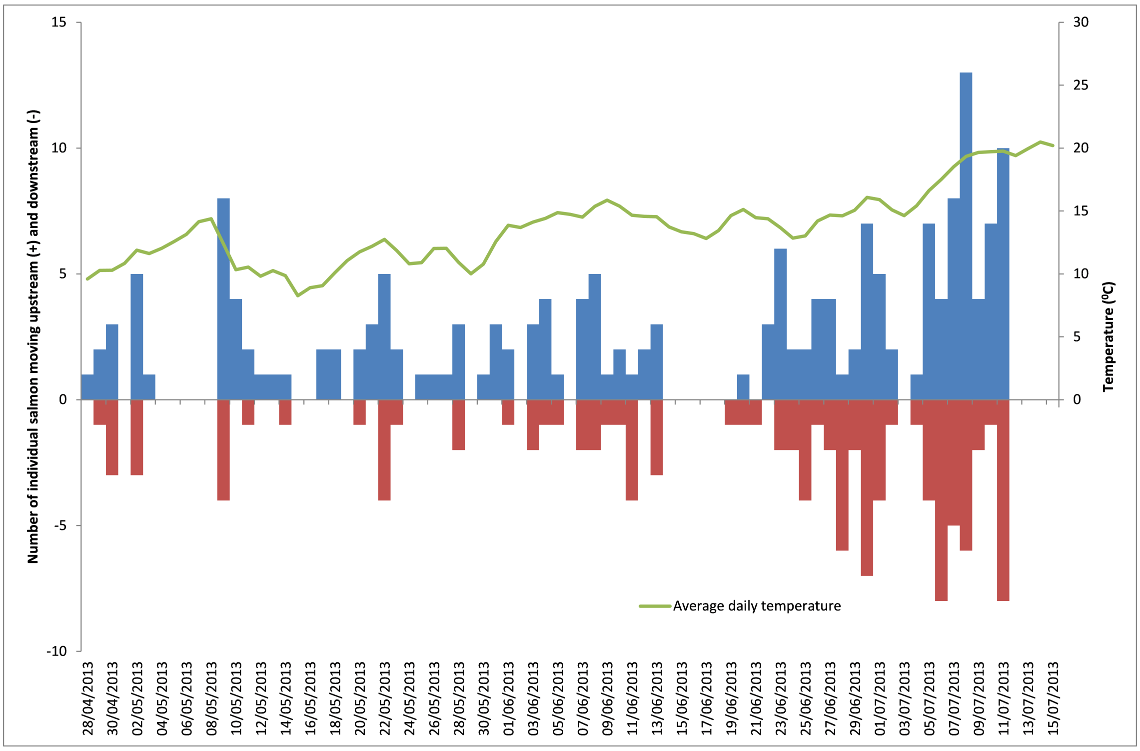

Figure 5.8 Up (blue) and downstream (red) movements of salmon in the River Usk in relation to temperature.

The overall net migration of salmon in both rivers could be calculated as the direct of each fish swimming was individually recorded. The total amount of salmon migrating downstream was subtracted from those migrating upstream in order to produce figures Figure 5.9 and Figure 5.10.

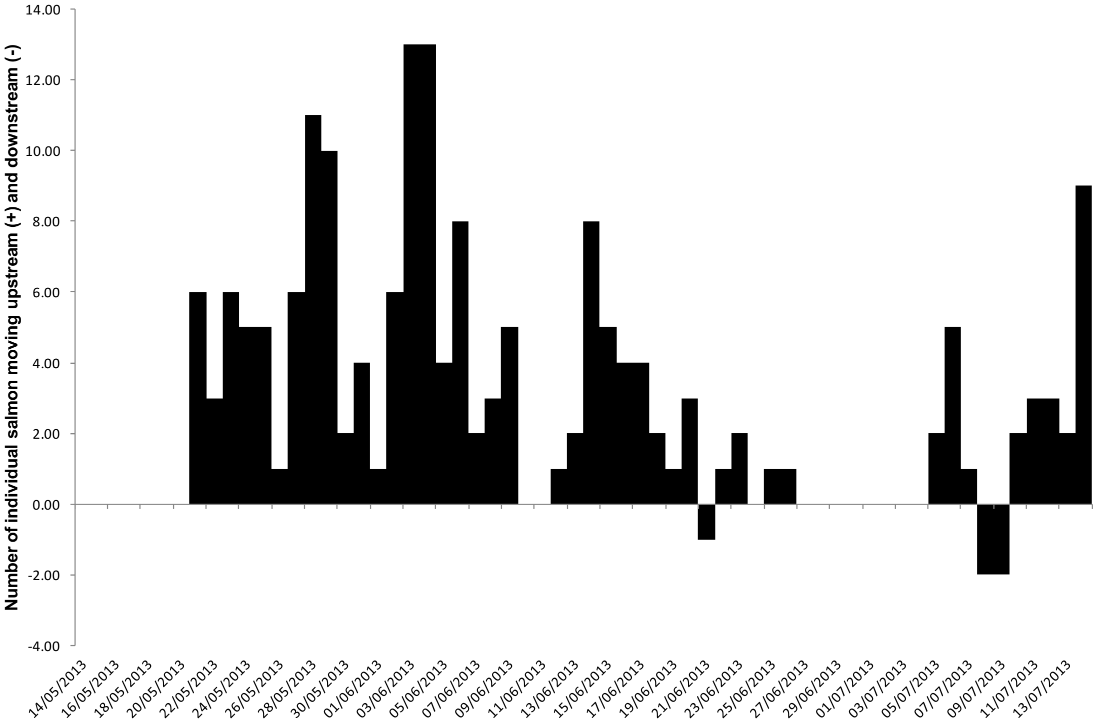

Figure 5.9 Net migration of salmon in the River Wye.

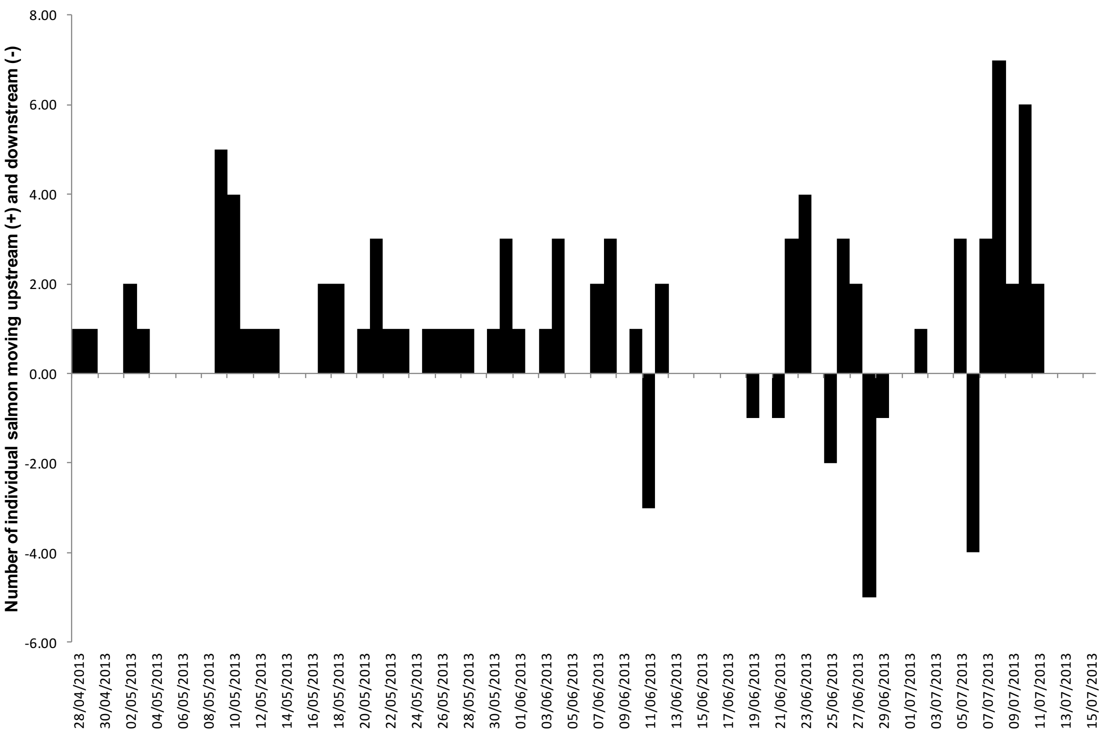

Figure 5.10 Net migration of salmon in the River Usk

Net migration in both rivers showed a clear upstream pattern with very minimal downstream movement. Days when net downstream movements were seen in both rivers were during July when temperatures were above 18°C.

Salmon in the Wye showed an overall net upstream migration (Figure 5.9). Fewer individuals were seen moving downstream which may point to salmon migrating quickly through the section of the Wye observed and little falling back on the tides (Figure 5.9).

In the Usk (Figure 5.10), there were seven days that showed net downstream migration compared to the three on the Wye. The total number of salmon moving downstream (5), however, was lower than those seen in the Usk (18), and this may not reflect true migration and could represent the fish finding station within the study area until favourable conditions for migration are met (Figure 5.9). In the Wye (Figure 5.9), the largest observed net upstream migration of salmon occurred between 21 May and 15 June when 182 salmon were observed. These dates coincided with the optimal temperature range of migration (8-15°C) when the high numbers of salmon in the Wye occurred between 9-16°C.

The timing of salmon migration in both the rivers Wye and Usk (20 May-11 July and 08 May-11 July respectively) are consistent with the literature outlined in section 5.1, although it must be noted that as previously mentioned, the cameras were deployed with the primary purpose of observing shad movements and as such, salmon migration will have taken place both before and after the start and end date observed as abiotic and biotic conditions needed for migration were met.

5.2.1.2 Smolts

Images of smolts were only captured in the river Usk due to the technical difficulties had with the camera array in the Wye. The first smolts observed were on 23 April and were seen moving upstream, presumably this behaviour was in response waiting to for favourable conditions in the river or finding other smolts for shoaling as described by Jonsson and Jonsson (2011). The main downstream migration period observed on the Usk occurred in late April-early May (Figure 5.11) peaking on 01 and 02 May 2013 with 327 and 213 individuals observed respectively. Smolts were seen migrating in large shoals averaging 49 individuals, with the largest shoal accounting for 84 individuals. During their migration window (24 April-26 May), 110 individuals were seen moving back upstream compared to 996 moving downstream, showing a strong net migration out of the system.

There were, however, camera malfunctions between 04 and 10 May (shown as a purple line in Figure 5.11) and a large spate event (increasing turbidity levels) between 15 and 18 May which prevented the recording of data. It was therefore not possible to observe any smolts during these periods and as such the presented data should be seen as a resemblance of their overall migration; although there are gaps in the data, there is ample evidence to show that the migration window continued until 26 May where the last smolt was observed migrating downstream.

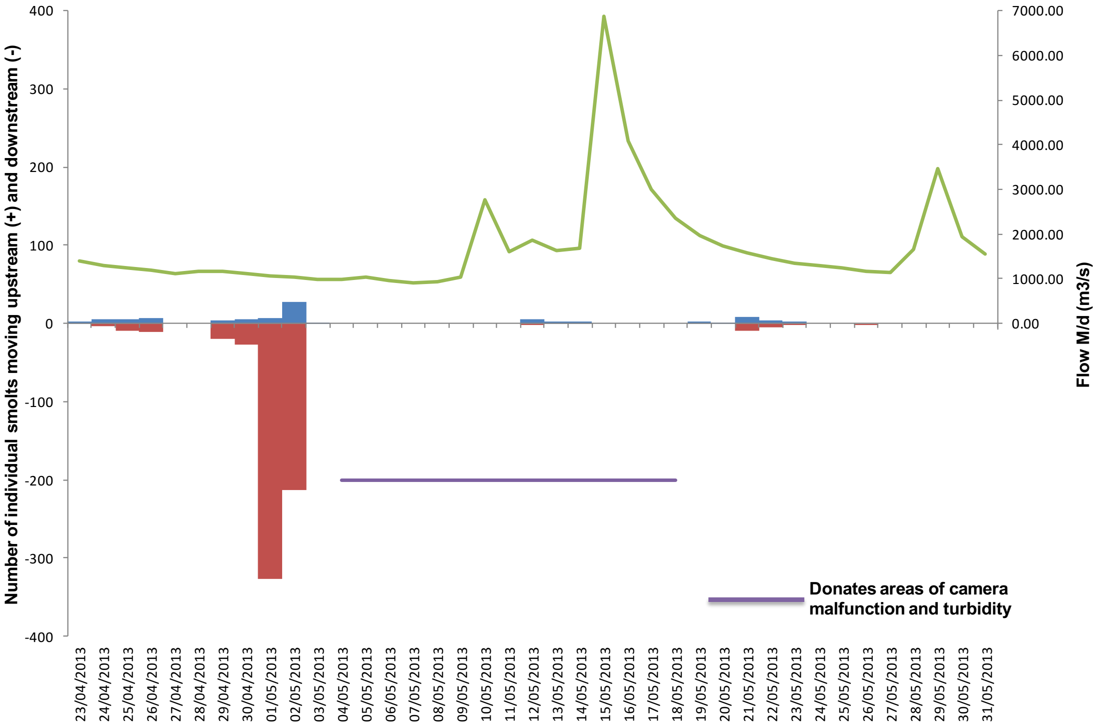

Figure 5.11 Up (blue) and downstream (red) movements of smolts in relation to flow. Purple line denotes areas of camera malfunction or high turbidity.

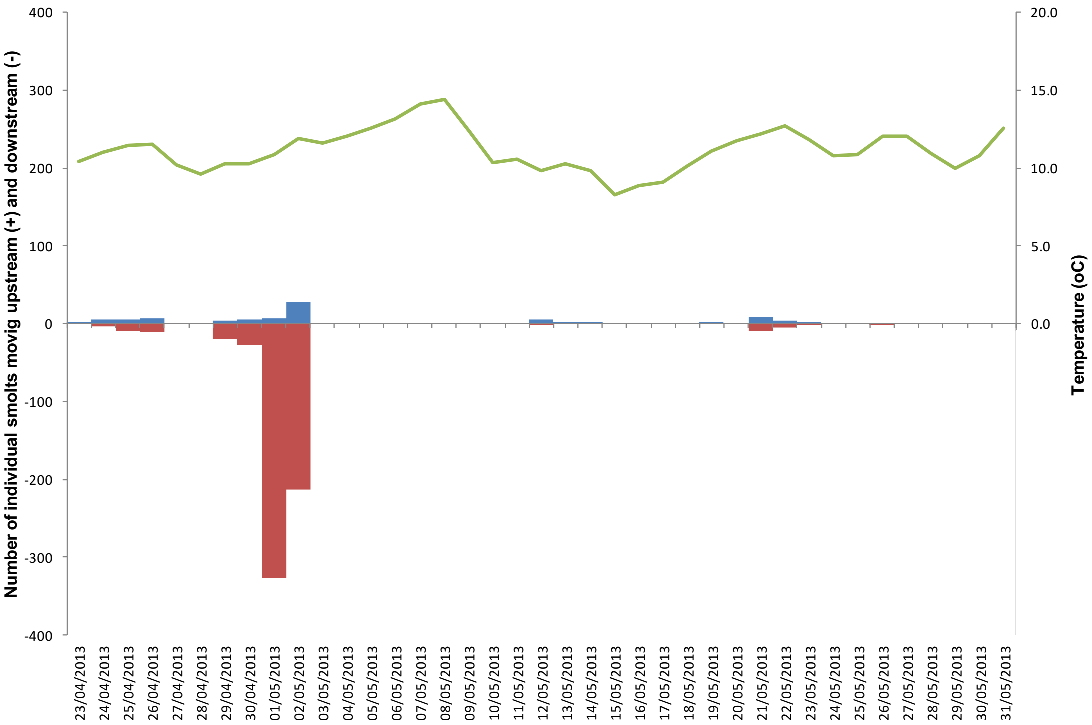

Figure 5.12 Up (blue) and downstream (red) movements of smolts in relation to temperature.

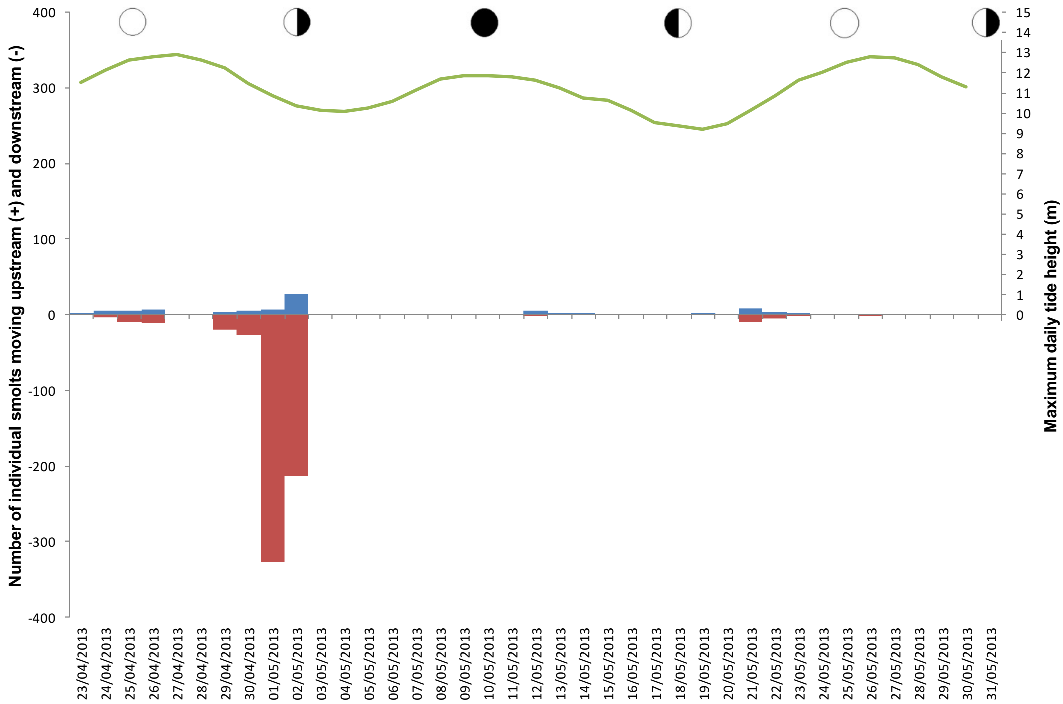

Figure 5.13 Up (blue) and downstream (red) movements of smolts in relation to tide height and lunar cycle.

During the main migration window, the flow, measured at Chain Bridge, remained stable between 1000-1200 Ml/d (Figure 5.11). During the spate period (10-19 May), flows reached 6875.85 Ml/d preventing the images being processed due to the high levels of turbidity. After the initial spike in flow (10 May) and before the main spate event there was a small number of smolts (12) observed when the flows dropped below 1800 Ml/d.

Temperature remained stable during the migration period with small rises and falls associated with the spate event (Figure 5.12). The first smolts were seen at a temperature of 10.4^{o}C and during the whole migration window the average temperature was 11.1^{o}C.

The largest spike in smolt migration within these results (327) was observed during the waning moon on the descending limb of the spring hydrograph, where smolts were observed moving out with the the bi-monthly tidal cycle between spring and neap tides (Figure 5.13).

5.2.2 Diel movements

5.2.2.1 Adults

In both rivers, salmon predominantly moved upstream during daylight hours (05.00-21.00) (Figure 5.14 and Figure 5.15) with very little movements during the night (22:00-04:00).

In the Wye (Figure 5.14), a very similar pattern was found with most migration occurring during daylight, peaking at 05:00 with substantial migration continuing until 08:00. There are further smaller peaks in migration at 10:00, 13:00, 14:00 and 21:00, although again these numbers are considerably less, specifically during the night.

In the Usk (Figure 5.15) salmon moved during daylight with peaks in migration at 05:00 and 08:00, with little to no migration during the night. Further migration occurred throughout the day with smaller peaks in migration at 14:00, 18:00 and 21:00 although these numbers are considerably less.

Total numbers of salmon migrating both up- and downstream were recorded in both rivers to compare any changes in diel movements between both phases in migration. Upstream migration in the Usk (Figure 5.17) still exhibits dawn migration patterns with peaks at 05:00 and 08:00, although there is a rise in numbers at 14:00. Migration is primarily throughout the day with only two fish seen migrating over the night period. Downstream migration in the Usk (Figure 5.17), similar to upstream migration shows a large spike at 05:00 but an even larger spike at 08:00. After 08:00, migration becomes erratic with no obvious diel patterns. Again migration is predominantly during the day although there is a spike at 00:00 with 5 fish migrating during the course of the night.

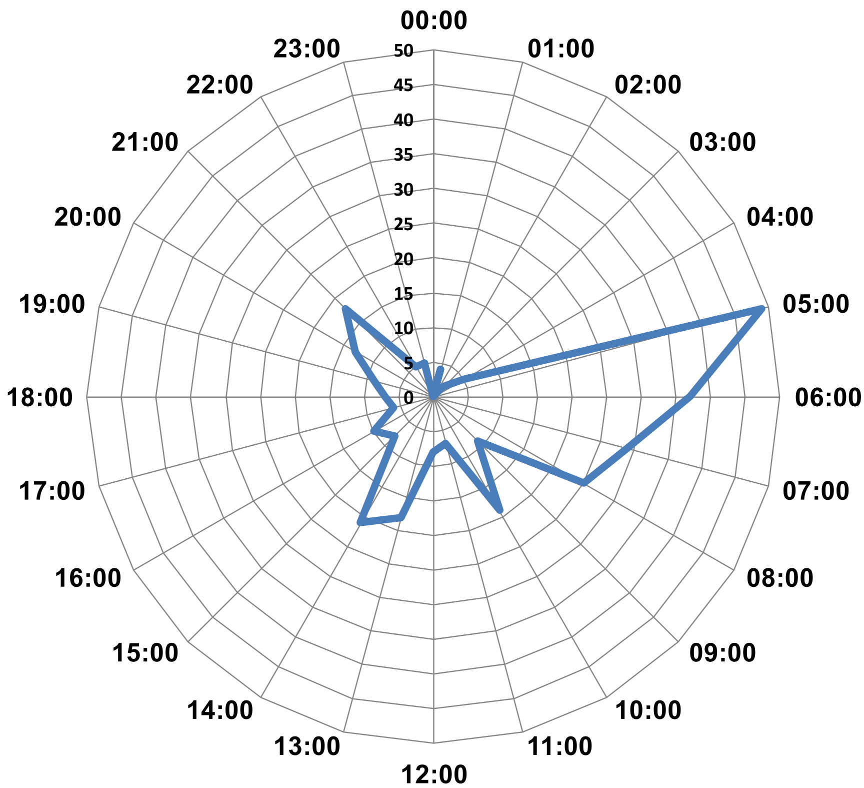

Figure 5.14 Diel movements of salmon in the Wye.

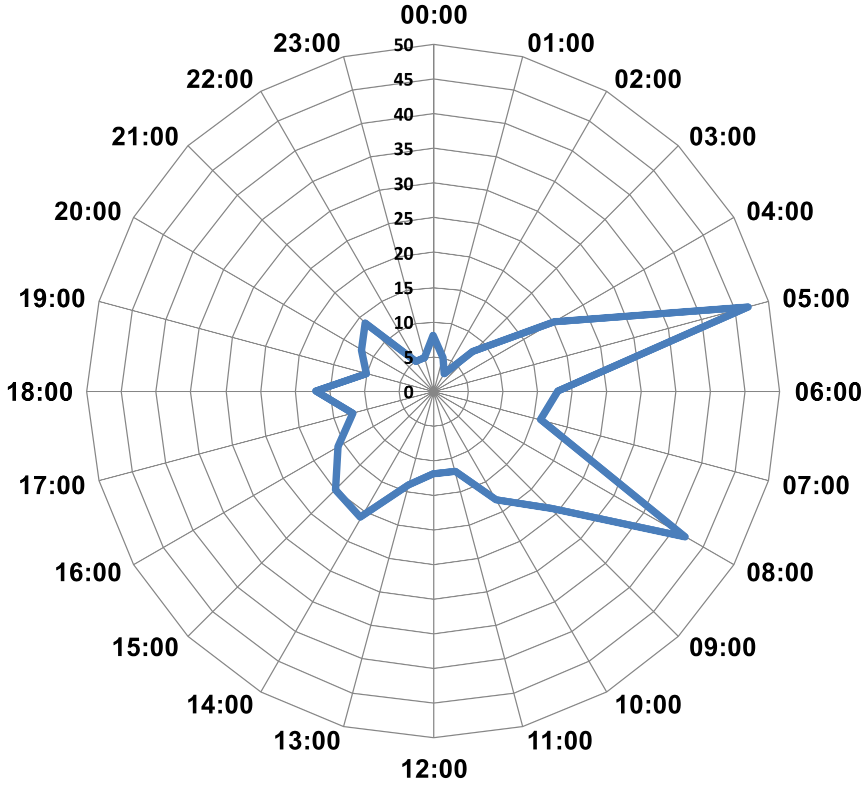

Figure 5.15 Diel movements of salmon in the Usk.

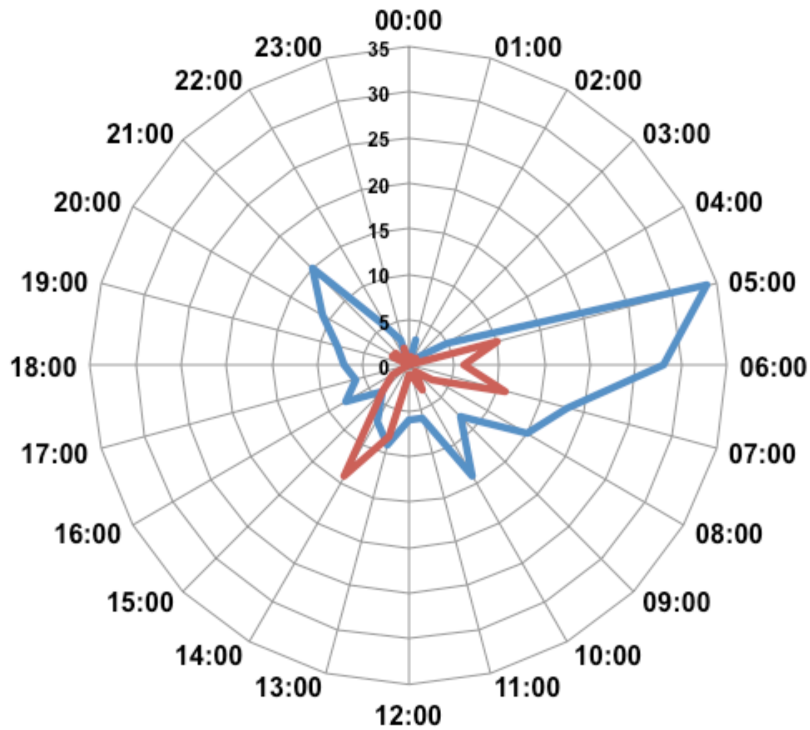

Figure 5.16 Up (blue) and downstream (red) total diel movements of salmon in the River Wye

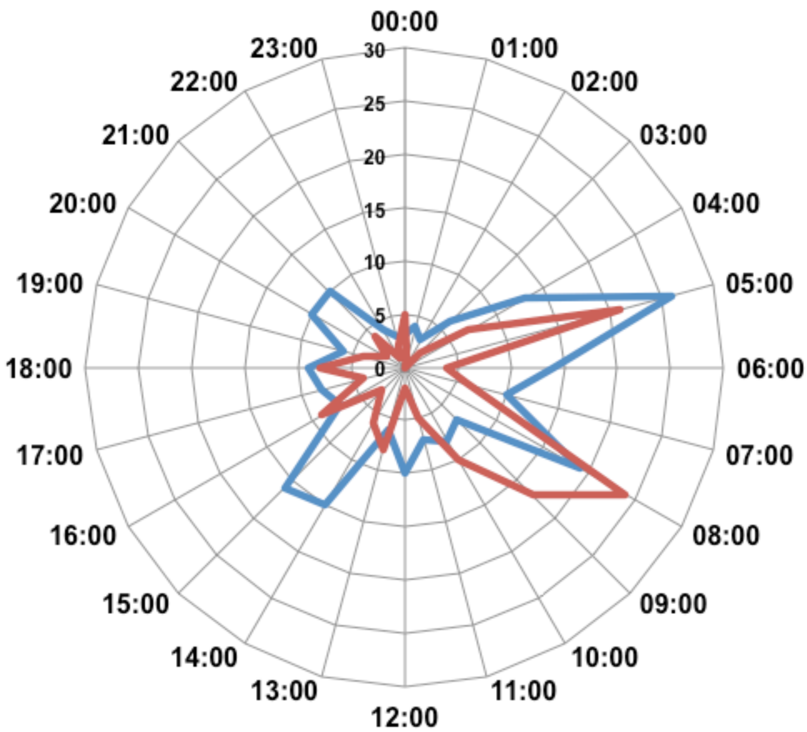

Figure 5.17 Up (blue) and downstream (red) total diel movements of salmon in the River Usk.

The upstream migration of salmon in the River Wye was predominantly at dawn (05:00-07:00) although unlike the Usk, there was a rise at dusk with a spike at 21:00. Migration was predominantly through the day with no migration during night hours. Downstream migration (Figure 5.16) in the Wye was distinctly different to the other diel movements. Although the main migratory movements occur at dawn (05:00-08:00), the peak was between 13:00 and 14:00. This was also observed with upstream movements in the Usk (Figure 5.17) although not in the high numbers seen here.

5.2.2.2 Smolts

Diel movements amongst smolts were predominantly during the day (10:00-20:00) with little movement overnight (21:00-05:00). There were two main migration peaks throughout the study, firstly between 10:00-12:00 and secondly between 14:00-15:00 followed by a smaller peak between 17:00-20:00. Smolts move predominantly during the day, which contradicts the literature (Ibbotson *et al*. 2006; Jonsson and Jonsson, 2011) given the abiotic factors at the time of migration.

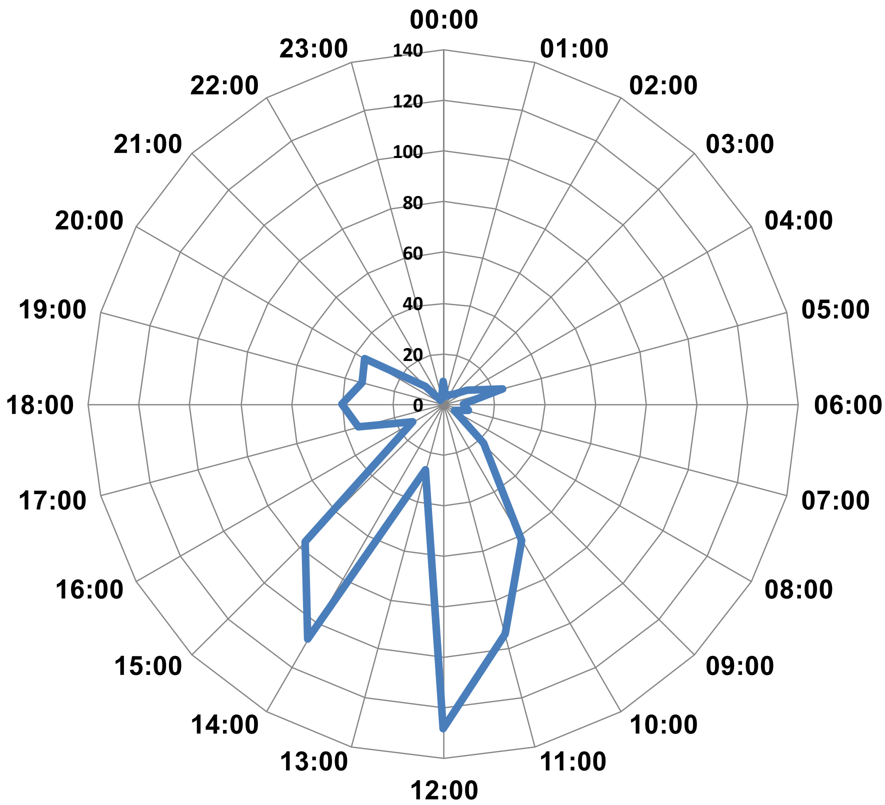

Figure 5.18 Diel movements of smolts.

5.2.3 Position over the camera array

5.2.3.1 Adults

Along with noting species and direction of migration against time, the camera at which the salmon moved over the array was also noted (Figure 5.19 and Figure 5.20). The camera positions in the river are the same as previously described in section 4.2.3 (Figure 4.18) where camera 1 is closest to the left bank and camera 12 is closest to the right bank.

In the River Usk (Figure 5.20), salmon movements across the arrays were erratic with no relationship found. There were, however, six notable peaks across cameras 1, 3, 4, 7, 8 and 12, with the largest peak over camera 4 with 56 individuals. This erratic behaviour shows no real preference towards their position in the water in relation to the cameras. When compared against the ADCP profile (Figure 4.19), it shows the position of camera 4 to be in a high velocity area. This goes against the literature (Tetzlaff *et al.* 2005) where salmon are thought to migrate upstream in lower flows to conserve energy. As such the expected number of salmon seen over cameras 9, 10, 11 and 12 should be significantly higher as they are in the areas of lowest flows.

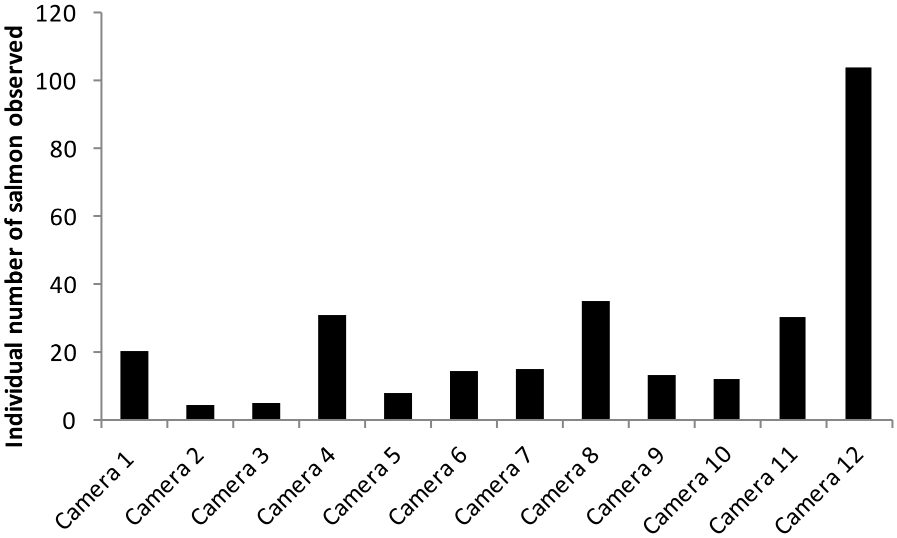

Figure 5.19 Position of salmon movements across the camera array in the River Wye.

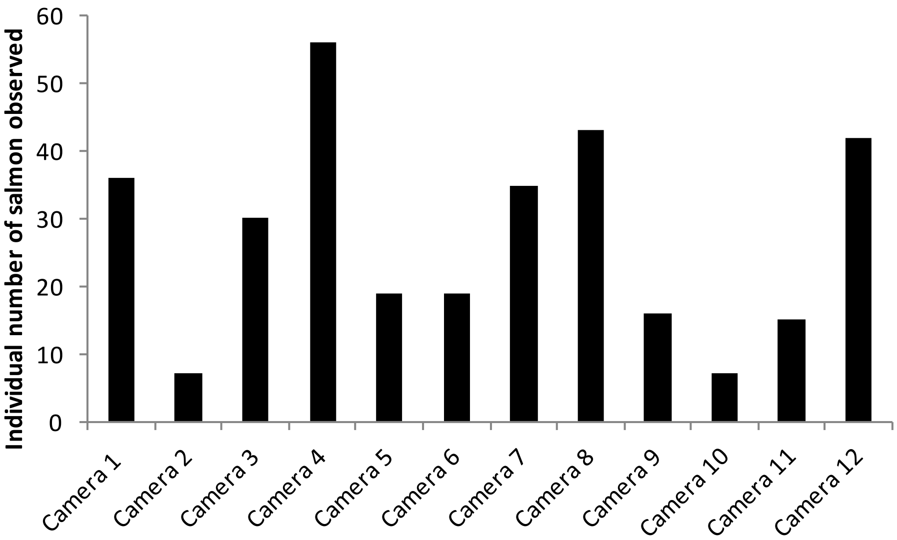

Figure 5.20 Position of salmon movements across the camera array in the River Usk.

Salmon movements across the arrays in the River Wye (Figure 5.19) are distinctly different from the Usk (Figure 5.20). Predominantly, salmon move across the final camera in the array (camera 12) with 104 individuals observed. There is a fairly even distribution across the other cameras with slight peaks in 1 4, 8 and 11.

5.2.3.2 Smolts

Smolt movements over the camera array show a strong preference for camera 8 with 657 individuals recorded, that represents 61% of the total smolts observed. There were smaller peaks over cameras 4 and 12 with 214 and 84 individuals, respectively. When compared with the ADCP data (Figure 5.21), it is clear that smolt movements are seen over the highest velocities of the river.

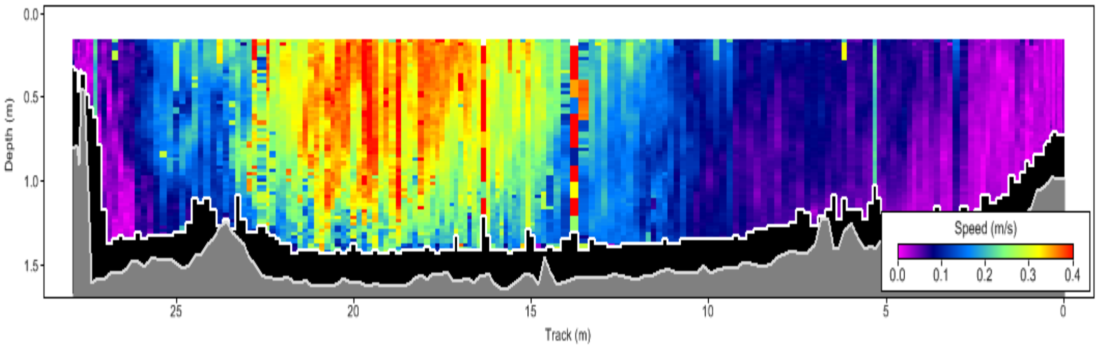

Figure 5.21 ADCP cross-sectional water velocity profile at position of camera array at Llantrisant on the River Usk. Left bank (and hence intake and camera) is on the left side of the graph.

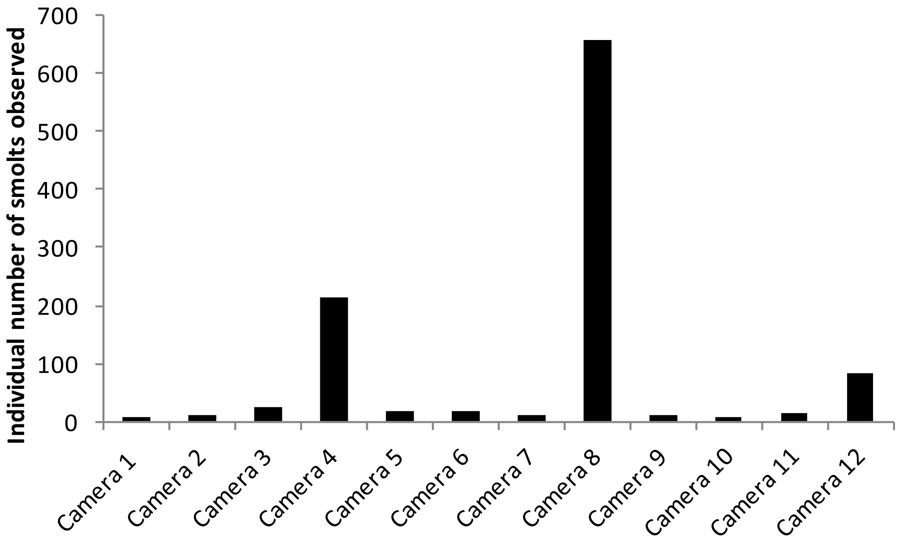

Figure 5.22 Position of smolt movements across the camera array.

The peaks over cameras 4 and 12 provides some evidence of smolts milling around the Usk camera array (Figure 5.11) possibly waiting for the optimal conditions to enter the estuary.

5.3 Discussion

5.3.1 Adults

Salmon migrated throughout the whole study period with the first recording being seen in the Usk on the day the cameras were turned on (28 April 2013). Due to the discussed camera malfunction, the first recording in the Wye was not seen until 21 May.

Salmon migration was effected by changes in flows, in both the Wye and Usk, with numbers decreasing during high flows only to increase after a flow event. This is consistent with literature where high flows were found to halt salmon migrations, and they lay up in deep pools holding until conditions improve (Brawn, 1982; Aprahamian *et al,* 1998; Tetzlaff *et al.* 2005).

In both rivers the first peak in migration was observed as the temperature rose above 10°C, which is consistent with the prevalence of adult fish in rod catches and counter records at temperatures above 10°C (Cowx *et al.* 2014). Salmon were also observed moving past the camera array at temperatures around 20^{o}C in the mid July period. This was somewhat unexpected given the optimal temperature regime for salmon migration (10-16^{o}C) found from counter and rod catch data based upon the Wye (Cowx *et al.* 2014) and 8-15^{o}C as stated in the literature. In the Usk no salmon moved at temperatures above 20^{o}C , but in the Wye, a total of 79 fish were observed moving at temperatures above 20^{o}C . It is possible these salmon are holding up or are moving towards deeper water around the Redbrook area awaiting optimal environmental conditions to move upstream. In general, there appears to be no direct relationship between salmon movements and temperature in both the rivers Wye and Usk (Figure 5.7 and Figure 5.8). This challenges the literature which shows that temperature is a key trigger to migration (Jensen *et al*. 1986; Gowans *et al*. 1999; Salinger and Anderson, 2006). However, as temperatures remained fairly constant throughout the study, the ability to draw trends from the data is difficult.

Like shad, salmon movements appear to correspond with tidal state as migration was observed in waves. Salmon were observed to moving during the bi-monthly tidal cycle between spring and neap tides. Therefore as the camera arrays are situated just above the tidal limit (Figure 2.1), the increased numbers of salmon is likely to be an energy saving mechanism where swimming with the tides allow salmon to conserve energy for the entry into freshwater phase of migration and their exit to the sea. These findings are consistent with the literature (Brawn, 1982; Aprahamian *et al,* 1998) where salmon were seen exhibiting the same migration behaviour on tides.

Net migration amongst both rivers showed a clear upstream pattern with very minimal downstream movement. Days with net downstream movements in both rivers were during July when temperatures were above 18^{o}C. Salmon are most likely holding up in the area awaiting more favourable conditions due to the high temperatures (Salinger and Anderson, 2006; Jonsson and Jonsson, 2011).

In both rivers diel patterns amongst salmon migration were predominantly during the day with particular preference to dawn (05:00-08:00). There is little known about diel movements amongst salmon populations (Jonsson and Jonsson, 2011) but Karlsson *et al.* (1996) also found no patterns in diel movements. Scheuerell and Schindler (2003) however, concluded that salmon move at night close to the surface to avoid predation. Diel movements appear to be controlled primarily by temperature, light intensity, and the availability of food, which was shown during experiments using Atlantic salmon in sea cages (Juell and Fosseidengen 2004; Johansson *et al.* 2006; Føre *et al.* 2009).

Positions over the camera array between the two rivers show stark contrasts. The Usk showed no trends in position over the camera array with the highest peak in fish seen over camera 4. When compared against the ADCP profile (Figure 4.19), it shows the position of camera 4 to be in a high velocity area. This goes against the literature (Tetzlaff *et al.* 2005) where salmon are thought to migrate upstream in lower flows to conserve energy. As such the expected number of salmon seen over cameras 9, 10, 11 and 12 should be significantly higher as they are in the areas of lowest flows.

The Wye on the other hand shows a distinct preference to camera number 12. Although ADCP data are not available for the Wye, with 35% of salmon moving across the furthest camera (compared to an even distribution amongst the others), you can assume that this is preferential behaviour to avoid the high flows and thus conserve energy. This may be accountable to a modification to the river where a concrete structure has been installed which measures roughly 5m in length. This is located only 10m downstream of the array and is positioned on the same bank as camera 12 is facing. This structure has a dual purpose to aid anglers in getting out into the river and a flow break to act as refugia for fish – in particular salmon during unfavourable migration conditions. Salmon could therefore be drawn to this change in river hydraulics and is a potential reason why more salmon were seen on camera 12 than any other cameras.

5.3.2 Smolts

Smolts moved predominantly during the day which contradicts the literature given the abiotic factors at the time of migration (Ibbotson *et al.* 2006; Jonsson and Jonsson, 2011).

During the smolt migration, flows remained steady, although during the tail end of migration (09 May onwards) there was a spate event. Observations of smolts during this event decreased and small numbers of smolts were seen moving downstream after the flow subsided – presumably out of the system. Davidsen *et al.* (2009) points out that smolt movement is highest during high flow events as a mechanism to save energy for their seaward migration, increasing survival rates. It is therefore possible that during the spate event, high numbers of smolts would have moved out of the system but the turbidity was too high to visually account for them. Furthermore, as the camera didn't fully span the length of the river, smolts could have moved tight on the right hand bank out of sight from the camera.

Much like flow, temperature remained steady between 10-11^{o}C during the migration window. This temperature range supports with the literature, which shows that smolt migrate when sea surface temperatures reach above 8°C and river temperature above 10°C (Hoar, 1988; Moore 1997; Hvidsten *et al.* 1998; McCormick, 2002; Zydlewski *et al.* 2005). There were peaks to 14°C in conjunction with the beginning of the spate event, although the potential mortality zone of 15°C and above where smoltification is inhibited was never reached, which would suggest a successful migration run out of the system (Zydlewski *et al.* 2005; Cowx *et al.* 2014).

Smolt migration was associated with tides, where the largest spike in numbers was observed (327) during the waning moon where movement was observed on the bi-monthly tidal cycle between spring and neap tides which is believed to be the ebbing tide. These findings are consistent with the literature which shows that the peak in smolt migration is observed on the descending limb of the spring hydrograph moving out with the ebbing tide (McCormick *et al.* 1998 and Davidsen *et al.* 2009).

There is also considerable evidence that smolts tend to migrate into and through the estuary at night, suggesting that they migrate downstream during the late afternoon and early evening at temperatures below 12°C (Tytler *et al.* 1978; Moore *et al.* 1992, 1995; Aprahamian & Jones 1997; Riley 2012; Mawle 2013). It has also been shown that daytime movements can occur if temperatures are above 13°C or where smaller numbers of smolts join the migration window late missing the main run (Thorpe and Morgan, 1978). These changes in their diurnal movements is thought to be a strategy to increase food intake from invertebrate drift, migrate quickly out of the system to avoid high temperatures or as mentioned previously, to reduce the risk of predation from piscivores (Jonsson and Jonsson, 2011).

These findings contradict the diel migration observed in the Usk camera array, where movements were predominantly seen during daylight hours. Temperature cannot explain this daytime movement as only two days reached above the critical 13°C during the whole migration period (Figure 5.18). Literature suggests that both temperature and flow are the most likely cues for starting downstream migration (Jonsson & Ruud-Hansen 1985; Jutila *et al.* 2005; Riley *et al.* 2012), although it would appear that in this study, flow is more prominent. The timing is also believed to be synchronised with the smolts entering the estuary on an ebbing tide as they were seen moving on the bi-monthly tidal cycle between spring and neap tides which is believed to be the ebbing tide. Aprahamian and Jones (1997) similarly found the downstream migration of smolts in the Usk was greatest during the day but in their study found migration was associated with the flood tide. The difference between their study and the results from the 2013 camera monitoring may relate to position in the river. The Aprahamian and Jones study was based on entrapment of salmon smolts at Uskmouth power station in the Usk estuary, whilst the camera array in this study was positioned in the lower freshwater reach of the river (Figure 2.1). The daytime movement that was observed, in contrast to the literature is likely to be related to entry into the estuary. This is considered a compromise between migrating on ebbing tides and smolts being vulnerable to predation, in particular piscivorous birds (cormorants).

The peaks over cameras 4 and 12 provides some evidence of smolts milling around the Usk camera array (Figure 5.11) possibly waiting for the optimal conditions to enter the estuary. Moore (1997) found smolts held up in deep pools of the River Tawe during the day, possibly to avoid predation, and this may also be the mechanism operating in the Usk. Furthermore, Jonsson and Jonsson (2011) discussed how smolts stop on average every 100m on their course to sea to save energy and to locate other smolts for schooling. Daytime entry to the Usk estuary probably arises as a result of the naturally turbid characteristics of the water reducing the foraging efficiency of predators in particular, cormorants.

The positional movements of smolts over the cameras show a large preference over camera 8 with smaller peaks over cameras 4 and 12. The ADCP (Figure 4.19) showed that camera 8 was situated in the middle of the river and in an area with the highest velocity. It therefore appears, in agreement with the literature, to be an energy efficient strategy to pass through the river as fast and effortlessly as possible. Smolts face downstream (negative rheotaxis) to be transported with the natural flow regime (Jonsson and Jonsson, 2011) as well as trying to locate other smolts where they take on schooling behaviour (Hoar, 1988).

6 OTHER FISH

Outside of the key migratory species already discussed, due to the quality of the outputs from the camera arrays it became possible to assess other fish populations that reside in the rivers Wye and Usk. It is important to assess these species as although they are not under the same protection as shad or salmon (except Sea Lamprey (*Petromyzon marinus L.*) and Eel (*Anguilla anguilla (L.)*)), they do have an affinity with flow and are perceived as prime angling species that are a valuable asset to both the rivers and local businesses.

The relationship between flow and non-salmonids has been discussed by Cowx *et al.* (2012) and much like shad and salmon they are reliant upon the natural flow regime to carry out their life cycles and ultimately increase recruitment. One area which they require flow is migrations within their home river, normally for spawning up stream in gravel beds (Lucas and Baras, 2001). However, unlike salmon and shad, their affinity and requirements towards flow is lower, although barriers can restrict their migration to their respective spawning grounds and thus can reduce successful recruitment.

During the camera array deployment, the study recorded every species and their movement in relation to the camera, which produced a large dataset where all species could subsequently be analysed. This ability to identify every fish is a powerful tool when looking at spatial and temporal changes and means that the methodology was not restricted to one species like most other telemetry studies.

This section therefore concentrates on the diel movements of these other species to further inform the review of abstraction regimes. It is hypothesised that increased levels of abstraction would have little to no effect upon the resident species in both rivers. However, the movements of other migratory species such as eels and sea lampreys could be impeded.

6.1 Fish species

In total, 11152 and 5684 individual fish were recorded in the Wye and Usk respectively when conditions allowed, in addition to both shad and salmon. Minnows (*Phoxinus phoxinus (L.)*) were the predominant species in both rivers with a total of 8057 recorded in the Wye and 1049 in the Usk, accounting for 18.46% and 72.25% of the total species composition. This large number of minnows suggests they are one of the most abundant species in both rivers – in particular the Wye. However, this data may be inflated due to their schooling and milling behaviour around the camera array causing difficultly in quantitatively assessing their population abundance. As a consequence of this and their insignificance in terms of an angling species, minnows have been omitted from further analysis.

The cameras were also able to record other animals. In the Wye, 14 European otters (*Lutra lutra (L.)*) and 7 Great Cormorants (*Phalacrocorax carbo (L.)*) were observed whereas in the Usk, 7 European otters, 102 Great Cormorants and 1 Common frog (*Rana temporaria L.*) were recorded.

Unfortunately, not all species of fish were able to be recorded. This was primarily due to two reasons, firstly the fish were too far from the camera as the camera didn't span the whole length of the river and secondly the river water was too turbid. In the Wye, unidentified species accounted for only 0.86% of the total species, whereas the Usk had a higher unidentified count of 4.66%.

In total 11 species were observed in the Usk with the two main species being trout (*Salmo trutta L.*) (Figure 6.1) (1507) and mullet (*Liza ramada (R.)*) (2188), and less numbers of eel (252) and dace (*Leuciscus leuciscus (L.)*) (245) (Figure 6.2). The presences of mullet indicates the close proximity to the estuary with their movements coincided with the tides. Trout were seen in high numbers during the day (04:00-21:00), but with little movement overnight (22:00-03:00) (Figure 6.5) and no notable trend in an up- or downstream direction. Mullet movements were predominantly during the day (06:00-21:00) with little movement overnight (22:00-05:00). A number of cyprinids and eels were observed across the array, each showing different diel patterns in movements (Figure 6.4). Eels were seen moving in high numbers almost exclusively at night (21:00-04:00), as were gudgeon and stone loach (Figure 6.4). By contrast, dace was seen to move chiefly during the day (04:00-21:00), whilst chub (*Squalius cephalus (L.)*) was the only species to exhibit a diel pattern that encompassed both day and night movements. Two individual roach were also identified both being seen together at 09:37 on 25 April (Figure 6.4).

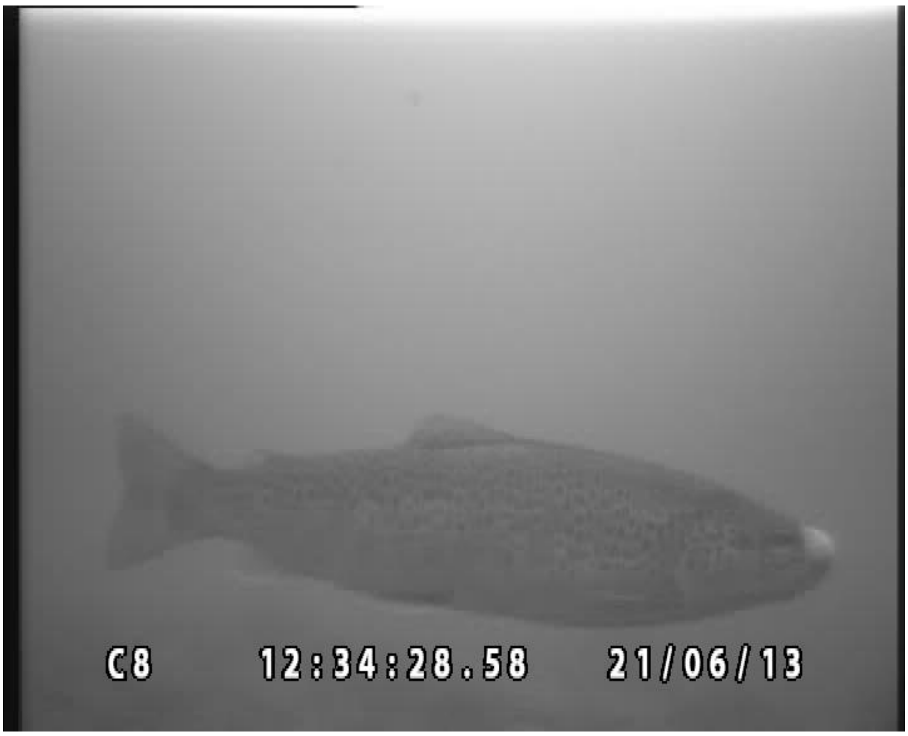

Figure 6.1 Image of a trout infected with fungus on its nose recorded at the Llantrisant camera array on the River Usk.

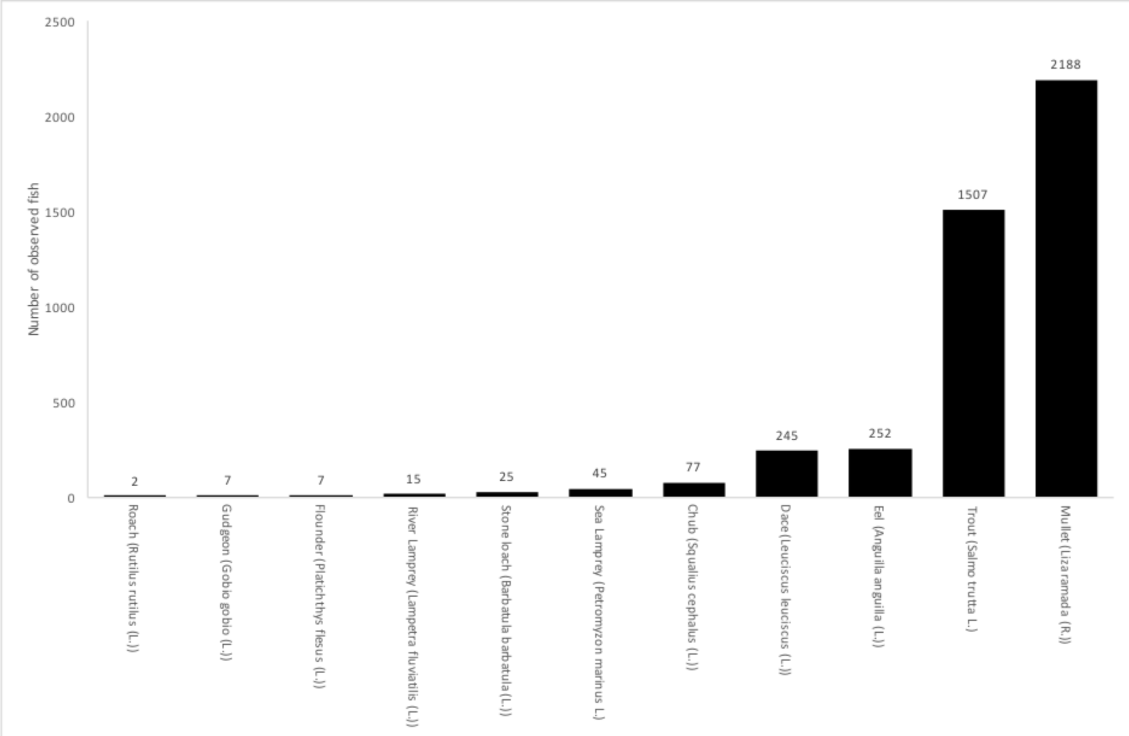

Figure 6.2 River Usk species composition of observed fish species in the camera array (N = 4370).

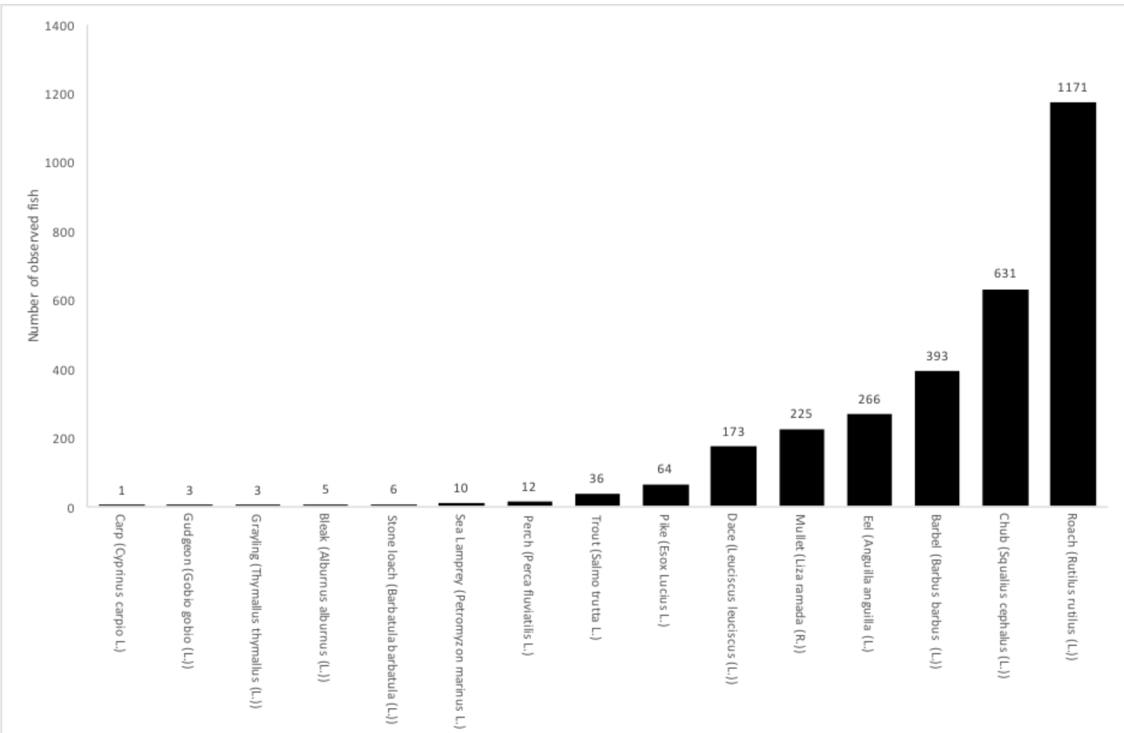

Figure 6.3 River Wye species composition of observed fish species in the camera array (N = 4370).

Sea lamprey and river lamprey were also observed in the Usk (Figure 6.5). Both river and sea lamprey were seen predominantly moving upstream during the night (21:00-04:00), although downstream movements of sea lamprey were also recorded (Figure 6.5). Flounder was the final species seen in the study, with movements predominantly at night (20:00-03:00).

In the Wye, a total of 16 species of fish were identified in addition to shad and salmon across the camera array with two main species being roach (1171) and chub (631), with less numbers of barbel (*Barbus barbus (L.)*) (393), eel (266) and mullet (225) (Figure 6.3). The presences of mullet indicates the close proximity to the estuary, with their movements coincided with the tides. Roach were seen in very high numbers during the day (04:00-21:00) with no movement overnight (Figure 6.6). Although chub, like roach, were predominantly seen during daylight hours (04:00-21:00), they were also seen to move in lesser numbers during the night (22:00-03:00): (528 during the day in comparison to 44 at night). Both of these species were seen moving up and downstream with no notable trend in an up- or downstream direction.

A number of cyprinids and eels were observed across the array each showing different diel patterns in movement (Figure 6.6). Eel and stone loach were predominantly observed, like in the Usk, moving upstream during the night (23:00-03:00) with very little activity during the day. By contrast, barbel were seen moving up- and downstream throughout the day with peaks at both dawn and dusk (05:00-07:00 and 18:00-21:00), exhibiting a crepuscular pattern. Most dace were observed (173) moving during the day between 05:00-20:00. Other species of cyprinids, bleak, gudgeon and carp, were also seen in very low numbers (Figure 6.6). The five bleak and three gudgeon were seen in daylight hours (04:00-21:00) and the single carp at 05:28 (Figure 6.8). This carp was unexpected in the River Wye and is thought to be an escapee from a local fishing lake. As the numbers between these particular cyprinids were so low, no relationships can be drawn about their directional movements.

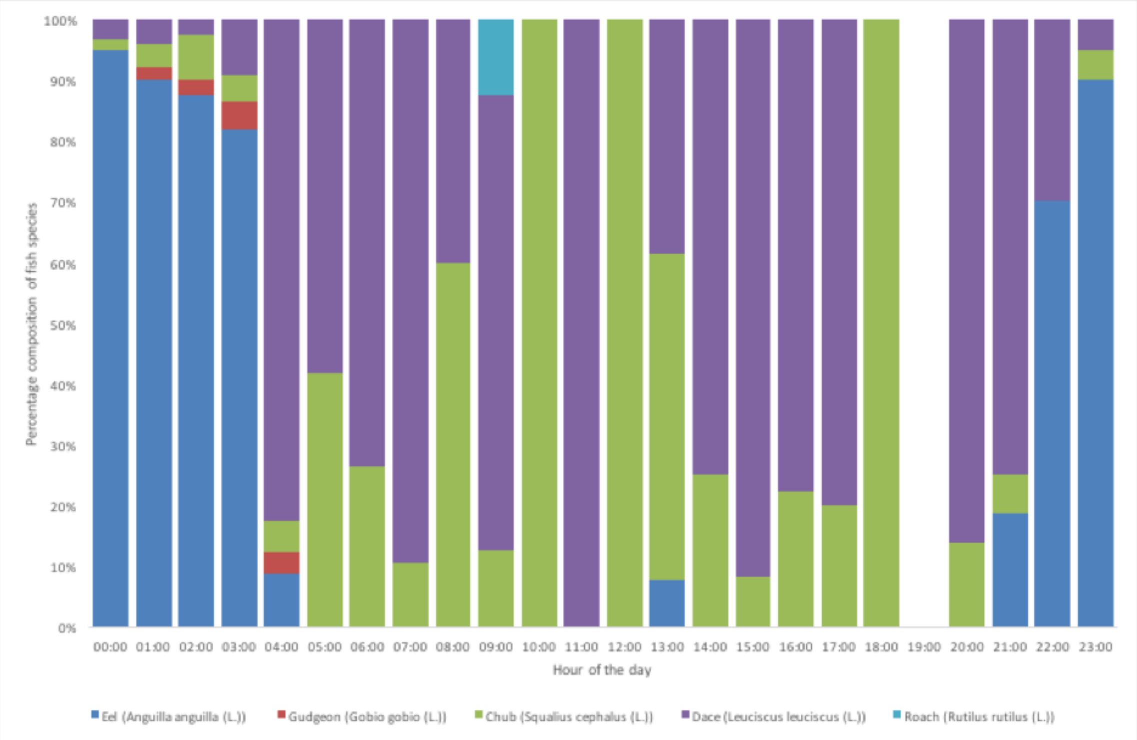

Figure 6.4 Percentage of cyprinids and eels observed in the River Usk camera array in each hour of the day.

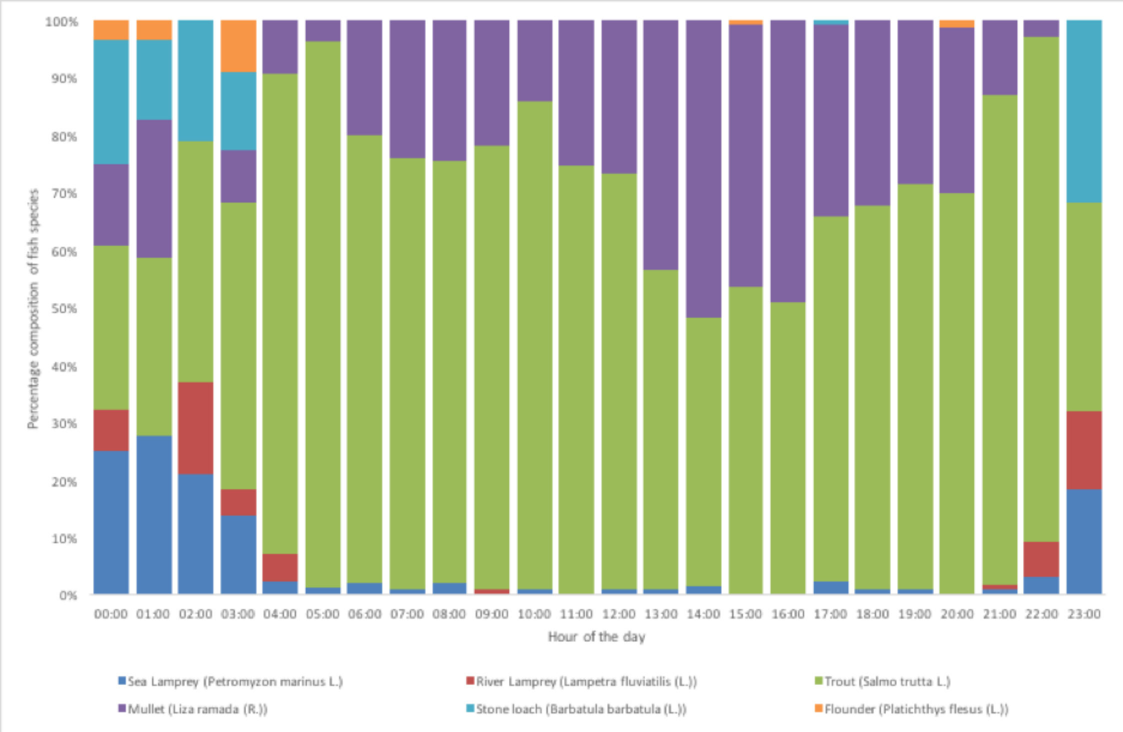

Figure 6.5 Percentage of other species observed in the River Usk camera array in each hour of the day.

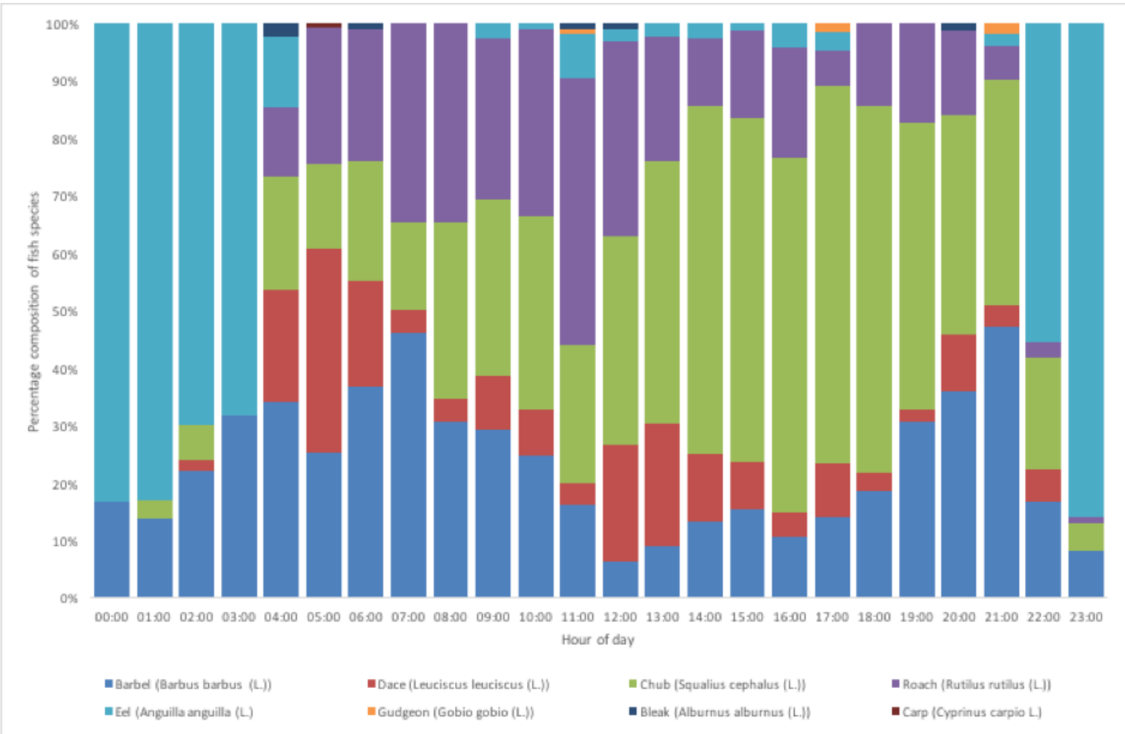

Figure 6.6 Percentage of cyprinids and eels observed in the River Wye camera array in each hour of the day.

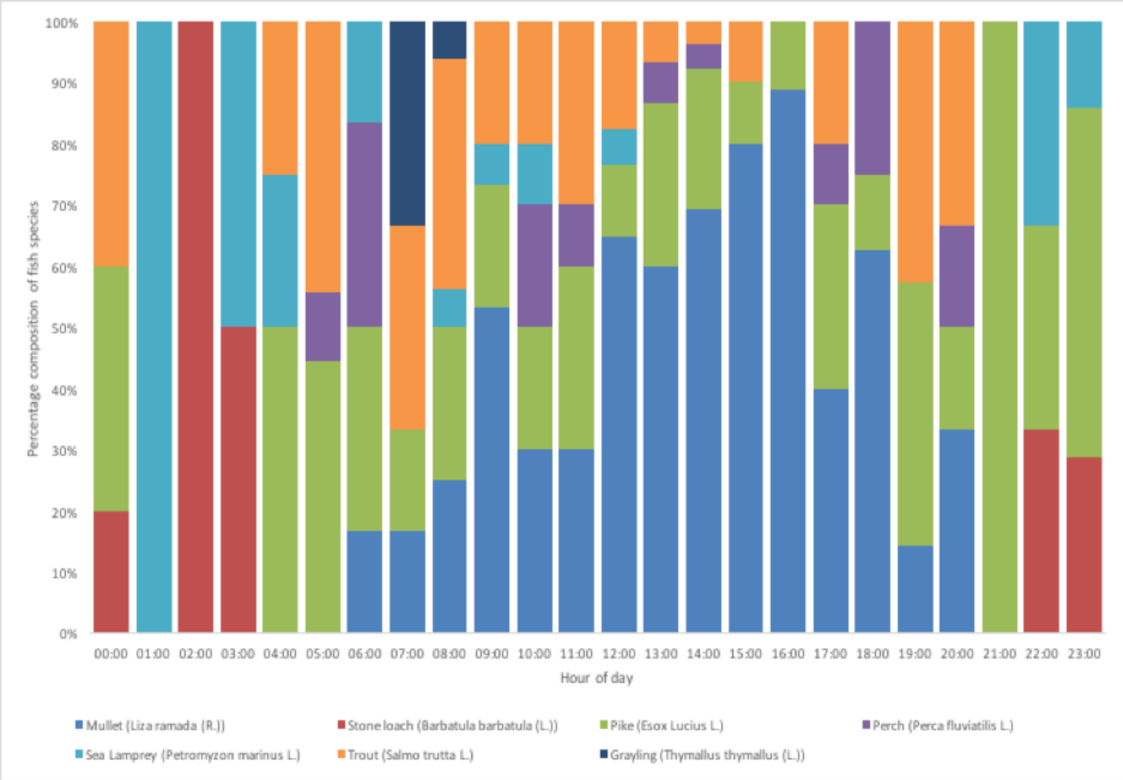

Figure 6.7 Percentage of other species observed in the River Wye camera array in each hour of the day.

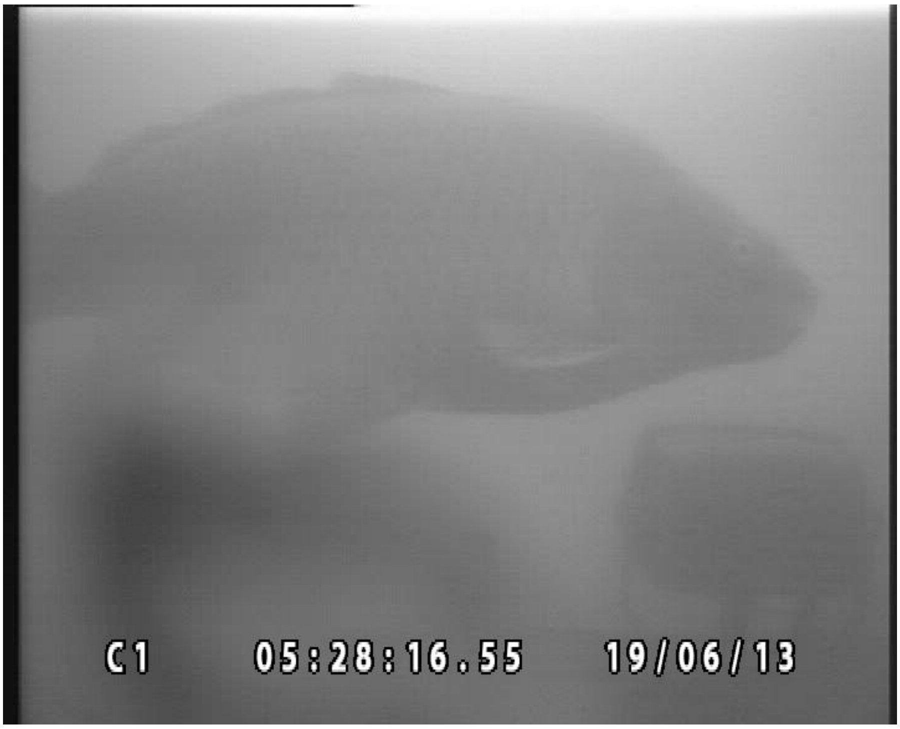

Figure 6.8 Image of the only carp recorded moving upstream across the Wye camera array.

Amongst the non-salmonids (Figure 6.7), mullet accounted for the highest numbers with 225 individuals observed. Like the Usk, their movements into the freshwater system coincided with the tides with movements being exclusively during the day (06:00-20:00), although one hour less than the daylight hours shown in the Usk (Figure 6.6).

Two predatory fish, pike and perch, were observed in the Wye (Figure 6.7). Whilst neither fish demonstrated preference to a particular direction, pike were seen to move throughout the entire day, except between the hours of 01:00-03:00, whilst perch were seen to move exclusively during the day (05:00-20:00).

Trout and grayling compromised small amounts of the total species composition across the Wye camera arrays (Figure 6.7) with trout accounting for 36 individuals and grayling for 3. Trout moved between 22:00-12:00 with a preference to dawn, contrasting with grayling which only moved during the hours of 07:00 and 08:00. Both trout and grayling showed strong preference to upstream migration, but with only three grayling seen it is hard to draw explicit conclusions from these movements.

In contrast to the Usk, the 10 sea lamprey observed in the Wye were seen solely migrating upstream. Furthermore, no preference to diel movements was shown with a 50/50 split between day (05:00-20:00) and night (21:00-04:00) movement.

6.2 Non-fish species

European otter and the great cormorant (Figure 6.9) were observed in both rivers. Seven otters and 102 cormorants were observed in the Usk, and 14 otters and seven cormorants in the Wye. Both species pose predatory and mortality risk to both shad and smolt during their respective migratory stages.

Figure 6.9 Image of a cormorant (left) and otter (right) at the Llantrisant camera array on the River Usk.

6.3 Discussion

Although the species composition between the two rivers differed slightly, they are both typical of the lower reaches of rivers without an extensive floodplain. Trout and mullet are the two main ‘other’ species of the River Usk (Figure 6.2) whereas in the Wye, two primary species dominate (roach and chub) with slightly smaller numbers of barbel present. These changes in species composition between the two rivers are accountable due to the width, depth and gradient change. However, the unexpected single carp that was observed in the river Wye (Figure 6.8) was not expected of this zonation type and as a consequence is thought to be an escapee from a local fishing lake during a flood event.

In both rivers there are high numbers of mullet that indicates close proximity to the estuary with their movements coinciding with the tides. Sea lamprey, one of the species that falls under Annex II Habitats Directive, was also observed in both rivers. This presence of sea lamprey is one of the primary reasons for both rivers being selected as an SAC. Along with salmon and shad therefore, sea lamprey require both protection and monitoring during their anadromous migration. Surprisingly, downstream movements of sea lamprey were observed in the Usk despite them being semelparous. This downstream movement could therefore point towards a barrier to their migration further upstream of Llantrisant. A potential barrier to migration in the Usk is already known at Crickhowell Bridge and as such this could be restricting sea lamprey movements. By contrast, all observed sea lamprey in the Wye were migrating upstream past the Redbrook array and as such their migration appears to be unimpeded. It must be noted, however, that only 10 sea lamprey were observed in the Wye and 45 in the Usk. These numbers are extremely low and most likely accountable to their migration taking place along the river bed and thus not observed by the cameras. Although it may also point towards a dwindling population that requires further attention.

In both rivers, the non-salmonid species are resident in their respective reaches and are unlikely to be impacted by any flow modifications caused by abstraction This is due to their flow requirements being lower than that of the protected migration species (Aprahamian and Aprahamian, 2001 & Jonsson and Jonsson, 2011) and their nomadic nature meaning they can migrate to a section of river unaffected by potential over abstraction (Lucas & Baras, 2001). This can also be true of resident trout although their migration could become impeded if water levels dropped significantly enough for weirs to become barriers. Flow modifications could also affect the migration of sea lamprey. This is particularly important in the Usk where movements noted downstream could point to an existing barrier and lower flows could exacerbate the potential problem.

Large numbers of both otters and cormorants were seen in both camera arrays. Halts of otters are seen at the Llantrisant pumping station and the Wye has the densest population of otters known in Wales. Cormorants were observed in higher densities at Llantrisant (102 in comparison to 7 at Redbrook) with breeding roosts being situated opposite the survey site.

The River Wye in particular is known to suffer from heavy predation from piscivorous birds (cormorants and goosanders) (Feltham *et al.* 1996), with cormorants in particular targeting downstream smolt migration. Several cormorants were observed foraging in the camera images at both Redbrook and Llantrisant (Figure 6.9).

As highlighted previously, predation by fish-eating birds, especially cormorants, could severely impact smolt and shad outputs from the Wye and Usk and cause high levels of mortality. Mortality associated with fish species may be further increased with the presence of otters in both rivers (21 combined) (Figure 6.9). As a consequence, this source of mortality would need to be factored into any life history model (if developed at a later stage) examining the impact of abstraction regimes on fisheries.

7 DISCUSSION AND CONCLUSION

The rivers Wye and Usk [and Severn Estuary] are designated SACs with twaite shad and salmon as conditions for site selection. The criteria on which the condition assessment is based are provided in Appendices 4 and 6. Before any changes in water abstraction can be approved on these rivers, a RoC must be completed to assess the potential environmental impacts upon the water bodies' natural flow regime. The effects of changing the natural flow regime have already been outlined previously, although with species specific flow requirements, the effects of abstraction will need to be assessed and quantified.

7.1.1 Methodology

As previously stated, the cameras were able to monitor every fish and as such the study expanded from the original shad migration study to encapsulate returning adult salmon and sea bound smolts. When conditions permitted, identification of all fish species were accurate due to good picture quality. There were, however, many limitations with the use of underwater cameras. First, the time needed to analyse the data was painstaking with an average of 8-12 hours of camera footage successfully analysed each day. The total amount of hours processed per day could not have been increased due to a speed limit imposed upon the computer software (Timespace PCLink™) capping the rate at which the footage could be viewed. With no converter software available due to the privately owned codec (file extension .xba), no alternative viewing software could be found. Conversely faster speeds could increase the chance of error by overlooking fish and as such a balance is required between speed and detection accuracy.

Furthermore, regular maintenance of the cameras was essential. The removable hard drives at the sites required changing every 10-14 days or the new files would begin to overwrite the older files causing loss of data. Additionally, biofouling (build-up of algal and fine sediment) on both the camera lens and infra-red lights caused camera footage to be difficult to view or in some instances, for data to be lost. This factor was exacerbated during the summer months where increased sunlight amplified algal growth making weekly camera maintenance and cleaning necessary. This was particularly evident in the Usk where the clear, shallower waters allowed for more sunlight penetration. During periods of high flows, however, access into the river was not possible causing data to be lost, as is annotated on the flow graphs in the analysis.

Methods to overcome this algal growth were researched although no viable options were identified. Many of the 'solutions' investigated came from the aquatic industry with anti-algal growth gels used for aquariums. These are translucent and were deemed, in regards to this study, to inhibit camera function preventing adequate fish identification.

With copper inhibiting algal growth, the use of copper wire was also examined (Rice and Wood, 2014, pers. comm., 14 Feb). However, due to the small nature of the cameras, fully preventing the growth of algae proved difficult and also failed to prevent the build-up of fine sediment. It was therefore concluded that continued maintenance was the only viable option, despite the large expense of man hours.

As previously mentioned, the cameras were unable to assess the whole channel width with some fish species potentially being missed due to swimming behind the first camera or swimming close to the far right bank out of sight. It is unlikely that fish swam behind camera one as it was almost flush with the bank. However, there was a small enough area on the far right bank which could not have been surveyed by camera 12. This could have potentially been rectified with the addition of another two cameras and an infrared light. Conversely, this may have been rectified by changing the area of deployment to a narrower section of channel. This final point is not liable however, as the array set up required a continuous power source within the safety of an area which is away from potential tampering or theft from the general public. Furthermore, the location of the camera arrays was placed just above the tidal limit in an area where the shad and salmon are known to pass. As such, changing location may have put the cameras into the tidal limit with very deep water - potentially adding to fish missed by the cameras - or too high in the catchment where a barrier could prevent their migration passing the cameras.

Studies using underwater cameras now use complex computer algorithms that can identify shapes, i.e. fish morphology, recording and comparing each encounter with one of these pre-set shapes (Larsen *et al.* 2009 and Booma *et al.* 2014). Although turbid conditions would lead to these shapes becoming distorted or unrecognisable to the program, these algorithms process and analyse a whole days footage in a couple of hours (dependent upon file size and positive recordings), and thus would take considerably less time than the methodology applied here. For this method to be applied, however, the installation cost of the system would need to outweigh the cost of man hours used in any specific study.

7.1.2 Salmon

Salmon were seen to migrate throughout the whole study period with the first recording in the Usk on the first day the cameras were turned on (28 April 2013). Due to the camera malfunction, the first recording in the Wye was not seen until 21 May.

Like shad, salmon migration appears to correspond with both flow and tidal state. Both the Wye and Usk salmon migration is impacted by changes in flows, with numbers decreasing during high flows and subsequently increasing after flow events. This is consistent with literature where salmon were seen to halt their migrations during high flows by laying up in deep pools until conditions improved (Brawn, 1982; Aprahamian *et al,* 1998; Tetzlaff *et al.* 2005). Tide was a primary factor influencing migration with salmon moving in waves upstream on rising tides and downstream during the ebb tides. Peak migration was observed when temperatures rose above 10^{o}C, which is consistent with the literature, although migration was observed above 20^{o}C, which is thought to hinder if not halt the migration of salmon due to the rise in oxygen demand (Jensen *et al.* 1986; Gowans *et al.* 1999; Salinger and Anderson, 2006). Diel movements were observed, but movements were predominately at dawn (05:00-08:00). Movements across the camera array in the Usk showed no relationship whereas the Wye showed a strong preference to camera 12, thought to be in response to the installation of a wall to aid fishing and used as a flow break by the salmon.

7.1.3 Smolts

Smolts were observed migrating out of the system in the Usk from 23 April until 22 May, consistent with the literature (Byrne *et al.* 2003; Cowx *et al.* 2014; Jonsson and Jonsson, 2011). Downstream migration peaked on 01 and 02 May 2013, associated with a waning moon. During this period, water temperature remained constant at 10-11°C with flows hardly differing from 1000 Ml/d. Tide and flow appears to be a main factor inducing migration as smolts were seen moving during the descending limb of the overall spring hydrograph. Temperature also appears to be a co-trigger along with day length, with smolts moving at temperatures above 10^{o}C. This is known to be the main environmental cue for migration (Hoar, 1988; Hvidsten *et al.* 1998; Gowans *et al.* 1999; Jensen *et al.* 1986; Salinger and Anderson, 2006) and the results from this study support that. Smolts moved mostly during the day with peaks between 11:00-12:00 and 14:00-15:00 with little movement overnight. contradicting the literature (Jonsson and Jonsson, 2011; Ibbotson et al. 2006). This suggests that the main cue for downstream movements is more likely to be flow and temperature. Their movements over the cameras showed a strong preference towards camera 8, which in conjunction with the ADCP, shows that smolts use the highest velocities for moving downstream as an energy efficient mechanism which is consistent with the literature (Jonsson and Jonsson, 2011).

There is was also a risk to smolts from predation with 7 cormorants and 14 otters in the Wye and 12 cormorants and 7 otters in the Usk. As a consequence, the potential high mortality rates between this natural predation and abstraction will be hard to differentiate, particularly when they change their epibenthic behaviour increasing their risk to predation (Hoar, 1988; Jonsson et al. 1998).

WUF (2012) found, "*that smolt migration is not significantly affected by very low flows in the spring, provided at least one spate occurs in April or May. There is no evidence that outward migration of salmon smolts was affected by the natural droughts of 1976 and 1984, which both had exceptionally dry springs, or that abstraction had any impact.*" It is unclear, however, why WUF have indicated there is a need for and what represents '*at least one spate*'. Flows are generally higher in spring and there is no evidence that low flows (including those subjected to abstraction and regulation) affect outmigration of smolts or spates act as a cue to downstream migration. The requirement for a spate is not supported by the migration pattern elucidated from the Llanstrisant camera data where migration appears to be initiated during a period of stable flow (around 1000 Ml/d) in late April early May 2013 (Figure 5.11).

Further support for this conclusion can be found from subsequent rod catch of one and two winter salmon following dry springs, which appear to be unaffected by the lower flows experienced during the spring in these years. This was confirmed by WUF (2012) who looked at the impact of major drought years on salmon migration in the Wye using fish catch and flow data, including smolt migration, and found:

- **"1976 drought**. Spring spates reduced and low flows (as measured at Erwood) considered to potentially adversely affect smolt migration. However, the smolt class of 1976 produced good returns of grilse in 1977 and good returns of 2-sea-winter fish in 1978 (see Figure 26 of the WUF report). **This shows that the flows in the dry spring of 1976 were adequate for smolt migration,** despite the significant reduction in the spates of April and May by the retention of the reservoirs. The smolts of 1976 seem to have been hardly affected by the dry spring and migrated out of the river before the effects of the drought became severe."

- **"1984 drought**. (Figure 28 of WUF report) Success of smolt and juvenile year classes after the drought of 1984) shows that, despite the exceptionally dry spring, the smolts migrating out of the river in 1984 provided good returns of grilse in 1985 and good returns of 2-sea-winter fish in 1986. Although there is no specific data on the flows needed for migration of Wye salmon smolts, the generally accepted view is that flows are important, for example as expressed by the Salmon Advisory Committee 1993 Report on "Factors affecting emigrating smolts and returning adults" which stated that '*Smolt emigration is also greatly enhanced by elevated flows, but evidence from several studies shows that fish will emigrate even in the absence of freshets. However, such emigration is delayed and this can have an impact on marine survival. Thus flow depletion by abstraction can also have an impact on smolt migration and possible survival.*' However, the experience of 1984 suggests that, in the climate of mid-Wales, **even the most adverse flow conditions will provide a successful smolt migration**."

Similarly, Mawle (2013) stated **'***With sustained higher flows, abstraction is unlikely to affect the smolt migration, assuming the risk of entrainment is addressed*', but qualified this by stating '*Abstraction at lower flows will reduce migration speed, potentially severely, reducing smolt survival in the river and possibly at sea, thereby affecting the stock. Delay and predation at obstructions, principally Newton Weir [Brecon], are particular concerns*.' Whilst there is no definitive evidence for the latter statement, reducing abstraction at low flows on the lower River Usk may provide protection for downstream migrating smolts although the location of the Usk abstractions at the bottom of the river would mean limited benefits.

7.1.4 Shad

The condition status of shad in the rivers Wye and Usk (DEFRA, 2013), indicate that twaite shad are in unfavourable condition and allis shad are not present. Unfortunately, empirical information on the shad populations in both rivers is limited. This lack of data is exemplified in regards to upstream movements in relation to environmental drivers, i.e. flow. This study provides valuable information as about potential changes in the abstraction regime on the migration success of shad, and shows the species requires protection under the RoC process.

Migration of shad was observed in the Wye between 20 May-11 July 2013 and in the Usk between 08 May–11 July 2013 with the majority seen in June. No net migration was observed in the Usk whereas in the Wye there was a clear shift observed on the 19 June when shad were seen to change from predominantly moving upstream to downstream. Temperature also influences movement in both rivers with shad only moving once temperatures reached >10.6^{o}C. However, the main factor in migration appears to be tidal influence as temperature remained steady throughout the study. Shad were seen migrating in waves corresponding to the lunar cycle with the peak migration at the onset of the high spring tidal cycles. The key migration stages appear to be influenced by the lunar cycle where the initial migration coincided with the first full moon when fish entered on the rising tide. The second full moon coincided with the predicted end of the spawning cycle and the potential cue to emigrate out of the system. The last full moon of the study coincided with the last shad leaving on the falling tide. River flow and discharge also appears to influence movement of shad although the literature points at this not being a driver in migration (Boisneau et al. 1985) but inhibits their movements at high flows (Boisneau et al. 1985; Clabburn, 2002). It appears shad avoid high flow events and do not migrate upstream until flow is below the 4500 Ml/d flow band in the Wye and 2000 Ml/d in the Usk. Finally, the movements of shad were observed to move during the day (05:00 and 20:00) in a crepuscular pattern with little movement overnight. Interestingly, their physical position in the river appears to be skewed towards the last camera of each array (cameras 4, 8 and 12) which is believed to be due to flow preference. This flow preference was explored through the use of an ADCP in the Usk and showed that preference is flow related although avoidance reaction from the camera array itself could play a part.

Evidence from the shad spawning surveys shows that shad spawn as far upstream as Bulith Wells on the Wye and Crickhowell bridge on the Usk. It was therefore concluded that there are currently no barriers to migration on the Wye, whereas in the Usk, shad eggs, spawning and nursery grounds were found exclusively below Crickhowell bridge. This suggests that Crickhowelll Bridge is potentially a barrier to further upstream.

Low flows are likely to be significant particularly in relation to passage over major barriers such as Usk Town Bridge and Crickhowell Town Bridge and potentially Newbridge-on-Wye in the Wye, with lower flows potentially increasing the barrier effect and hence restricting movements upstream, as was found for salmon on the River Exe (Solomon *et al.* 1999; Sambrook & Cowx 2000). This means that in certain years the interaction between flow conditions and weirs along the rivers Wye and Usk may act to restrict the spawning range of shad.

7.1.5 Other species

Both the lower reaches of the rivers Wye and Usk support a mixed fish community with mullet, barbel, chub and roach predominantly in the Wye and mullet and trout in the Usk. The Wye had a larger abundance of cyprinids than the Usk, whereas the Usk had a greater abundance of trout. Movements of cyprinids in both rivers primarily followed a crepuscular pattern, whereas eels in both rivers moved predominant at night. Sea lampreys were observed moving upstream during all hours of the day, although downstream movements were also observed in the Usk. This could point towards a barrier to their migration further upstream of Llantrisant, which is consistent with the barriers at Usk Town Bridge and Crickhowell Town Bridge. The cyprinids are unlikely to be affected by any flow modification as they are resident within the reaches of their respective river. Sea lamprey and trout are, however, likely to be negatively affected by increased abstraction during their upstream migration, principally in the Usk as downstream migration was observed with potential barriers already identified.

7.2 Compounding factors

The data presented can be used to inform any modifications to the abstraction regime under the RoC and suggests the need to protect flows in the key species during the spring migration window (April to mid June).

Several other factors also need to be considered when interpreting the information about upstream and downstream migration of said species in relation to the RoC process. These are important because they need to be accounted for when establishing abstraction rules or have potentially significant impact on the survival of shad and salmon and thus need to be factored into any life history modelling or assessment of conservation [condition] status to isolate the impacts of flow abstraction.

7.2.1 Hydrology

As discussed previously (section 2.3) historical flow data suggest there is little evidence of substantial alteration in the flow regime during the spring period (March-June) when most smolts are out-migrating from the Wye and Usk and when most shad are migrating in, e.g. for the period 2008-2011 which are noted for being particularly dry years for the Wye and Usk respectively. This is confirmed by the spring only flow duration curves for these rivers.

7.2.2 Screening of Intakes

The EAW Stage 3 RoC process raised concern about loss of downstream migrating fish at abstraction intakes. This specifically refers to loss of fish through entrainment at abstraction pumping station intakes, and included possible effects of diurnal pumping regimes. EAW (now NRW) indicated that downstream migrating juvenile shad, salmon smolts, eel and transformed river and sea lampreys are vulnerable to entrainment and suggested all intakes should be appropriately screened to minimise any impact. The coarse trash screens in combination with drum and band screens, coupled with poor fish return systems, at Prioress Mill (5 miles upstream of study site in the Usk) and Llantrisant abstraction intakes (< 100 m from Usk study site; Figure 2.1) were considered inadequate and this could adversely affect upon SAC feature integrity due to entrainment. Similarly, these inadequacies were found in the Wye with the abstraction point at Monmouth (Figure 2.1). These screen intakes can effect both the upstream and downstream migration of shad and salmon as they must pass them in order to reach their respective spawning grounds in the upper reaches of the rivers. They then consequently migrate downstream of adults after spawning and juveniles returning to sea meaning adults must pass this hazard twice and juveniles once potentially increasing the risk of death significantly. This can have detrimental effects upon population size by reducing the number of spawning adults and juveniles. Consequently, screening of abstractions was considered further in the Stage 4 options appraisal with the RAM and appropriate screening measures are being proposed for these locations.

The issue of diurnal pumping arises because of the belief that smolts and shad migrate during the night when DCWW pump more intensively because of the lower cost of electricity (Mawle 2013). However, the Llantrisant camera data suggest that, at least in 2013, smolts and shad

(Cowx *et* al. 2013, 2014) tended to migrate past Llantrisant during daylight hours. Concerns about specific pumping regimes could, nevertheless, be largely overcome by using appropriate screening at the intakes, and any problem that is likely to arise is probably overshadowed by predation from fish-eating birds (Figure 6.9). In any event current abstraction proposals involve a constant abstraction rate (as far as operationally practicable over 24 hours) between April and November.

7.2.3 Water temperature

During extreme abstraction regimes, it is possible that they can inadvertently alter the temperature of the surrounding water by lowering the water levels which can decrease temperatures in winter and increase temperatures in summer. However, the effect of abstraction on water temperature is likely to be indirect where controlled releases of cooler hypolimnion water from reservoirs will be used to top up the river to maintain the natural flow regime. According to the literature (Aprahamian 1985; 1988; Claridge & Gardner 1978; Hoar, 1988; Jensen et al. 1986) (Sections 5.1 & 4.1), water temperature (above 10˚C) is considered to be a cue for the onset of downstream migration of smolts and shad. Thus, any modification of the water temperature as a result of change in flow regime may change the timing of migration, with potential impact on the survival of both these species. Similarly, adult salmon have a close affinity with temperature with temperatures of 8-15°C triggering the freshwater phase of migration and as such, can alter the runs of salmon into freshwater. Furthermore, Salmon movement is inhibited at both low (5-6°C) and high (22°C) temperatures ceasing entirely between 22°C and 25°C, where these temperatures become lethal (Jensen *et al*. 1986; Gowans *et al*. 1999).

Temperature data – provided by NRW (Figure 7.1) – shows the water temperatures of three locations on the Wye representing the upper, middle and lower sections of the river. It is possible to track water temperature changes from controlled releases in the head waters through the river to just above the tidal limit in the lower reaches. This allows potential conclusions to be drawn on prospective indirect spatial and temporal effects abstraction may have upon water temperature.

Caban Coch Reservoir is part of the Elan valley complex (Figure 2.1) and regularly carries out controlled releases of water into the Wye to help maintain the natural flow regime. Erwood is located in the middle reaches of the Wye - 25 km below the Wye/Elan confluence - and Redbrook is the study reach located in the lower reach of the Wye. Unfortunately, water temperature data for the Usk is not provided apart from at Sennybridge which is located downstream of Usk reservoir (Figure 2.1). When plotted against the temperature data from the Wye for comparison, it follows a similar trend to that of the Wye until 2005 where the annual temperature became higher due to a warm year. This trend is followed by Caban Coch, the comparative location on the Wye.

While the time frame in which this data spans (1993 – 2008) does not co-inside with this investigation, comparisons can be drawn as abstraction has taken place during these periods.

Although water temperature data is somewhat fragmented and noisy, there is no evidence that water temperature is adversely affected by flow modifications in the Wye, especially in the spring period, except the suppression of water temperature downstream of the Elan Valley reservoirs (Figure 7.1). As mentioned previously this is a typical suppression of the water temperature caused by release of cooler hypolimnion water (Cowx *et al.* 1987) and the effects appear to be dissipated by the lower reaches of the Wye. As such, it is believed that abstraction will likely to be have minimal effect upon water temperature though a specific study is recommended to quantify this.

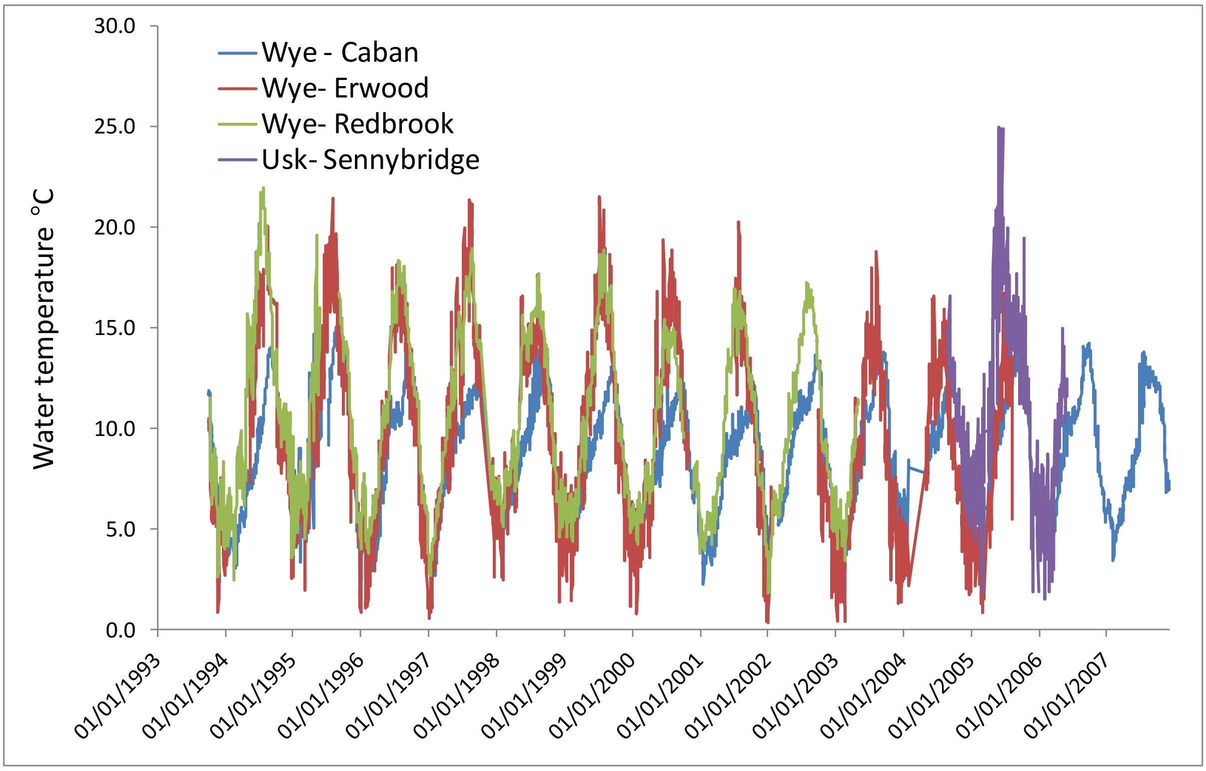

Figure 7.1 Temperature profiles for the river Wye and Usk (Source: EA Temperature database)

7.2.4 Predation

As highlighted previously, predation by fish-eating birds, especially cormorants, can potentially impact smolt outputs from the Wye and Usk (Feltham *et al.* 1999). The literature has shown that the River Wye in particular was once shown to suffer from heavy predation by piscivorous birds (cormorants and goosanders) (Feltham *et al.* 1999), and it was shown that cormorants targeted smolts in particular as they migrate downstream. As such, if abstraction caused river levels to decrease, it may increase predation rates by reducing available protective cover. As a consequence, the mortalities that this may cause would have to be taken into consideration if trying to quantify the mortality caused by abstraction with the use of a life history model (if developed at a later stage) examining the impact of abstraction regimes on fisheries.

This type of predation is not likely to affect adult salmon and shad, though they may be susceptible to otters which were observed foraging in the camera images from both Redbrook and Llantrisant.

7.3 Conclusions

The rivers Wye and Usk are designated SAC rivers with twaite shad and Atlantic salmon being two of the primary reasons for site designation. The criteria on which the condition assessment is based are provided in Appendices 4 and 5 for shad and 6 and 7 for salmon. In view of their conservation status and importance to the Wye and Usk's SACs status, there is a clear need to understand any potential impact of change in flow as a result of abstraction on shad and salmon populations. As such, precautions must be put in place to preserve the remaining populations and attempt to increase their abundance.

The deployment of underwater cameras at Redbrook (Wye) and Llantrisant (Usk) has provided sufficient information on the relationships between flow, temperature, tide and time of day on migration of shad and salmon over daily/monthly temporal scales. The Usk cameras have also provided information on smolt migration. The relationships found in both the rivers Wye and Usk will help to provide vital information for future management strategies for authorities and stakeholders alike.

It can be concluded from this investigation that the hydrological data (Figure 2.4 -Figure 2.8) and the camera analysis footage (summarised in Table 7.1), that **the impact of abstraction on the migratory species and output is likely to be marginal and will be difficult to separate from other climatic or compounding effects. Furthermore, discriminating any negative effects of abstraction will be problematic as the tools for such assessment are not well developed and in particular reference to smolts, the knowledge of their migration in the Wye and Usk limited.** However, it must be noted that as this investigation is a one-year study and was subject to multiple caveats as previously stated, it is difficult to definitively conclude these findings. Further work should be carried out to conclude if the results are a one off caused caused by unknown drivers and factors or are a true reflection of the river and migratory fish dynamics.

Table 7.1: Summary of relationships observed between environmental drivers and the migration amongst the studied species in the rivers Wye and Usk.

	Flow	Tide/Lunar cycle	Temperature	Diel movements
Adult Salmon	Avoided high flows and consequently higher numbers were observed after a high flow event	Migration positively correlated with the tide moving upstream and downstream with the ebb tides (between spring and neap tides)	Migration occurs when temperature exceeds 10°C	Diurnal movements between 05:00-20:00
Smolts	Main migration seen during periods of very stable flows around 1000 Ml/d. No smolts seen during high flows.	Out-migrate during the descending limb of the overall spring hydrograph. Associated with a waning moon	10°C cue for migration out of the system	Diurnal movements between 10:00-20:00 which contradicts the literature
Shad	Avoided high flows and consequently higher numbers were observed after a high flow event	Peaks at the onset of high spring tidal cycles. Onset of migration, spawning and out migration all correlate with the full moon cycles of spring	Migration occurs when temperature exceeds 11°C	Diurnal movements between 05:00-20:00

7.4 Recommendations

Both rivers exhibit similar migration patterns for shad and salmon, so recommendations can be made that encapsulate both catchments. These findings provide guidance for protecting shad and salmon - specifically adult migration behavioural patterns - and smolts for their seaward migration.

Flow has been shown to be a primary factor in migration and protecting the natural flow regime could prove vital in improving the conservation status of both shad and salmon. It must be noted, however, that abstraction during high flows is highly unlikely to have a direct impact on shad and salmon migration as both avoid moving during high flow events. Although care must be taken at abstraction points that they are not being used as holding areas from both shad and salmon actively avoiding the high flows as they could be taken into the abstraction intakes and killed. Care must also be taken when abstraction takes place during low flows as this is the most crucial period which can cause the most environmental damage. As such, it is necessary to follow the guidelines set out by the UKTAG, (2013) (Table 2.5 and Table 2.6).

Although low flows can cause significant damage as described previously, it is unlikely that low flows on the Wye will be significant enough to effect the respective migrations unless increased abstraction takes place during dry years. This is supported by the 2012 egg surveys where no barriers to migration in the Wye were observed as eggs were found beyond each potential barrier. This study was particularly relevant as it was conducted during a dry year when flows were below average. It must be noted, however, that increased abstraction during this timeframe can increase the risk of barriers to migration by lowing the river levels further.

In the Usk low flows are highly likely to be significant particularly in relation to passage over major barriers such as the footings of Usk Town Bridge and Crickhowell Town Bridge. Lower flows will potentially increase the barrier effect by restricting the movements upstream of both salmon and shad. There is therefore potential for abstraction in the lower Usk to affect the spawning range of shad, in particular if abstraction from Prioress Mill reduces flow at Usk Town Bridge sufficiently to prevent passage. Unfortunately, there is insufficient data on which to assess the extent that abstractions could influence adult shad spawning runs and the distribution of spawning activity within the catchment. To take a precautionary approach, given the diversity of species that need accommodating at this time and the complexity of flow needs, efforts should be made to support migration by protecting spring flows in low flow years by restricting abstraction. This is essential around the onset of the high spring tidal cycles to allow negotiation of obstacles and permit adult shad and salmon access to their respective spawning grounds.

If abstraction was to occur, diel movements would need to be taken into consideration and to abstract water at times when it would cause the least ecological damage (Figure 7.2). It is clear that the movements amongst both shad and salmon are diurnal and both migrations overlap with each other leaving a window between 20:00 and 05:00 when abstraction would be the least ecologically damaging with regards to these species migrations. However, it must be noted that the findings of smolt migration contradicts the literature (Jonsson and Jonsson, 2011; Ibbotson et al. 2006) and should be treated with care, especially if abstraction levels are to increase during the night in the Wye and Usk. Furthermore, shad occupy holding stations during the night to conserve energy and to avoid predation, as such abstraction at night could cause mortality as they may hold station at the abstraction intakes. The migration window for shad and salmon coincide and as such, great care should be taken with abstraction during the spring to accommodate all species and life stages.

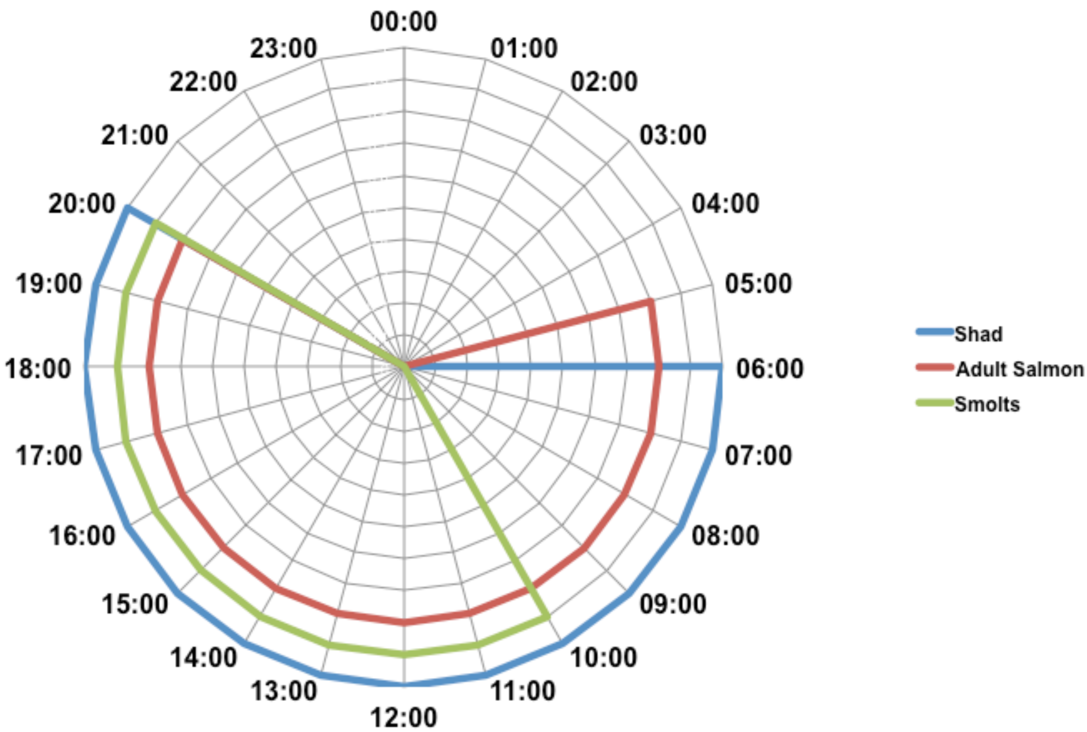

Figure 7.2 Simplified summary of diel movements between shad (blue), adult salmon (red) and smolts (green) in both the rivers Wye and Usk.

The outputs of this study provide a valuable understanding of the relationship between flow and migratory fish and it is recommended that further monitoring is carried out on both rivers to improve the understanding of any impact abstraction could have on these key life stages amongst these migratory fish. This can be done through multiple camera arrays being selectively deployed for several years to advance understanding of the spatial and temporal relationships between environmental drivers and these migratory species. These recordings will allow for a more detailed study to take place compared with most telemetry studies as it allows for a fixed-point window to be assessed observing all the fish that move both upstream and downstream of the array. Furthermore, the deployment of cameras can quantitatively and qualitatively assess any future changes in abstraction on both rivers to provide a better understanding on this anthropogenic effect on the natural flow regime.

Although these conclusions must be treated with caution as they are only based on one year's observations, but they confirm the literature on both shad and salmon migration (Aprahamian *et al.* 2003; Jonsson and Jonsson, 2011). Until further information from a number of years is available it will not be possible to isolate definitely the individual effects of each of these environmental factors in addition to increased abstraction itself. This is particularly important as temperature is known to be a cue to start migration and with the rise in temperatures seen from global warming (Aprahamian, 2006) it is postulated, in particular reference to shad, that populations further south of their geographical range will migrate earlier and as such management strategies will need to be dynamic and reviewed periodically.

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APPENDIX 1: Current surface water WFD status' for the rivers Wye and Usk and proposed finish to reach good status/potential. Adapted from Environment Agency, 2011 from Annex A & B

Water Body Name	Catchment Name	Current Overall Status	Proposed Objective Finish
Tedstone Bk - source to conf R Frome	Wye	Bad	Good Status by 2027
Knobley Bk - source to conf Hindwell Bk	Wye	Bad	Good Status by 2027
Tintern Bk - source to conf R Wye	Wye	Good	Good Status by 2015
Norton Bk - source to conf R Monnow	Wye	Good	Good Status by 2015
R Trothy - conf Llanymynach Bk to conf	Wye	Good	Good Status by 2015
Llymon Bk - source to conf R Trothy	Wye	Good	Good Status by 2015
R Trothy - source to conf Llanymynech Bk	Wye	Good	Good Status by 2015
Valley Bk - source to conf R Wye	Wye	Good	Good Status by 2015
R Trothy - conf Llymon Bk to conf R Wye	Wye	Good	Good Status by 2015
Garren Bk - source to conf Gamber Bk	Wye	Good	Good Status by 2015
R Monnow - conf Afon Honddu to conf R	Wye	Good	Good Status by 2015
R Arrow - source to conf Gladestry Bk	Wye	Good	Good Status by 2015
Gladestry Bk - source to conf R Arrow	Wye	Good	Good Status by 2015
R Arrow - conf Gladestry Bk to conf	Wye	Good	Good Status by 2015
Tippets Bk - source to conf Stretford Bk	Wye	Good	Good Status by 2015
Tarrington Bk - source to conf R Frome	Wye	Good	Good Status by 2015
Pentaloe Bk - source to conf R Wye	Wye	Good	Good Status by 2015
Cledan - source to conf R Irfon	Wye	Good	Good Status by 2015
Tirabad Dulas - source to conf R Irfon	Wye	Good	Good Status by 2015
R Irfon - conf Cledan to conf Tirabad Dulas	Wye	Good	Good Status by 2015
Humber Bk - conf Holly Bk to conf R Legg	Wye	Good	Good Status by 2015
R Monnow - source to conf Escley Bk	Wye	Good	Good Status by 2015
Escley Bk - source to conf R Monnow	Wye	Good	Good Status by 2015
Dulas Bk - source to conf Afon Llynfi	Wye	Good	Good Status by 2015
How Caple Bk - source to conf R Wye	Wye	Good	Good Status by 2015
Preston Bk - source to conf R Wye	Wye	Good	Good Status by 2015
Clyro Bk - source to conf R Wye	Wye	Good	Good Status by 2015
R Duhonw - source to conf R Wye	Wye	Good	Good Status by 2015
Bach Howey Bk - source to conf R Wye	Wye	Good	Good Status by 2015
R Wye - Hampton Bishop to conf Kerne Br	Wye	Good	Good Status by 2015
R Wye - Bredwardine Br to Hampton	Wye	Good	Good Status by 2015
R Edw - conf Camnant Bk to conf Clas Bk	Wye	Good	Good Status by 2015
Clas Bk - source to conf R Edw	Wye	Good	Good Status by 2015
Curl Bk - source to conf R Arrow	Wye	Good	Good Status by 2015
Howey Bk - source to conf R Ithon	Wye	Good	Good Status by 2015
Cascob Bk - source to conf R Lugg	Wye	Good	Good Status by 2015
R Lugg - conf Cascob Bk to conf Norton Bk	Wye	Good	Good Status by 2015
R Lugg - conf Norton Bk to conf R Arrow	Wye	Good	Good Status by 2015
Bleddfa Bk - source to conf R Lugg	Wye	Good	Good Status by 2015
Nantmel Dulas - source to conf R Ithon	Wye	Good	Good Status by 2015
Clywedog Bk - source to conf Bachell Bk	Wye	Good	Good Status by 2015
Lugg Bk - source to conf Bleddfa Bk	Wye	Good	Good Status by 2015
Bachell Bk - source to conf Clywedog Bk	Wye	Good	Good Status by 2015

Camddwr Bk - source to conf R Ithon	Wye	Good	Good Status by 2015
R Ithon - conf Gwenlas Bk to conf	Wye	Good	Good Status by 2015
R Ithon - conf Llaethdy Bk to conf Gwenlas	Wye	Good	Good Status by 2015
Llaethdy Bk - source to conf R Ithon	Wye	Good	Good Status by 2015
R Ithon - source to conf Llaethdy Bk	Wye	Good	Good Status by 2015
Camnant Brook - source to confluence R	Wye	Good	Good Status by 2015
Sturch Pill - source to conf R Severn	Wye	Moderate	Good Status by 2027
Mounton Bk - source to R Severn Estuary	Wye	Moderate	Good Potential by
R Monnow - conf Escley Bk to conf Afon	Wye	Moderate	Good Status by 2027
Llanymynech Bk - source to conf R Trothy	Wye	Moderate	Good Status by 2027
Walford Bk - source to conf R Wye	Wye	Moderate	Good Status by 2027
Rudhall Bk - source to conf R Wye	Wye	Moderate	Good Status by 2027
Stretford Bk - source to conf Tippets Bk	Wye	Moderate	Good Status by 2027
Honeylake Bk - source to conf Little Arrow	Wye	Moderate	Good Status by 2027
Stretford Bk - conf Tippets Bk to conf R	Wye	Moderate	Good Status by 2027
Withington Marsh Bk - source to conf R	Wye	Moderate	Good Status by 2027
R Little Lugg - near Wyatt Fm to conf R	Wye	Moderate	Good Status by 2027
R Little Lugg - source to near Wyatt Fm	Wye	Moderate	Good Status by 2027
Bodenham Bk - source to conf R Lugg	Wye	Moderate	Good Status by 2027
Wellington Bk - source to conf R Lugg	Wye	Moderate	Good Status by 2027
Dulas Bk - source to conf R Dore	Wye	Moderate	Good Status by 2027
Olchon Bk - source to conf R Monnow	Wye	Moderate	Good Status by 2027
Afon Honddu - source to conf R Monnow	Wye	Moderate	Good Status by 2027
Worm Bk - source to conf R Monnow	Wye	Moderate	Good Status by 2027
R Dore - source to conf Worm Bk	Wye	Moderate	Good Status by 2027
Gamber Bk - source to conf Garren Bk	Wye	Moderate	Good Status by 2027
Wriggle Bk - source to conf R Wye	Wye	Moderate	Good Status by 2027
R Ennig - source to conf Afon Llynfi	Wye	Moderate	Good Status by 2027
Norton Bk - source to conf R Wye	Wye	Moderate	Good Status by 2027
Afon Llynfi - conf Dulas Bk to conf R Wye	Wye	Moderate	Good Status by 2027
Unnamed trib - source to conf R Wye	Wye	Moderate	Good Status by 2015
Scithwen Bk - source to conf R Wye	Wye	Moderate	Good Status by 2015
Clettwr Bk - source to conf R Wye	Wye	Moderate	Good Status by 2015
Yazor Bk - source to conf R Wye	Wye	Moderate	Good Status by 2027
Willersley Bk - source to conf R Wye	Wye	Moderate	Good Status by 2027
R Edw - conf Clas Bk to conf R Wye	Wye	Moderate	Good Status by 2015
R Irfon - conf Tirabad Dulas to conf R Wye	Wye	Moderate	Good Status by 2015
Kinnersley Bk - source to conf R Wye	Wye	Moderate	Good Status by 2027
R Wye (Avon Gwy) - conf R Ithon to conf R	Wye	Moderate	Good Status by 2027
Builth Dulas Bk - source to conf R Wye	Wye	Moderate	Good Status by 2015
Unnamed trib of Moreton Bk to Long	Wye	Moderate	Good Status by 2027
Moreton Bk - source to conf R Lugg	Wye	Moderate	Good Status by 2027
Gilwern Bk - source to conf R Arrow	Wye	Moderate	Good Status by 2015
R Arrow - conf Gilwern Bk to conf R Lugg	Wye	Moderate	Good Status by 2027
Afon Cammarch - source to conf R Irfon	Wye	Moderate	Good Status by 2027
Afon Garth Dulas - source to conf R Irfon	Wye	Moderate	Good Status by 2027
Pinsley Bk - source to conf R Lugg	Wye	Moderate	Good Status by 2027
Mithil Bk - source to conf R Ithon	Wye	Moderate	Good Status by 2027
Hindwell Bk - source to conf Knobley Bk	Wye	Moderate	Good Status by 2027
Ridgemoor Bk - source to conf R Lugg	Wye	Moderate	Good Status by 2027
R Lugg - conf Bleddfa Bk to conf Cascob	Wye	Moderate	Good Status by 2027

Norton Bk - source to conf R Lugg	Wye	Moderate	Good Status by 2027
Clywedog Bk - conf Bachell Bk to conf R	Wye	Moderate	Good Status by 2015
R Aran - source to conf R Ithon	Wye	Moderate	Good Status by 2027
Gwenlas Bk - source to conf R Ithon	Wye	Moderate	Good Status by 2027
Afon Chwefru - source to conf R Irfon	Wye	Moderate	Good Status by 2015
R Edw - source to conf Colwyn Bk	Wye	Moderate	Good Status by 2027
Rhiwnant - source to conf Afon Claerwen	Wye	Moderate	Good Status by 2027
R Claerwen - conf Rhiwnant to	Wye	Moderate	Good Potential by
Afon Claerwen - conf Afon Arban to conf	Wye	Moderate	Good Potential by
Afon Arban - source to conf Afon Claerwen	Wye	Moderate	Good Status by 2027
R Wye - conf Afon Elan to conf R Ithon	Wye	Moderate	Good Status by 2015
Afon Elan - Caban-coch Rsvr to conf R	Wye	Moderate	Good Potential by
R Ithon - conf Camddwr Bk to conf R Wye	Wye	Moderate	Good Status by 2027
R Wye - conf to conf Afon Marteg to conf	Wye	Moderate	Good Status by 2027
Afon Claerwen - source to conf Afon Arban	Wye	Moderate	Good Potential by
Afon Elan - source to Pont ar Elan	Wye	Moderate	Good Potential by
Afon Marteg - source to conf R Wye	Wye	Moderate	Good Status by 2027
Garren Bk - conf Gamber Bk to conf R Wye	Wye	Poor	Good Status by 2027
R Lodon - source to conf R Frome	Wye	Poor	Good Status by 2027
R Irfon - conf Afon Gwesyn to conf Cledan	Wye	Poor	Good Status by 2027
R Frome - conf Tedstone Bk to conf R	Wye	Poor	Good Status by 2027
R Lugg - conf R Arrow to conf R Wye	Wye	Poor	Good Status by 2027
Holly Bk - source to conf Humber Bk	Wye	Poor	Good Status by 2027
Afon Llynfi - source to conf Dulas Bk	Wye	Poor	Good Status by 2027
Cage Bk - source to conf R Wye	Wye	Poor	Good Status by 2027
Digedi Bk - source to conf R Wye	Wye	Poor	Good Status by 2027
Hay Dulas Bk - source to conf R Wye	Wye	Poor	Good Status by 2015
R Wye - conf Walford Bk to Bigsweir Br	Wye	Poor	Good Status by 2015
R Wye - conf R Irfon to Brewardine Br	Wye	Poor	Good Status by 2027
Letton Lake Bk - source to conf R Wye	Wye	Poor	Good Status by 2027
R Frome - source to conf Tedstone Bk	Wye	Poor	Good Status by 2027
Afon Gwesyn - source to conf R Irfon	Wye	Poor	Good Status by 2027
R Irfon - source to conf Afon Gwesyn	Wye	Poor	Good Status by 2027
Humber Bk - source to conf Holly Bk	Wye	Poor	Good Status by 2027
Hindwell Bk - conf Knobley Bk to conf R	Wye	Poor	Good Status by 2027
Cheaton Bk - source to conf R Lugg	Wye	Poor	Good Status by 2027
Lime Bk - source to conf R Lugg	Wye	Poor	Good Status by 2027
R Wye - conf Afon Bidno to conf Afon	Wye	Poor	Good Status by 2027
R Wye - conf Afon Tarenig to conf Afon	Wye	Poor	Good Status by 2027
Afon Bidno - source to conf R Wye	Wye	Poor	Good Status by 2027
Afon Tarenig - source to conf R Wye	Wye	Poor	Good Status by 2027
R Wye - source to conf Afon Tarenig	Wye	Poor	Good Status by 2027
Sor Bk - source to Sor Bk Br	Usk	Good	Good Potential by
Grwyne Fawr - source to conf Grwyne-	Usk	Good	Good Potential by
R Usk - conf Olway Bk to New Br	Usk	Good	Good Status by 2015
Pill Bk - source to conf Olway Bk	Usk	Good	Good Status by 2015
Afon Yscir - conf Yscir Fechan to conf R	Usk	Good	Good Status by 2015
Cilieni - source to conf R Usk	Usk	Good	Good Status by 2015
Yscir Fechan - source to conf Afon Yscir	Usk	Good	Good Status by 2015
Honddu - source to conf R Usk	Usk	Good	Good Status by 2015
Usk u/s Brecon	Usk	Good	Good Status by 2015

Monks Ditch - Wainbridge to mouth	Usk	Moderate	Good Potential by
Great-Spytty Reen - source to conf R Usk	Usk	Moderate	Good Potential by
W PIll Reen - source to R Severn Estuary	Usk	Moderate	Good Potential by
Monks Ditch - source to Wainbridge	Usk	Moderate	Good Potential by
Mill Reen - source to R Severn Estuary	Usk	Moderate	Good Potential by
Caerfanell - source to conf R Usk	Usk	Moderate	Good Potential by
Afon Crai - source to conf R Usk	Usk	Moderate	Good Potential by
R Usk - source to conf Afon Hydfer	Usk	Moderate	Good Potential by
R Usk - conf R Gavenny to conf Olway Bk	Usk	Moderate	Good Potential by
Olway Bk - source to conf Nant y Wilcae	Usk	Moderate	Good Status by 2015
Nant y Wilcae - source to conf Olway Bk	Usk	Moderate	Good Status by 2015
Nant Onnau - source to conf R Usk	Usk	Moderate	Good Status by 2015
Grwyne Fawr - conf Grwyne-Fechan to	Usk	Moderate	Good Status by 2015
Afon Cynrig - source to conf R Usk	Usk	Moderate	Good Status by 2015
Afon Senni - source to conf unnamed trib	Usk	Moderate	Good Status by 2015
R Usk - conf Afon Hydfer to conf Afon Crai	Usk	Moderate	Good Status by 2015
Afon Yscir - source to conf Yscir Fechan	Usk	Moderate	Good Status by 2015
R Usk conf Afon Crawnon to conf Gavenny	Usk	Moderate	Good Status by 2015
Pantyreos Bk - source to Barrack Hill	Usk	Moderate	Good Status by 2027
Nedern Bk - souce to R Severn Estuary	Usk	Moderate	Good Status by 2027
Llwynau Bk - source to conf R Usk	Usk	Moderate	Good Status by 2027
Clawdd Bk - source to conf R Usk	Usk	Moderate	Good Status by 2027
Nant Cleisfer - source to conf R Usk	Usk	Moderate	Good Status by 2027
R Gavenny - source to conflence R Usk	Usk	Moderate	Good Status by 2027
Nant Menasgin - source to conf R Usk	Usk	Moderate	Good Status by 2027
Afon Hydfer - source to conf R Usk	Usk	Moderate	Good Status by 2027
Unnamed trib - source to conf Afon Senni	Usk	Moderate	Good Status by 2027
Afon Tarell - source to conf R Usk	Usk	Moderate	Good Status by 2027
Grwyne-Fechan - source to conf Grwyne	Usk	Moderate	Good Status by 2027
Rhiangoll - source to conf R Usk	Usk	Moderate	Good Status by 2027
R Usk - conf Afon Crai to conf Afon Senni	Usk	Moderate	Good Status by 2027
Nant Bran - source to conf R Usk	Usk	Moderate	Good Status by 2027
R Usk - conf Afon Senni to conf Afon	Usk	Moderate	Good Status by 2027
Olway Bk - conf Nant y Wilcae to conf Pill	Usk	Poor	Good Status by 2027
Olway Bk - conf Pill Bk to conf R Usk	Usk	Poor	Good Status by 2027
Berthin Bk - source to conf R Usk	Usk	Poor	Good Status by 2027
Afon Crawnon - source to conf R Usk	Usk	Poor	Good Status by 2027
Afon Senni - conf unnamed trib to conf R	Usk	Poor	Good Status by 2027
R Clydach - source to conf R Usk	Usk	Poor	Good Status by 2027

APPENDIX 2: A note on the seasonal presence of adult shad (*alosa* spp.) and sea lamprey (*petromyzon marinus*) in the lower reaches of the River Usk. Guy mawle, Wye & Usk Foundation

These records are made at the Upper Llangybi Fishery (ULF) (ST 38 98) downstream of Usk town and about 3 km upstream of Newbridge-on-Usk, the head of tide on Mean High Water Springs.

The Upper Llangybi Fishery Company has owned the fishery since 2000. Anglers are required to record their catches of salmonids in a record book before leaving the fishery. Whilst there is no requirement to record other species, caught or seen, the book contains a section for comments where anglers often note wildlife of interest, including shad and lamprey species. Shad are often taken as a by-catch when salmon fishing while sea lamprey spawn in the fishery at several points and are most often seen on their redds. Also, the remains of lamprey and less frequently shad are sometimes found having been taken and partially eaten by otter. In addition to records in the catch book, other sightings have been noted from photographs taken at the fishery.

Year	Sea lamprey	Shad sp.
2000	21/6 to 25/6	12/5; 13/6; 14/6
2001	Foot & Mouth Disease	Foot & Mouth Disease
2002	21/6	None recorded
2003	9/5 to 18/6	11/5; 31/5
2004	1/5 to 17/5	2/6
2005	27/4 to 18/6	27/5; 29/5; 2/6; 4/6; 21/6
2006	None recorded	25/5; 28/5; 29/5; 1/6
2007	25/5	19/5; 23/5; 1/6; 2/6; 6/6; 9/6; 8/7; 10/7
2008	3/5 to 1/6	4/5; 14/5; 23/5; 1/6; 24/6
2009	None recorded	20/5; 22/5; 23/5; 15/6
2010	6/6	23/5
2011	24/4 to 11/6	18/5; 11/6; 27/6; 29/6
2012	None recorded	None recorded
2013	30/5 to 19/6	None recorded
Range	24/4 to 25/6	4/5 to 10/7

After the frequency of records of shad in the years 2005 to 2011, it is perhaps surprising that none have been recorded in the last two years.

On 4 June 2013, shad were seen spawning at dusk on the Hardwick beat (SO 298 119) of the Usk just downstream of Abergavenny.

On 30 April 2013, a dead river lamprey (23cms) was found at ULF with a redd just upstream.

APPENDIX 3: GENERIC RIVER WATER REACH TYPES ADAPTED FROM SNIFFER REPORT (2006)

Type A		Type B		Type C		Type D	
Clay and/or Chalk low altitude; low slope; eutrophic; silt-gravel bed; smooth flow; predominantly		Hard limestone and sandstone low-medium altitude, low-medium slope; mesotrophic; gravel-boulder (predominantly pebble-cobble), mostly smooth flow, small turbulent areas		Non-calcareous shales, hard limestone and sandstone, medium altitude, medium slope, oligo- meso-trophic; pebble, cobble, boulder bed, smooth flow with abundant riffles and rapids		Granites and other hard rocks; low and high altitudes; gentle and steep slopes; ultraoligo – oligotrophic; cobble, boulder, bedrock, pebble; smooth with turbulent areas – torrential	
Type A1	**Type A2**	**Type B1**	**Type B2**	**Type C1**	**Type C2**	**Type D1**	**Type D2**
Lowest gradients (0.8 +/- 0.4 m/km) and altitudes (36 +/- 25 m), predominantly clay	Slightly steeper (1.7 +/- 0.8 m/km), low altitude (55 +/- 38 m)	Gradient (4.1 +/- 9.9 m/km), altitude 93 +/- 69 m	Shallower than B1 (2.7 +/- 10.7 m/km); altitude 71 +/- 58 m	Gradient 5.4 +/- 6.5 m/km; altitude 101 +/- 84 m;	Steeper than C1 (7.3 +/- 10.8 m/km); altitude 130 +/- 90 m; non-calcareous shales; pebble- bedrock;	Medium gradient (11.3 +/- 15.6 m/km); low altitude (93 +/- 92 m)	High gradient (25.5 +/- 33 m/km); high altitude (178 +/- 131 m)
SE England and East Anglia & Cheshire plain	Chalk catchments; predominantly gravel beds base-rich;	Hard sandstone, calcareous shales; predominantly S. & SW England and SW Wales	Predominantly NW England, E Scotland	Hard limestone; more silt and sand than C2; mesotrophic	Oligo- mesotrophic	Oligotrophic, substrate finer than D2 (incl silt & sand); more slow flow areas than D2	Stream order 1 & 2; bed rock and boulder; ultra-oligo trophic torrential

APPENDIX 4: Shad observations made by members of the general public on behalf of the Wye and Usk Foundation

Date	Time	River	Location	Comments
20/05/2013	19.00	Wye	Boughrood	1 2lbs (safely returned)
24/05/2013	unknown	Wye	Ross-on-Wye	Aramstone, Wye above Ross - 2 x shad 24th May (females, I think) 24th May, taken o salmon tube fly
27/05/2013	05.30 - 11.30	Wye	"White House" (Farm), Hereford.	Number of fish unintentionally landed and safely released without physical contact: 1 4lb+ and 2@ 2-3lb Number of fish observed: A small shoal of approx. 20, never manage to get a count above 12, a tight group moving in and out of the slack water just downstrea of the left bank croy. Once found it was quite a simple task to avoid hooking any mor There were others at the tail of the same pool but I was unable to observe these b deduced, from the occasional and characteristic attempts to take a large salmon fly, th these fish were shad of quite a smaller size.
29/05/2013	unknown	Wye	Erwood	Pwll y Faedda, upper Wye at Erwood - 1 x shad (female, roe, I think) 29th May, taken o salmon spinner
30/05/2013	12.00	Wye	Builth Wells	landed-all returned safely
30/05/2013	18.00	Wye	Builth Wells	landed-all returned safely
30/05/2013	19.00	Wye	Builth Wells	landed-all returned safely
30/05/2013	unknown	Wye	Glangwy	HI 30th may caught 6 on the salmon fly at spread eagle Glasbury at Glangwye all ve fresh up to 4 lbs !
31/05/2013	10.30 - 12.00	Wye	Llyswen	I caught some shad on the River Wye on 31st May in Rock Pool and Bridge Pool. Numb Eight fish between 1.5lb and 3.5lb Caught on fly
01/06/2013	10:30	Wye	Wyesham	1 caught - 3lb. Others suspected observations.
02/06/2013	unknown	Usk	Usk Town Bridge	Spotted a few shoals of shad below the bridge at the town of Usk on the river Usk.
02/06/2013	10.00-11.30	Wye	Wyesham	Saw a number and caught and released (barbless hook) while fishing for salmon 2 Shad about 2lbs each.
05/06/2013	14.00	Wye	Llyswen	Just a few words to report a shad that I caught on the 5th June at 2pm on the Rectory be at Llanswen. A nice bright fish of 2lb plus.
07/06/2013	unknown	Wye	Builth Wells	Saw dozens of shad on Friday 7th June at the junction of the rivers Irfon and Wye at Buil Wells & caught 10 between us which were returned safely to the river, all were about pounds in weight, unfortunately I'm not sure which species.
13/06/2013	14.45	Usk	Monkswood	I caught a twaite shad while spinning for salmon (silver & black flying C) on the Low Monkswood beat of the river Usk on Thursday 13th June 2013 at 2.45 pm. This is my fi shad of 2013 and in my experience very late this year, in previous years I usually sta catching shad while trout fishing the beat using a sinking line and a gold ribbed hares e but the shad usually appear towards the end of the second week in May and stay arou until the last few days of the month . I found 2008 a prolific year for shad catches. The fi was approximately 2lbs weight and in truly beautiful condition, it was carefully unhook and returned safely back into the river.
23/06/2013	unknown	Wye	Letton on Wye	Caught one 23 June at letton on the wye...... Took a Toby intended for salmon in t evening.... Weighed about a pound and a half... Returned safely.

unknown	12.00	Wye	Hay bridge	saw a shad under hay bridge, about 2lbs, yesterday, midday ... just the one
unknown	unknown	Wye	Lydbrook	To let you know hardly any twaite shad seen at Lydbrook so far this year as last year. th location 10 years ago boiled with spawning shad. Largest shad last year about 6lbs a previous years we have had good sized allis shad most years in very small numbe maybe 2 0r 3 up to around 7lbs.
unknown	unknown	Wye	Boughrood	3 shad landed over the weekend. Biggest 2ld in the Langoed pool the others on the Recto beat near Boughrood.

APPENDIX 5: Favourable condition table (generic attributes) for twaite shad *(alosa fallax)* and allis shad *(alosa alosa)* as described by the Joint Nature Conservation Committee

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Attribute	Target	Method of Assessment	Comments
Population: Adult run size	Adult run size should comply with an agreed target for each river. No drop in the annual run size greater than would be expected from variations in natural mortality alone.	Fish counters	The use of hydroacoustic counters for estimating run size is currently being investigated by Environment Agency.
Population: Juvenile densities	Juvenile densities should exceed a specified minimum target at least two years in six.	Seine netting in lower rivers and estuaries	Methodology has been developed by the LIFE project. Further testing is required to establ its viability.
Population: Spawning distribution	No decline in spawning distribution.	Kick sampling during May and June	Where there are man-made barriers to migration, the site should automatically be classed unfavourable. Historic records and GIS data should be used to determine the likely extent spawning on affected catchments and set monitoring sites accordingly.
Water quality	Biological GQA Class: b/B	England, Wales & N.I only (EA & EP standard monitoring protocol)	Generally, water quality should not be injurious to any life stage. A wide range of water qua parameters can affect the status of interest features, but standard biological monitor techniques provide a reasonably integrated picture in relation to many parameters. classified reaches within the site that contain, or should contain, twaite or allis shad un conditions of high environmental quality should comply with the targets given.
	Chemical GQA Class: B	England, Wales & N.I. only (EA & EP standard monitoring protocol)	The Chemical GQA classifications set standards for England & Wales and for Northern Irela for dissolved oxygen (DO), biochemical oxygen demand (BOD) and ammonia. They theref cover a number of water quality parameters that can cause problems within river systems. classified reaches within the site that should contain twaite or allis shad under conditions high environmental quality should comply with the targets given.
	Water Quality Class: A2	Scotland only (SEPA standard monitoring protocol)	The system in Scotland differs from that used elsewhere in the UK. A scale of five Wa Quality Classes are used (A1, A2, B, C, D) for assessing water chemistry, biology, nutrien aesthetic condition, and toxic substances. The overall classification of a water is given by lowest class derived from these values. All classified reaches within the site that contain sh should comply with the target given.

Attribute	Target	Method of Assessment	Comments
	Suspended solids: Mean value <25mg L^{-1} between April and September	Environmental agencies' monitoring programmes	Elevated levels of suspended solids can clog the respiratory structures of fish. The target 25mg L^{-1} is based on the EC Freshwater Fish Directive.
Flow	Flow regime should be characteristic of the river.	Gauging stations	River flow affects a range of habitat factors of critical importance to shad, including curr velocity, water depth, wetted area, substrate quality, dissolved oxygen levels and wa temperature. The maintenance of both flushing flows and base flows, based on natu hydrological processes, is vital. Detailed investigations of habitat-flow relationships m indicate that a more or less stringent threshold may be appropriate for a specified rea however, a precautionary approach would need to be taken to the use of less stringent valu As a guideline, at least 90% of the naturalised daily mean flow should remain in the ri throughout the year. Naturalised flow is defined as the flow in the absence of abstractions and discharges. T availability and reliability of data is patchy - long-term gauged data can be used until adequ naturalised data become available, although the impact of abstractions on historical fl records should be considered. Shad are particularly sensitive to flow. The ideal regime is one of relatively high flows in Mar May, to allow maximum penetration of adults upstream, followed by rather low flows in Ju September, which ensures that the juveniles are not washed prematurely into saline wat and grow rapidly under warmer conditions. The release of freshets to encourage salmo migration should therefore be discouraged on shad rivers.
River morphology	River habitat SSSI features should be in favourable condition. Holding areas in particular should be maintained. Note: In a few cases the SAC is not underpinned by an SSSI. Where this is the case the target is to maintain the characteristic physical features of the river channel, banks and riparian zone.	Assess river morphology using RHS and fluvial audit Fluvial audit should indicate that sediment transport processes in the catchment and channel should be appropriate for the maintenance of holding areas and spawning sites.	The characteristic channel morphology provides the diversity of water depths, current velocit and substrate types necessary to fulfil the spawning, juvenile and migratory requirements the species. The close proximity of different habitats facilitates movement to new prefer habitats with age. Operations that widen, deepen and/or straighten the channel redu variations in habitat. New operations that would have this impact are not acceptable within SAC, whilst restoration may be needed in some reaches. <u>Holding areas</u> are defined as pools of at least 200 cm depth, with cover from features such undercut banks, vegetation, submerged objects and surface turbulence. Spawning habitat is defined as stable, clean gravel/pebble-dominated (approximately 70 substrate without an armoured layer and with <10% fines in the top 30 cm. Water depth dur the spawning and incubation periods should be 50-75 cm.

APPENDIX 6: Aspects of environmental disturbance to be noted as an accompaniment to assessing condition: twaite shad and allis shad

Objective	Specified assessment method (if appropriate)	Comment
No artificial barriers significantly impairing adults from reaching existing and historical spawning grounds.	Video / fish counter monitoring at obstacles identified as problematic.	Artificial barriers are probably the single most important factor in the decline of shad in Euro Impassable obstacles between suitable spawning areas and the sea can eliminate breec populations of shad. Both species (but particularly allis shad) can make migrations of hundreds kilometres from the estuary to spawning grounds in the absence of artificial barriers. Exist passes are often not effective for shad, and any new provisions need to take their requirements i account.
No stocking of shad unless agreed to be in the best interests of the population, or as part of a restoration project. No stocking of other species at excessive densities in spawning or nursery areas.	No specific monitoring required. Impact assessments of stocking consents on a catchment scale may be required to determine an acceptable level.	Available evidence suggests that shad have a high degree of fidelity to natal spawning grour There are genetic differences between populations that may have adaptive significance. The nat conservation focus is on securing appropriate habitat for the species and the managemen losses from fishing. Artificially enhanced densities of other fish may introduce unacceptable competition or preda pressure.
All exploitation should be undertaken sustainably without compromising any components of the stock. No deliberate netting for shad until sustainable takes can be determined. Minimisation of by-catch		Anglers occasionally fish for shad, and they are sometimes taken in quite large numbers. Furt research is necessary to define sustainable levels of angling. If this shows there is cause concern, a temporary cessation of fishing activity in the vicinity of known spawning grounds dur the spawning period should be considered, particularly where shad are known to be tal regularly. Commercial fishermen also take shad as a by-catch, with whitebait and shrimp fishing beinc particular concern. Changes in fishing methods need to be promoted to minimize captures, wh both anglers and trawler men should be encouraged to return alive any individuals caught. Controls on exploitation should include migratory passage to the SAC within territorial wat including estuarine and coastal net fisheries, as well as exploitation within the SAC from fisheries.

APPENDIX 7: Favourable condition table (generic attributes) for Atlantic salmon (*Salmo Salar*) as described by the Joint Nature Conservation Committee

Attribute	Target	Method of Assessment	Comments
Adult run	Total run size at least matching an agreed reference level, including a seasonal pattern of migration characteristic of the river and maintenance of the multi-sea-winter component.	Fish counters where available and Rod catch data	Comprehensive guidance on determining favourable condition in relation to adult salmon population parameters can be obtained in *Cowx, 2002.
Juvenile population densities	These should not differ significantly from those expected for the river type/reach under conditions of high physical and chemical quality.	Electrofishing	Comprehensive guidance on determining favourable condition in relation to adult salmon population parameters can be obtained in *Cowx, 2002.
Water quality: These targets relate to nursery and spawning grounds. Water quality should also be sufficient to permit the passage of migratory fish at all times.	Biological GQA Class: a/A	England, Wales and N.I. only (EA and EP standard monitoring protocol)	Generally, water quality should not be injurious to any life stage. A wide range of water quality parameters can affect the status of interest features, but standard biological monitoring techniques provide a reasonably integrated picture in relation to many parameters. All classified reaches within the site that contain, or should contain, Atlantic salmon under conditions of high environmental quality should comply with the targets given.

	Chemical GQA Class: A	England, Wales and N.I. only (EA and EP standard monitoring protocol)	The Chemical GQA classifications set standards for England & Wales and for Northern Ireland for dissolved oxygen (DO), biochemical oxygen demand (BOD) and ammonia. They therefore cover a number of water quality parameters that can cause problems within river systems. All classified reaches within the site that should contain salmon under conditions of high environmental quality should comply with the targets given.
	Suspended solids: Annual mean <10 mg L -1 (nursery grounds). Annual mean <25 mg L –1 (migratory passage).	Standard monitoring method	Elevated levels of suspended solids can clog the respiratory structures of salmon. The target of 25 mg L -1 is based on the EC Freshwater Fish Directive; a more precautionary figure has been used for salmon to help protect juvenile stages.
	Soluble Reactive Phosphorus: Targets should be set in relation to river/reach type(s) and should be near background levels (see guidance for Generic River SSSIs/ ASSIs).	Chemical analysis (EA/ SEPA/ EHS data)	Elevated phosphorus levels can result in enhanced plant growth leading to large diurnal sags in dissolved oxygen levels.
Flow	As a guideline, flow should be at least 90% and not more than 110% of the naturalised daily flow throughout the year. Existing flow criteria for salmon should also be complied with.	Gauging stations	River flow affects a range of habitat factors of critical importance to designated interest features, including current velocity, water depth, wetted area, substrate quality, dissolved oxygen levels and water temperature. The maintenance of both flushing flows and baseflows, based on natural hydrological processes, is vital. Detailed investigations of habitat-flow relationships may indicate that a more or less stringent threshold may be appropriate for a specified reach; however, a precautionary approach would need to be taken to the use of less stringent values. As a guideline, at least 90% of the naturalised daily mean flow should remain in the river throughout the year. Naturalised flow is defined as the flow in the absence of abstractions and discharges. The availability and reliability of data is patchy – long-term gauged data can be used until adequate naturalised data become available, although the impact of abstractions on historical flow records should be considered. Headwater sections are particularly vulnerable to abstraction, and downstream migration of perennial heads, other than in drought conditions, is a sign of unfavourable condition.
River morphology	No artificial barriers significantly preventing adults from reaching existing and historical spawning grounds, and smolts from reaching the sea.	Baseline survey, then check every 6 years.	In all river types, artificial barriers should be made passable. Natural barriers to potentially suitable spawning areas should not be circumvented** Appropriate steps should be taken to ensure that migrating smolts are not entrained in off-takes from the river (such as in fish-farm intakes).

	Maintain the characteristic physical features of the river channel, banks and riparian zone. Site specific targets should be set based on advice in comments column.	Assess habitat suitability using HABSCORE.	The characteristic channel morphology provides the diversity of water depths, current velocities and substrate types necessary to fulfil the spawning, juvenile and migratory requirements of Atlantic salmon. The close proximity of different habitats facilitates movement to new preferred habitats with age. Operations that widen, deepen and/or straighten the channel reduce variations in habitat. New operations that would have this impact are not acceptable within an SAC, whilst restoration may be needed in some reaches. Spawning habitat: defined as stable coarse substrate without an armoured layer, in the pebble to cobble size range (16-256 mm) but with the majority being <150 mm. Water depth during the spawning and incubation periods should be 15-75 cm. Coarse woody debris should not be removed from rivers as it plays a significant role in the formation of new gravel beds, except where infrastructure, human life or property is under threat. Fry habitat: indicated by water of <20 cm deep and a gravel/pebble/cobble substrate. Parr habitat is indicated by water 20-40 cm deep and similar substrate. Holding areas: defined as pools of at least 1.5 m depth, with cover from features such as undercut banks, vegetation, submerged objects and surface turbulence. Areas of submerged and marginal plants: juvenile salmon in chalk rivers use submerged and marginal vegetation as cover. Cutting operations should aim to leave at least 50% of the vegetation. Bankside tree cover: overhanging trees provide valuable shade and food sources, whilst tree root systems provide important cover and flow refuge for juveniles.
River substrate	Suitable spawning sites should be dominated by clean gravels.	Visual observation.	Elevated levels of fines (particles <0.83 mm) can interfere with egg and fry survival through suffocation of eggs and loss of interstitial refugia for fry. Most river SSSIs/ ASSIs and SACs do not extend to the entire catchment. Some life-cycle stages are potentially susceptible to damage from siltation, the source of which may lie elsewhere in the catchment outside the site boundary. Sources of fines include run-off from arable land, land (especially banks) trampled by livestock, sewage and industrial discharges. Where there is a perceived risk of damage occurring, or where salmon are already believed to be in decline, a fluvial audit of the catchment is recommended. This is a relatively new approach developed by fluvial geomorphologists in the UK; further guidance should be sought from the appropriate freshwater specialists in the country conservation agencies.
Negative indicators	No introduction, or stocking, of other species, or sub-species, at excessively high densities in salmon spawning and nursery areas.	Liaison with fisheries officers. Impact assessments of stocking consents on a catchment scale may be required to determine an acceptable level.	The presence of artificially high densities of other fish creates unacceptably high levels of predatory and competitive pressure on juvenile salmon.

APPENDIX 8: Aspects of environmental disturbance to be noted as an accompaniment to assessing condition: Atlantic salmon

Objective	Specified assessment method (if appropriate)	Comment
The management objectives of SAC salmon populations are to attain naturally self-sustaining populations. Stocking should not be routinely used as a management measure.	Liaison with fisheries officers and, in England and Wales, by input into Salmon Action Plans as and when these are reviewed.	The nature conservation aim is to provide conditions in the river that support a healthy natural population, achieved through habitat protection/restoration and the contro exploitation as necessary. Stocking represents a loss of naturalness and, if succes obscures the underlying causes of poor performance (potentially allowing these risk perpetuate). It carries various ecological risks, including the loss of natural spawning broodstock, competition between stocked and naturally produced individuals, dise introduction and genetic alterations to the population.
Effective screening on all fish farm intakes and discharges.		Escapes from fish farms are a form of uncontrolled introduction and should be prevented.
All exploitation should be undertaken sustainably without compromising any components of the stock.	Liaison and agreement with fisheries officers	Controls on exploitation should include migratory passage to an SAC within territorial wa including estuarine and coastal net fisheries, as well as exploitation within an SAC from fisheries