Banking on the River: The Anglers' Riverfly Monitoring

Service type	Final goods/service	Description/examples

Initiative and an Ecosystem Approach to Fisheries

Lucy Brookfield

University of Sheffield Animal and Plant Sciences

Summary

An ecosystem approach is widely accepted as a valuable way in which to integrate social, environmental and economic perspectives into the management of fisheries. The approach is not currently specified in UK freshwater fishery policy but its' main aims are largely supported by the European Water Framework Directive (WFD), which requires extensive monitoring of water bodies in order to assess their condition. Citizen science monitoring schemes greatly reduce the cost and time taken to carry out monitoring and allow collection of data across a wide geographical range. One such scheme in inland fisheries is the Anglers' Riverfly Monitoring Initiative, which relies on anglers to collect information about the abundance and distribution of common riverside flies. However, the extent to which the information gathered can support an ecosystem approach and its' ability to detect changes in ecosystem status and provisioning has not been evaluated. The relative importance of 'Riverflies' in river ecosystems is discussed and their ability to inform fisheries management is assessed.

Introduction

Conservation of the natural environment has traditionally focused on preserving biodiversity for aesthetic and intellectual value due to moral responsibility (Ingram *et al.,* 2012). However, there is an increasing realisation that functioning ecosystems are also an essential requirement for human life (Millennium Ecosystem Assessment, 2005). The earth's network of ecosystems acts as a life support system, providing renewable resources and regulating services which the development of human society is dependent upon (European Environment Information and Observation Network, 2012). Freshwater ecosystems are an essential part of this network, supporting a range of provisioning, regulating and cultural services (Table 1.).

Table 1. Ecosystem goods and services provided by freshwater lakes and rivers (Adapted from UK National Ecosystem Assessment, 2011)

Provisioning	Fish	Crayfish, salmon and trout fisheries can be commercially significant.
	Water	Used for public supply, irrigating crops, power station cooling , industrial processing and fish farming
	Biomass: fibre and energy materials.	Peat from lakes can be used as composts for horticulture, reeds used for basket making.
	Health products	Medicinal plants and medical leeches
Regulating	Flood regulation	Store water which can prevent flooding
	Water quality regulation	Dilute, store and detoxify waste and pollutants
	Fire regulation	Form natural fire breaks
	Human health regulation	Can increase well being and quality of life if visually attractive and supports physical recreation. Can also be a source of biocontrol agents.
Cultural	Science and education	Source of information about past environments and may contain historical artefacts. Provides an outdoor laboratory.
	Religion	Sites of historical baptism and religious festivals.
	Tourism and Recreation	Recreational fisheries, swimming and boating.
	Sense of place and history	May have an important literary and cultural identity. Historical battlefields and settlements often occur around water, giving important folklore connections.
Supporting	Biodiversity	Supports functioning ecosystems. Fish are commercially important, iconic species may be important for tourism and recreation.

Within ecosystems, complex feedbacks between different goods and services may result in tradeoffs in provisioning between services and conflicts between stakeholders. For example, freshwater fisheries are predominantly managed for their ability to provide recreational value to anglers, but the ecosystems in which they are found provide a range of other services (Table 1). Whilst provisioning of drinking water quality and biodiversity maintenance may be conserved in line with fishery aims, other processes such as hydropower generation may be detrimental to fisheries, with fisheries often given low priority over other uses (Beard *et al.,* 2011; Suuronen and Bartley, 2014). Failure to account for the value of fisheries has resulted in continuing overexploitation and degradation as well as severe biodiversity loss (Millenium Ecosystem Assessment, 2005). Due to pollution and overfishing, UK eel stocks have declined by 90% in the last 30 years and salmon stocks in England and Wales remain low (DEFRA, 2013).

The UK National Ecosystem Assessment (2011) highlighted that in order to maintain healthy and resilient ecosystems under the demands of a growing human population, an ecosystem approach to the management of the natural environment is required (Figure 1.). Incorporating ecological, economic and institutional perspectives (Goldman *et al.,* 2008), an ecosystem approach provides a framework for looking at ecosystems as a whole and for valuing the services they provide (European Environment Information and Observation Network, 2012). There are numerous guidelines for managing fisheries in an ecosystem context (Nguyen, 2009) but despite this, the approach is not well defined (Nguyen, 2009; Beard *et al.,* 2011; Daily *et al.,*2009; Suuronen and Bartley, 2014), with many management decisions made based on assumptions which are not yet supported by evidence (Carpenter *et al.,* 2009; Seppelt *et al.,* 2011).

Figure 1. Key principles of the ecosystem approach (Ecosystems Knowledge Network, 2014)

One way that the knowledge base for management decisions could be improved is through better assessment methods of current ecosystem state (Daily *et al*. 2009). A monitoring programme which reflects the ecosystem services and values fisheries provide using appropriate indicators is a basic element of establishing an ecosystem approach to inland fisheries (Suuronen and Bartley, 2014; Goldman *et al.,* 2008). There has been widespread recognition of the need for indicators whose parameters, such as density, presence or absence, or infant survivorship, can be directly linked to ecosystem conditions (Hilty and Merenlender, 2000; Carpenter *et al.,* 2009; Parliamentary Office of Science and Technology, 2007) However, systematic monitoring of ecosystem services in order to detect changes in their supply and quality has not been discussed in fisheries (Daily, 2000).

The idea that people who benefit from particular ecosystem services should play an active role in their management is central to the ecosystem approach (Hartje and Klaphake, 2006)(Figure 1). Therefore, citizen science schemes, which involve non-scientist 'citizens' in large scale data collection, have been identified as a valuable way to incorporate an ecosystems approach into monitoring (Roy *et al.,* 2012,; Ecosystems Knowledge Network, 2014). One such scheme in freshwater fisheries is the Anglers Riverfly Monitoring Initiative, where anglers are encouraged to collect information about the abundance of common flies found in river habitats. These 'Riverflies' have commonly been acknowledged as being important in fish diet and are often used as an indicator of water quality. However, their ability to indicate changes in the quality and quantity of ecosystem services has not been discussed.

This paper begins by summarising the importance of fisheries and identifies essential components in maintaining them (Figure 2). In order to protect these values, appropriate monitoring is needed to detect early changes in service provisioning (Environment Agency, 2004). Current monitoring methods under the Water Framework Directive (WFD) are described and evaluated for their ability to do this. The ideal properties of an indicator are discussed before the paper turns to the effectiveness of using Riverfly data to support an ecosystem approach to monitoring within the WFD. The relative importance of Riverflies in ecosystem service provisioning is discussed and the feasibility of translating structural measures of Riverfly abundance into a prediction of ecosystem service provisioning is assessed.

Table 2. The values of freshwater fisheries and factors affecting provisioning. It is important to understand a resource before making management decisions (Institute of Fisheries Management, 2012), particularly in fisheries where identification of key values and components affecting service provisioning has been acknowledged as lacking (Kremen,2005, Beard *et al.*,2011).

Type of Ecosystem service	Ecosystem Service	Value (Brown *et al.* 2012). Indicates social value Indicates environmental value Indicates economic value	Ecosystem service providers	Factors affecting ecosystem providers: Indicates Requirements, Indicates threats Indicates Management practices
Cultural	Recreation	Angling areas support other forms of outdoor recreation, including bird watching and walking. Engagement in conservation of freshwater systems by anglers may include removal of none native species, rubbish removal and planting of vegetation. Physical Activity helps improve fitness. This is particularly important for older and less able people. Freshwater fisheries provide £1bn of annual UK household income through sales of rod licences and angling tourism, which is particularly important in rural communities.	**Fish** **Angling participation** **Fishery management** **Ecosystem structure and function** **Aesthetic species**	The fish carrying capacity of freshwater habitats varies depending on **habitat quality**, which may be naturally low (Institute of fisheries management, 2012). Habitat preference and food requirements vary depending on species; grayling favour cool, clean water streams in fast flowing water, whilst tench needs very little oxygen and is often found in stagnant or polluted water. (Tomsett, 2005). Water temperature in the habitat also has significant effects on fish productivity, as well as depth and vegetation. **Fishing participation–** overfishing can result in reduced stocks. Reduced participation can reduce social and economic values and is dependent on many other factors including cost and disabled access. **Land use** in the river catchment area can influence production, with acidification, pollution and siltation all having consequences for water quality (Institute of Fisheries Management, 2012) Salmonids are very sensitive to water pollution (CEFAS,2014; Giles *et al.*, 2004) and may be unable to reproduce in polluted areas (Linde *et al.*, 1998).
Cultural	Aesthetics	Regeneration of neglected areas for angling can reduce prevalence of anti soicial behaviour and fly tipping. Access to nature improves mental well being and reduces stress. which was the primary motivation for participation in angling amongst the 219 anglers who completed the Young People's Angling Survey.		**Climate change** is likely to play a role in fish production as water temperature and associated factors (eg. Lower dissolved O_2,pathogen interactions, reduced stream flow) have a large effect on the growth and survival of all species (EA, 2008). **Invasive species** can have extensively damaging effects on native biodiversity and ecosystem functioning through direct predation, competition, introduction of parasites and disease, and reduced fecundity due to interbreeding (Hickley and Chare, 2004).
Cultural	Education	73% of anglers are members of angling clubs which can be a gateway for education work. Anglers have a good understanding of aquatic systems and notice changes which could be indicative of ecosystem degradation.		**Stocking** can be useful to reintroduce fish into areas with improved water quality but can cause outbreeding depression in fish populations which are locally adapted, and may introduce parasites or disease (Hickley and Chare, 2004). Many anglers also have a preference for wild caught fish. **Physical barriers to fish migration** such as dams or hydro-electric power generation may disrupt migratory fish (Beard *et al.*, 2011)

The Water Framework Directive

Currently, the most comprehensive monitoring policy affecting UK fisheries, the European Water Framework Directive (WFD), does not specify an ecosystem based approach, although its objectives are broadly in line with one (Hartje and Klaphake, 2006; Vlachopoulou *et al.,* 2014). Implemented in the UK in 2006 in order to achieve sustainable management of water resources, the WFD describes an integrated approach, incorporating environmental, economic and social factors (Vlachopoulou *et al.,* 2014).

Monitoring is an integral part of the directive (Moss, 2008; Vlachopoulou *et al.,* 2014; Collins *et al.,* 2012); under its' requirements there are 1418 surveillance monitoring sites and 11,485 operational monitoring sites in UK lakes and rivers (European Commission, 2009)(Figure 2.). Annexe 5 of the Directive puts a strong emphasis on assessing the ecological quality of these sites, taking into account that the water bodies should also be able to support healthy ecosystems as well as having good water quality and physical habitat (European Commission, 2002).

Chemical, physico-chemical (e.g. thermal and oxygen conditions) and hydromorphological (e.g. depth variation) quality measurements are supported by measurements of phytoplankton, macroalgae, macro-invertebrates and fish composition, structure and abundance. The Directive is novel in it's consideration of a broad range of ecological components (Collins *et al.*, 2012). However, it largely focuses on static, structural measures of taxonomic composition rather than functional indicators linked to ecosystem process (UK National Ecosystem Assessment, 2011; Vlachopoulou *et al.,* 2014), which could reduce their ability to determine changes to ecosystem service provision. Also, the indicators used may not account for full range of ecosystem services (Hartje and Klaphake, 2006).

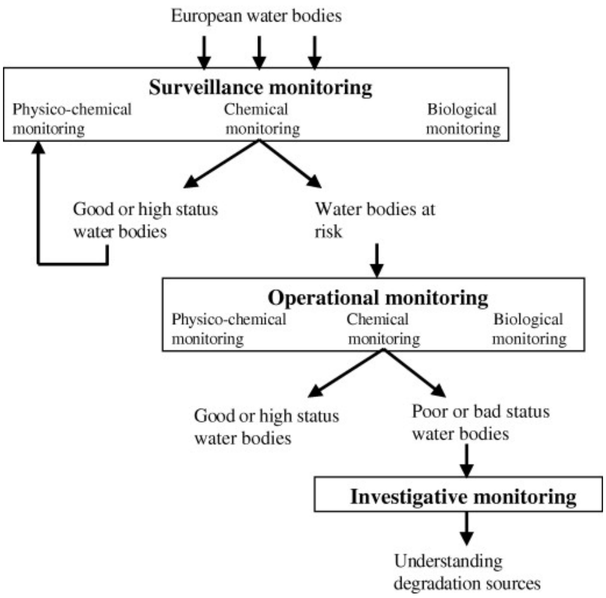

Figure 2. Different types of monitoring under the Directive (Sanchez and Porcher, 2009) Surveillance monitoring concerns all water bodies, whilst operational monitoring focuses on at risk waterbodies and investigative on those which have already been identified as poor or bad status.

Moss (2008) also argued that the ecological quality ratios (EQR) used by the Directive are flawed in their perception that the amount of fish present in a habitat should be proportional to environmental quality; it asserts that given x fish in a high quality water body, there should be 0.9x in a good and 0.5x in a moderate etc. (Moss, 2008). Whilst relationships between particular taxa and environmental conditions are well documented (eg. Rosenberg and Resh, 1993), these associations are often determined by multiple drivers and cannot be simply described using secondary characteristics to form a ratio. However, further quantification of the relative role of species and their drivers in service provisioning could help to establish reliable ratios.

Citizen Science and the Angler's Riverfly Monitoring Initiative

Citizen Science programmes provide large, low cost data sets across a wide geographical range whilst simultaneously providing pleasure and education for volunteers (Gommerman and Monroe, 2012; DeVictor *et al.,* 2010). The Angler's Riverfly Monitoring Initiative was launched in 2007 in response to long term declines in populations of common flies found in river habitats (Bradley,2005, The Riverfly Partnership, 2014a). Anglers attend a one-day Riverfly Partnership workshop, which instructs them on how to identify common families in 3 orders: the up-wing flies or mayflies (Ephemeroptera), the caddisflies or sedges (Trichoptera) and the stoneflies (Plecoptera). The aims of the project are to provide further information to stakeholders about the biological quality of water and identify severe drops in water quality (The Riverfly Partnership, 2014a) but its ability to do this has not been evaluated.

Indicators of Ecosystem State and Service Provisioning

Benthic macroinvertebrates are widely recognised as a useful indicator of organic pollution in freshwater ecosystems as well as responding rapidly to anthropogenic and natural stress (Rosenberg and Resh, 1993; Chinnery, 1993; Van Hoey, 2010). Invertebrate monitoring under the WFD is the aspect of monitoring which is carried out the most fully, with 16 out of 20 member states overseeing invertebrate monitoring at a greater number of sites than other biological elements (EC, 2009). This highlights their importance as a cost effective and accessible indicator. However, the extent of such indicators effect on ecosystem -level processes is understudied (Noss, 1990)(table 3).

Riverflies in fishery ecosystems

There are 278 species of 'Riverflies'- members of the order Trichoptera, Ephemeroptera and Plecoptera- found in the British Isles, which play an important role in the diet of most freshwater fish and are sensitive to pollution (Chinnery, 1993). The majority of their lives are spent at the bottom of rivers and still waters as larvae before they emerge as adults in spring or summer (Chinnery, 1993). Riverflies are influenced by both top down and bottom up factors

(Wallace and Webster, 1996) and their specific tolerances to environmental conditions such as water quality, habitat type, water level and flow rate means that they have potential be linked to ecosystem service provisioning. However, whilst their functional role in ecosystems has been discussed (eg. Wallace and Webster, 1996) and is briefly summarised here, their ability to indicate changes in quality or quantity of service provisioning has not been previously evaluated. In this section, the importance of Riverflies and the monitoring project to the ecosystem providers detailed in Figure 2 is assessed, followed by an evaluation of their effectiveness as an indicator of each of the factors which affect ecosystem service provision.

Role of Riverflies in providing for the providers

Fish diet

Most river and still water fisheries rely on hatcheries of upwinged mayflies, stoneflies and caddisflies for food (Giles *et al.,* 2004) although quantifying the importance of these macroinvertebrates to fishery production is challenging (Wallace and Webster 1996). In some environments, Riverflies may be the primary food source of some fish; for example stoneflies tend to live in otherwise unproductive upland habitats and therefore may be a vital food source for some trout (Giles *et al.,* 2004), although terrestrial invertebrates such as craneflies, grasshoppers and heather beetles are also commonly consumed (Clarke, 1975) Diet often varies with season and habitat; even within lakes Arctic Char have been known to develop different morphological mouth types to specialise on either plankton or macroinvertebrates and small fish (Walker *et al.,* 1988). However, most freshwater fish are not particularly specific in what they eat (Bennet and Gilchrist, 2010) and in most habitats Riverflies are not the only food source available; chironomids are widespread and larger fish consume crayfish, shrimps, snails and other aquatic invertebrates.

Ecoystem Function

Macroinvertebrates play many important roles in nutrient cycles, primary productivity, decomposition and translocation of materials, which are processes critical to maintaining freshwater ecosystem function (Webster and Wallace, 1996). However, due to the large number of interacting factors, determining their relative importance is a challenge, with the importance of some species only becoming clear after disturbance (Wallace and Grutz, 1986). The effects of alterations to macroinvertebrate structure on service provision can often be masked due to compensation (Mckie and Malmqvist, 2009; Boulton *et al.,* 2008) so the ability to draw conclusions about these processes from Riverfly abundance is limited.

Table 3. Characteristics of 'ideal' indicator species (Noss, 1990; Pearson, 1994; Hilty and Merenlender 2000) and the ability of riverflies to fulfil these.

Property	Do Riverflies fulfil this trait for freshwater ecosystems?	Notes
Well understood Natural History	✓	Well studied since the 1900's although there is lots` still to know (Wallace, 2004)
Widely distributed	✓	Most species are widely distributed, although each has its favourite habitat (eg. Chinnery 1993).
Easy and cost effective to measure	✓	Citizen science projects can reduce the costs of monitoring by up to 75% (Kaartinen *et al.,*2013). Identification of families is easy with training (Wallace, 2004).
Numerical abundance	✓	Females of most species lay several hundred eggs (Chinnery, 1993). This makes sampling easier and allows for conclusions based on quantitative distribution patterns (Johnson *et al..,* 1993).
Based on quantitative tests of taxon appropriateness.	✓	Rosenberg and Resh (1993) provide a comprehensive analysis of the use of benthic macroinvertebrates in biomonitoring.
Clear taxonomy	✓	Taxonomy well understood (eg. Chinnery, 1993)
Economically important	✓	In the UK, freshwater fisheries have a capital value of £3bn (Environment Agency, 2004).
Limited mobility, non-migratory	✓	Most larvae live under rocks and in the surrounding sediment (Chinnery 1993). This means they are continuously exposed to the water in their area.
Linked to ecosystem condition	?	Only 3% of invertebrate indicator taxa referred to studies correlating changes in indicator status with ecosystem level changes (Hilty and Merenlender, 2000). Often pressure is put on the indicator taxa rather than what it's actually indicating (Pearson,1994)
Linked to ecosystem service provision	?	Indicators to monitor changes in the supply of ecosystem services have not been widely discussed (Daily, 2000)
Early response to stressors	?	Rosenberg and Resh (1993) analyse responses to many common pollutants but other responses to other stressors is lacking. 'Early' is relative- in order to determine the earliest taxa responses comparisons between indicators are needed (Mandelik *et al.* 2012).
Tolerance levels known	?	Use as an indicator may rely on 'generally accepted' organism sensitivities (Cairns and Pratt, 1993). Rosenberg and Resh (1993) provide some analysis of certain chemicals, but there is little research on the effect of pharmaceuticals on invertebrates (Bennett and Gilchrist, 2010). There are also growing concerns about combinations of factors which have no effects alone but can be damaging when in concert (CEFAS, 2014).

Aesthetic appeal

Riverflies may play a small role in contributing to human enjoyment of ecosystems and the feeling of being close to nature for which angling is appreciated (Brown *et al.,* 2012). However, Riverflies are not well known outside of entomology and angling (Chinnery, 1993) so are unlikely to play a large part in well being. However, their inclusion in the Anglers monitoring initiative may in itself provide an ecosystem service; citizen science encourages appreciation of nature and tends to spread knowledge and awareness, which are cultural services (Franco, 2013)(Table 2).

Role of Riverflies as indicators of change in the factors which affect service provision

Pollution

Members of the ephemeroptera, trichoptera and plecoptera are widely regarded as sensitive to pollution and have been extensively used to monitor freshwater quality (Rosenberg and Resh, 1993, Chinnery 1993). Kolkwitz and Marrson developed a classification system of saprobity- the degree of pollution in rivers- in which Plecoptera and Trichoptera were labelled clean water organisms (Rosen berg and Resh; 1993, Cairns and Pratt, 1993). Their use in the Riverfly project has already lead to identification of 4 serious pollution events within the first 10 months of the project, with two prosecutions made (Bennett and Gilchrist, 2010).

However, there are limitations to their use as indicators of pollution. Riverfly larvae can be carried into areas of pollution, or away from areas of high water quality due to flow conditions (Rosenberg and Resh, 1993), which can lead to false conclusions about ecosystem condition. Their low mobility may limit their ability to colonise areas that were once polluted, despite improved water quality. For example, Riverflies have been absent on from the River Wandle in London for 200 years. Improvements in water quality have seen the return of the brown trout, but mayflies have remained absent. However, introductions by the Riverfly monitoring scheme may help to resolve this issue (Bennet, 2014).

Riverflies may not respond to all types of stressor; for example Hawkes (1979) reported only slight effects of one herbicide on stream invertebrates despite indications of pollution by angiosperms downstream of the effluent. Each order contains a wide range of species with a range of sensitivities to pollution (Giles *et al.,* 2004) some of which will breed in every type of water except the most polluted (Wallace, 2004). Stoneflies can tolerate severe heavy metal pollution (Pryce, 2005) despite damaging effects on fish (Linde *et al*., 1998).

The importance of Riverflies as an indicator may vary depending on the fishery. For example, tench can survive quite happily in polluted, stagnant waters due to their ability to cope in low oxygen conditions. Fertiliser runoff has even been recorded to increase tench biomass through increased quality of aquatic vegetation and invertebrates on which it feeds (Tomsett, 2005), resulting in better quality ecosystem service provision since most anglers value catching large fish.

Climate Change

Macroinvertebrate abundance and diversity dropped with increasing water temperature in rivers in China (Li *et al.,* 2012) which means they could be a good predictor of climate changes. Although determining responses to such large scale drivers is challenging (Van Hoey *et al.,* 2010; Moss, 2008), nationwide ecological experiments can help to identify climate impacts on ecosystem process at relevant spatial scales (Kaartinen *et al.,* 2013). However, information about Riverfly tolerance to climate change would be needed; evidence shows that Riverfly range and phenology is changing due to climate change which could disrupt their indicating abilities (Moss, 2008; Bennett, 2014).

Invasive Species

By encouraging participation in citizen science, the Riverfly project increases awareness and involvement of anglers in the management of ecosystems, particularly with respect to invasive species. A special email address is provided by the monitoring initiative for anglers to record invasives in a central database in order to understand and control their spread (The Riverfly Partnership, 2014b; Gallo and Waitt, 2011), whilst active removal of invasive plants such as Himalayan Balsam can keep it at bay. Increased understanding of invasive species may also help to prevent illegal introductions of non-native fish which can have detrimental effects on wild populations (The Riverfly Partnership, 2014b; Hickley and Chare, 2004; Dick *et al., 2002*) and which many anglers value less (Environment Agency, 2004). Invertebrates are also a good indicator of many invasive species; for example the killer shrimp *Dikerogammarus villosus*, kills greater amounts of macroinvertebrates than the native (*Gammarus duebeni)*, therefore population counts could be a good indicator of its presence (Dick *et al.,* 2002).

Conclusions

Evaluation of the quality of community structure and interrelationships within ecosystems is essential in order to understand its potential to provide a service (Vlachopoulou *et al.,* 2014). However, identifying the relative importance of particular taxa is challenging as ecosystem status relies on more than just the sum of physical, chemical and biological elements (Van Hoey *et al.,* 2010). Isolating drivers in multi-pressure environments is almost impossible, particularly with large scale drivers such as climate change where there are no impact free areas (Van Hoey *et al.,* 2010; Moss, 2008). No single taxa can accurately indicate every type of disturbance or stress (Hilty and Merenlender, 2000; Mandelik *et al.* 2012; Holt and Miller, 2010) but the importance of Riverflies in ecosystem function combined with several characteristics of an ideal indicator suggests they are a good way to estimate a fisheries ability to provide fish. A more direct measure of fish such as catch data may provide more accurate measurements of service provisioning, but environmental quality is likely to correlate closely with service provision. Further experiments testing the strength of this relationship could help determine Riverflies use an indicator of fish provision rather than just environmental condition.

Whilst the presence of Riverflies links to certain aspects of ecosystem condition and to the provision of fish as an ecosystem service, linking their presence to all aspects of provisioning (such as angler participation, or the influence of climate change) is not realistic and therefore multiple indicators are required in order to provide a comprehensive ecosystem approach (Hilty and Merenlender, 2000). The WFD recognises this and therefore several indicators are used. However, comparisons of the success of different indicators are rarely made (Mandelik *et al.,* 2012) and therefore the most appropriate taxa are not necessarily used (Everard, 2007). To avoid redundancy in indicators, analysis and evaluation of their relative tolerances and response times needs to be made (Young and Colllier, 2009). For example, salmonoids are extremely sensitive to pollution and have been labelled as the ultimate clean water indicators (Pollution tolerance of freshwater invertebrates) and therefore they may actually make a better indicator of pollution than Riverflies (Oberdorff, 2002).

Structural traits such as Riverfly abundance are often criticised as being poor indicators of ecosystem provisioning in comparison to functional traits (UK National Ecosystem Assessment,2011; Young *et al.,* 2004). However, structural traits may give different, but equally as important information about ecosystem provisioning; close links between structural and functional indices of river status don't always occur (Young and Collier, 2009) and therefore it is important to include a range of both structural and functional indicators in assessments of ecosystem condition (Noss, 1990; Young *et al.,* 2004). However, the use of biological indices as surrogates for primary measures of characteristics of good ecological quality such as nutrient parsimony (efficient recycling of scarce resources) should be avoided; such measurements can often be analysed more accurately using chemical analysis (Moss, 2008). In future, functional indicators need to be tested for their suitability to support a more ecosystem based approach to assessing ecosystem status alongside Riverfly counts (Vlachopoulou *et al.,* 2014; Young *et al.,* 2004). For example, functions of the ecosystem as a whole such as food web dynamics or leaf litter decomposition have been identified as potentially useful indicators of environmental status (Van Hoey *et al.,* 2010; Young *et al.,* 2004).

Despite high levels of monitoring for invertebrates in comparison to other measurements required by the directive, in the UK only 41.9% of sites are monitored for invertebrates (European Commission, 2009). National monitoring programs are largely restricted by the available budget (Van HOEY *et al.,* 2010) and therefore involvement of citizen science in monitoring schemes is a useful way to gain a wide data set at a fraction of the cost (Kaartinen *et al.*, 2013). Particularly within fisheries, where strong recreational values and wide participation result in high stakeholder interest (Cairns and Pratt, 1993; Brown *et al.,* 2012), citizen science is a good way to raise awareness of issues and encourage responsible use of resources (DeVictor *et al.,* 2010; Gommerman and Monroe, 2012). This is particularly important as conservation of the natural environment is still seen by some as an altruistic task rather than a necessity to secure the survival of future generations (Vlachopoulou *et al.,* 2014).

Inclusion of an ecosystem approach within the Riverfly Monitoring Project could make an important contribution to the scheme and encourage the use of citizen science to its full potential. For example, Riverfly goals for 2012 were purely about understanding more about particular Riverflies (The Riverfly Partnership, 2011), rather than understanding links between Riverflies and environment or Riverflies and service provision. Further understanding of Riverfly response to stressors or management could help to inform and justify management decisions.

An ecosystem approach helps to recognise the values fisheries provide (eg. Table 2) which is important in order to define and achieve management objectives (Link, 2002; Van Hoey *et al.,* 2010; Noss, 1990; Institute of Fisheries Management, 2012). Due to time constraints, here only services provided by fishery ecosystems were studied. However, the systems upon which they are built are also relied upon for other services (Table 1.) which should be included in assessments in order to fully support decision making. Approaches which claim to assess ecosystem status as a whole but only consider one component are common (Moss, 2008); more than 50% of studies in one review of ecosystem service articles looked at one ecosystem service with no thought to feedbacks and interrelationships (Seppelt *et al.* 2011). Monitoring using Riverfly data could help to increase the evidence base for an ecosystem approach; currently less than 40% of articles about ecosystem services derive results from primary data, with the majority using proxy variables (Seppelt *et al.,* 2011). Whilst monitoring using an ecosystem approach may not actually be possible due to the constraints of time and money, considering fisheries in an ecosystem framework is helpful as it ensures that a full range of values are identified. It also allows identification of areas of common interest between stakeholders who have different resources available to them, incorporation of which can provide a fuller and more effective approach. Here fisheries are used as an example, but the use of such schemes in other systems may also help the implementation of an ecosystem approach to monitoring.

REFERENCES

1. BEARD, T. D. et al (2011) Ecosystem approach to inland fisheries: research needs and implementation strategies. *Biology Letters*, 7, 481-483.
2. BENNETT, C. AND GILCHRIST, W. (2010) Chapter 22: Riverflies. In: Maclean, N. Silent Summer: the state of wildlife in Britain and Ireland. Cambridge University Press.
3. BENNETT, C. (2014) Riverfly monitoring project news. Salisbury & District Angling Club Centre for Riverfly Conservation [online] Available from: http://www.riverflies.org/sites/172.16.0.99.riverflies.local/files/SDACCentreforRiverflyConservationreport2014.pdf [Accessed 6/11/2014]
4. BOULTON, A. J. et al. (2008) Biodiversity, functional roles and ecosystem services of groundwater invertebrates. *Invertebrate Systematics* 22, 103-116.
5. BRADLEY, D. C. (2005) Submission of a Brief Paper regarding water Quality and Invertebrate Sampling Programmes and the Monitoring of Diffuse Water Pollution. *Aquatic Scientists*. APEM Paper 799
6. BROWN, A. et al. (2012) Fishing For Answers: the Final Report of the Social and Community Benefits of Angling Project. Substance, Manchester.
7. CAIRNS JR, J. and PRATT, J. R. 1993. A history of biological monitoring using benthic macroinvertebrates. *Freshwater biomonitoring and benthic macroinvertebrates*, 10, 27.
8. CARPENTER, S. R., et al. (2009) Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proceedings of the National Academy of Sciences of the United States of America*, 106, 1305-1312.
9. CEFAS, CENTRE FOR ENVIRONMENT, FISHERIES & AQUACULTURE SCIENCE (2014) Sustainability of freshwater fisheries and ecosystems [online]. Available from: http://www.cefas.defra.gov.uk/our-science/fisheries-information/freshwater-fisheries/sustainability.aspx [Accessed 21/10/2014]
10. CHINNERY, M. (1993) *Insects of Britain and Northern Europe. Collins Field Guide.* London. Harper Collins.
11. CLARKE, B. (1975) *The pursuit of stillwater trout*. A&C Black.
12. COLLINS, A., et al. (2012) Implementing the Water Framework Directive: a transition from established monitoring networks in England and Wales. *Environmental Science & Policy*, 17, 49-61.
13. DAILY, G. C. (2000) Management objectives for the protection of ecosystem services. *Environmental Science & Policy*, 3, 333-339.
14. DAILY, G.C., et al. (2009) Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment* **7**: 21–28
15. DEFRA, DEPARTMENT OF ENVIRONMENT, FOOD AND RURAL AFFAIRS (2013) Managing Freshwater Fisheries [online] Available from: https://www.gov.uk/government/policies/managing-freshwater-fisheries/supporting-pages/better-management-of-fish-stocks [Accessed 14/01/2014]
16. DEVICTOR, V., et al. (2010) Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. *Diversity and distributions*, 16, 354-362.
17. DICK, J. T. A., PLATVOET, D. and KELLY, D. W. (2002) Predatory impact of the freshwater invader Dikerogammarus villosus (Crustacea : Amphipoda). *Canadian Journal of Fisheries and Aquatic Sciences*, 59, 1078-1084.
18. ECOSYSTEMS KNOWLEDGE NETWORK, 2014 Ecosystems Approach Background [online] Available from: http://ecosystemsknowledge.net/about/background
19. ENVIRONMENT AGENCY (2004) Our Nations' Fisheries.
20. ENVIRONMENT AGENCY (2008) The thermal biology of brown trout and Atlantic Salmon

21. EUROPEAN COMMISSION (2002) Towards a Guidance on Establishment of the Intercalibration Network and the Process on the Intercalibration Exercise The Directorate General Environment of the European Commission, Brussels
22. EUROPEAN COMMISSION (2009) Report from the Commission to the European Parliament and the Council in Accordance with Article 18.3 of the Water Framework Directive 2000/60/Ec on Programmes for Monitoring of Water Status.
23. EUROPEAN ENVIRONMENT INFORMATION AND OBSERVATION NETWORK (2012) Freshwater ecosystem services and their vulnerability [online] Available from: http://forum.eionet.europa.eu/nrc-eionet-freshwater/library/public-section/2012-state-water-thematic-assessments/material-vulnerability-assessment-july-2012/vulnerability-report/3.-freshwater-ecosystem-services-and-their-vulnerability. [Accessed 29/11/2014]
24. EVERARD, M., (2012) Why does 'good ecological status' matter? *Water Environ J*, 26 (2) pp. 165–174
25. FRANCO, (2013) Does citizen Science By Itself Provide Evidence for Cultural Ecosystem Services? [online] Available from: https://uclexcites.wordpress.com/2013/03/20/does-citizen-science-by-itself-provide-an-evidence-for-cultural-ecosystem-services/#comments [Accessed 31/10/2014]
26. GALLO, T. & WAITT, D. (2011) Creating a successful citizen science model to detect and report invasive species. *BioScience*, 61, 459-465.
27. GILES, N., WESTGARTH, J., AND HEWLETT, N. (2004) Management advice for trout, grayling and Arctic char fisheries. *Fisheries Technical Manual No. 7*
28. GOLDMAN, R. L., TALLIS, H., KAREIVA, P. & DAILY, G. C. (2008) Field evidence that ecosystem service projects support biodiversity and diversify options. *Proceedings of the National Academy of Sciences of the United States of America*, 105, 9445-9448.
29. GOMMERMAN, L. & MONROE, M. C. (2012) Lessons learned from evaluations of citizen science programs. Institute of Food and Agricultural Sciences, University of Florida.
30. HARTJE, V. AND KLAPHAKE, A. (2006) Implementing the Ecosystem Approach for Freshwater Ecosystems – A case study on the Water Framework Directive of the European Union
31. HAWKES, H.A. (1979) Invertebrates as indicators of river water quality. In: Biological Indicators of Water Quality, eds. A.James and L. Evison, Cahpter 2. John Wiley, Chichester, England.
32. HICKLEY, P. AND CHARE, S. (2004) Fisheries for non-native species in England and Wales: angling or the environment? *Fisheries Management and Ecology*, 11, 203-212.
33. HILTY, J. AND MERENLENDER, A. (2000). Faunal indicator taxa selection for monitoring ecosystem health. *Biological conservation*, 92, 185-197.
34. HOLT, E. A. AND MILLER, S. W. (2011) Bioindicators: using organisms to measure environmental impacts. *Nature Education Knowledge*, 3, 8.
35. INGRAM J.C, et al. (2012) Applying Ecosystem Services Approaches for Biodiversity Conservation: Benefits and Challenges S.A.P.I.EN.S [Online] Available from: http://sapiens.revues.org/1459 [Accessed 21/102014]
36. INSTITUTE OF FISHERIES MANAGEMENT (2012) Code of Good Practice for Freshwater Fisheries Management. Part One: Salmon and Brown trout.
37. JOHNSON, R. K., WIEDERHOLM, T. & ROSENBERG, D. M. (1993) Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates. *Freshwater biomonitoring and benthic macroinvertebrates* 40-158.
38. KAARTINEN, R., et al. (2013) Using citizen scientists to measure an ecosystem service nationwide. *Ecology*, 94, 2645-2652.
39. KREMEN, C. (2005), Managing ecosystem services: what do we need to know about their ecology? *Ecology Letters*, 8: 468–479
40. LI, F., et al. (2012) The response of benthic macroinvertebrate communities to climate change: evidence from subtropical mountain streams in Central China*. International Review of Hydrobiology*, 97, 200-214.

41. LINDE, A., et al. (1998) Brown trout as biomonitor of heavy metal pollution: effect of age on the reliability of the assessment. *Ecotoxicology and Environmental Safety*, 40, 120-125.
42. LINK, J. S. (2002) What does ecosystem-based fisheries management mean? *Fisherie*s, 27, 18-21.
43. MANDELIK, Y., et al. (2012) The relative performance of taxonomic vs. environmental indicators for local biodiversity assessment: A comparative study. *Ecological Indicators*, 15, 171-180.
44. MCKIE, B. G. AND MALMQVIST, B. (2009) Assessing ecosystem functioning in streams affected by forest management: increased leaf decomposition occurs without changes to the composition of benthic assemblages. *Freshwater Biology*, 54, 2086-2100.
45. MILLENNIUM ECOSYSTEM ASSESSMENT (2005) Ecosystems and Human Wellbeing: wetlands and Water Synthesis. World Resources Institute, Washington, DC.
46. MOSS, B. (2008) The Water Framework Directive: Total environment or political compromise? *Science of the Total Environment*, 400, 32-41.
47. NGUYEN,T.H. (2009) Ecosystem-Based Fishery Management: A Critical Review of Concepts and Ecological Economic Models, Working Papers 94/09, University of Southern Denmark, Department of Environmental and Business Economics.
48. NOSS, R. F. (1990) Indicators for monitoring biodiversity: a hierarchical approach. *Conservation biology*, 4, 355-364.
49. OBERDORFF, T., et al. (2002) Development and validation of a fish-based index for the assessment of 'river health' in France. *Freshwater Biology*, 47, 1720-1734.
50. PARLIAMENTARY OFFICE OF SCIENCE AND TECHNOLOGY (2007) Postnote Number 281: Ecosystem Services.
51. PEARSON, D. L. (1994) Selecting indicator taxa for the quantitative assessment of biodiversity. *Philosophical Transactions of the Royal Society of London*. Series B: Biological Sciences, 345, 75-79.
52. PRYCE, D. (2005) Stoneflies: the forgotten fly? *Salmo Trutta*, 8
53. The Riverfly Partnership (2011) Riverfly Recording Schemes Report [online] Available from: http://www.riverflies.org/sites/172.16.0.99.riverflies.local/files/Riverfly%20Recording%20Schemes%20Report%202010-11.pdf [Accessed 06/11/2014
54. The Riverfly Partnership (2014a) Riverflies- the canary of the rivers. [online] Available from: http://www.riverflies.org/riverflies-canary-rivers [Accessed 28/09/2014]
55. The Riverfly Partnership (2014b) Non-natives. [online] Available from: http://www.riverflies.org/non-natives [Accessed 03/01/2015]
56. ROSENBERG, D. M. AND RESH, V. H. (1993) Freshwater biomonitoring and benthic macroinvertebrates. *Freshwater biomonitoring and benthic macroinvertebrates*., i-ix, 1-488.
57. ROY, H., et al. (2012) Understanding citizen science and environmental monitoring: final report on behalf of UK Environmental Observation Framework.
58. Sanchez, W. AND PORCHER, J. (2009) Fish biomarkers for environmental monitoring within the Water Framework Directive of the European Union *Trends in Analytical Chemistry*, 28 , pp. 150–158
59. SEPPELT, R., et al. (2011) A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. *Journal of Applied Ecology,* 48, 630-636.
60. SUURONEN, P. AND BARTLEY, D. M. (2014) Challenges in managing inland fisheries - using the ecosystem approach. *Boreal Environment Research*, 19, 245-255.
61. TOMSETT, A. (2005) *A Field Guide to the Wildife of the British Isles*. Atlantic Publishing, Oxford.
62. UK NATIONAL ECOSYSTEM ASSESSMENT (2011) The UK National Ecosystem Assessment: Chapter 9 Freshwaters – Openwaters, Wetlands and Floodplains UNEP-WCMC, Cambridge.

63. VAN HOEY, G., et al. (2010) The use of benthic indicators in Europe: From the Water Framework Directive to the Marine Strategy Framework Directive. *Marine Pollution Bulletin*, 60, 2187-2196.
64. VLACHOPOULOU, M., et al. (2014) The potential of using the Ecosystem Approach in the implementation of the EU Water Framework Directive. *Science of the Total Environment*, 470, 684-694.
65. WALKER, A.F., et al. (1988) Two ecologically distinct forms of Arctic char, Salvelinus alpinus in Loch Rannoch, Scotland. *Biological Conservation* 33, 43-61
66. WALLACE, I. (2004) The sedge of the water. *Salmo Trutta*, volume 7
67. WALLACE, J.B. AND GURTZ, M.E. (1986) Response of Baetis mayflies (Ephemeroptera) to catchment logging. *Am. Midl. Nut.* 115: 2541
68. WALLACE, J. B. & WEBSTER, J. R. (1996) The role of macroinvertebrates in stream ecosystem function. *Annual review of entomology*, 41, 115-139.
69. YOUNG, R. G. & COLLIER, K. J. (2009) Contrasting responses to catchment modification among a range of functional and structural indicators of river ecosystem health. *Freshwater Biology*, 54, 2155-2170.
70. YOUNG, R., et al. (2004) Functional indicators of river ecosystem health – an interim guide for use in New Zealand. Cawthron Report No. 870