## Citizen science and aquatic macroinvertebrates: public engagement for catchment-scale pollution vigilance

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**ABSTRACT**

The Riverfly Partnership, launched in 2004, is a UK network of organisations and individuals working to protect river habitats and macroinvertebrate communities. The Riverfly Partnership’s Anglers’ Riverfly Monitoring Initiative (ARMI), launched in 2007, supports citizen science volunteers to monitor macroinvertebrates in their local rivers. In Manchester and surrounding areas, ARMI monitoring began in 2011 with volunteers from a fishing club active across the Irwell catchment. Whilst there has been mixed success establishing a robust long-term monitoring programme, volunteers investigate issues raised by the local community and data provide a baseline against which river pollution events can be compared. For example, in April 2017 citizen scientists responding to a report of dead crayfish by an angler identified a pollution incident resulting in a catastrophic loss of macroinvertebrates along a 19km reach of the River Irwell. Recognising the limitations of the ARMI methodology for urban and degraded rivers nationwide led to development of the Urban Riverfly index through the Riverfly Partnership so that citizen scientists can more effectively contribute to the work of government agencies mitigating urban river pollution. Citizen science has importantly been a catalyst for public engagement and environmental projects which should encourage wider public participation in river catchment management.

**Keywords:** urban rivers; biological monitoring, Anglers’ Riverfly Monitoring Initiative; Riverfly; River Trusts

**1. Introduction**

***1.1. Macroinvertebrates as bioindicators***

The taxonomically and functionally diverse macroinvertebrates living amongst vegetation and within or on the substrate of rivers are key components of riverine ecological processes (Malmqvist, 2002). Their abundance and diversity of roles and sensitivities to environmental parameters means they provide a valuable resource for the assessment of a wide range of aquatic parameters (Armitage et al. 1983; Hawkes 1998; Everard 2008). Aquatic insects, including mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) are particularly sensitive to changes in dissolved oxygen, nutrients and suspended solids arising from sewage and agricultural pollution. Such groups are also very responsive to industrial pollutants such as trace metals and petrochemicals.

With the long residence time of individuals (typically one to three years), aquatic insects in particular act in effect as a data logger: their occurrence and relative numbers indicate the long-term average of water quality and whether the site experiences occasional intense pollution episodes. For example, from an examination of over 2,000 stream samples in Wisconsin (USA) subject to differing levels of organic pollution, Hilsenhoff (1988) established the relative tolerance of invertebrate families on a score of 0 (*in*tolerant) to 10 (tolerant). All Plecoptera (stonefly) families examined were intolerant with a score of between 0 and 2 whereas marked inter-family differences were found for mayflies: Baetidae (olives) and Heptagenidae (flat-bodied mayfly), for example, were tolerant with scores of 4 whereas Ephemeridae (true mayflies) were susceptible to organic pollution with a score of 1. Gammaridae (freshwater shrimp) were moderately tolerant with a score of 4 whereas Asellidae (freshwater hoglouse) were highly tolerant with a score of 10.

Monitoring the macroinvertebrate community will also allow changes to river flow and substrate composition to be assessed: for example, the Lotic‐invertebrate Index for Flow Evaluation based on English rivers (LIFE; Extence et al. 1999) and the Proportion of Sediment‐sensitive Invertebrates (PSI) tool for measuring sedimentation impacts (Glendell et al. 2014). Models such as the River Invertebrate Prediction and Classification System (RIVPACS; evaluated by Clarke et al., 2004) use databases of high quality reference sites and statistical techniques to predict the expected community in the absence of pollution or other environmental stress at a given site.

Macroinvertebrates are used worldwide for both routine and responsive monitoring of water quality, drought conditions, ecosystem function, pollution incidents and habitat restoration (Mason, 2002). In Europe, for example, benthic invertebrates account for one-quarter of the 297 assessment methods using aquatic organisms for the assessment of the status of surface waters under the Water Framework Directive analysed by Birk et al. (2012). Rigorous statutory monitoring of rivers using macroinvertebrate community sampling was developed in the UK through the 1970 National River Pollution Survey (Hawkes 1998) and subsequent BMWP (Biological Monitoring Working Party) system. The BMWP scores a comprehensive set of freshwater insects, crustaceans, worms, snails and other families (and the subclass Oligochaeta) on a scale 1-10 as taxa groups based on their tolerance to pollution and combines the total of taxa scores to generate the BMWP score (Armitage et al. 1983)

Statutory monitoring in the UK today uses an updated form of the BMWP score, the Walley Hawkes Paisley Trigg (WHPT) system, with more taxa and weighting for abundance (Brooks et al., 2019; Paisley et al. 2007; Walley & Hawkes 1996, 1997). Indices similar to the BMWP approach (sometimes explicitly based on it - for example, the Iberian BMWP; Alba-Tercedor & Sánchez-Ortega, 1988) are used globally, including the Australian River Assessment Scheme (AusRivAS; Smith et al., 1999), the South African Scoring System (SASS; Graham et al., 2004) and more (see examples discussed in Ollis et al., 2006). Indices are tailored to national or regional reference conditions, and biota.

A semi-quantitative kick sample technique is used to collect macroinvertebrate samples from rivers and streams (for methodology in the UK, see: UKTAG, 2008). A standardized net catches macroinvertebrates dislodged by an operative disturbing the substrate with the feet for a fixed period of time, taking a zigzag route across the river in an upstream direction to ensure that all habitats are included (Furse et al. 1981; Armitage et al. 1983). The same sampling technique can be employed with minimal training by the general public and is therefore readily used in citizen science monitoring programmes. Identification of the groups of insect larvae included in the BMWP score to family level requires specimen preservation, a microscope, and a high level of expertise - whereas the citizen science approach identifies a limited number of broad groupings according to clearly recognisable features such as presence and number of abdominal projections (‘tails’).

***1.2. Riverfly Partnership citizen science***

The Riverfly Partnership, currently hosted by the Freshwater Biological Association, is a network of organisations and individuals working together to protect and enhance the quality of UK rivers and conserve aquatic macroinvertebrates, also known as “riverflies” (Brooks et al., 2019). The partnership began in 2004 as a collaboration between the Freshwater Biological Association, the Natural History Museum London, the Salmon & Trout Association (now known as Salmon & Trout Conservation UK) and other interested parties.

The Riverfly Partnership recognised a growing consensus that citizen science monitoring can make important contributions to management aimed at improving water quality and in responses to pollution incidents (discussed more recently in Latimore & Steen 2014; Shupe 2016; Shuker et al. 2017) and launched its Anglers’ Riverfly Monitoring Initiative (ARMI) in 2007. Macroinvertebrates are of particular interest to anglers because they are a key food source for coarse fish such as roach *Rutilus rutilus* and game species such as Atlantic salmon *Salmo salar* and brown trout *Salmo trutta*. A healthy macroinvertebrate community is therefore essential in maintaining fish populations and feeding behavior (Wallace & Webster 1996), with game anglers using imitations (“flies”) of the living macroinvertebrates upon which the target fish are feeding in order to catch them. Whilst originally focused on anglers, the ARMI welcomes the involvement of non-anglers and aims "to provide a means for citizens to monitor the water quality of their local rivers" (Brooks et al., 2019).

Today, more than 3000 volunteers, organised into >150 groups (of which 69 are angling clubs, societies, or associations), are engaged with the Riverfly Partnership as active participants in the ARMI and are supported by a network of 50 catchment hubs across the UK (Fitch et al., 2018). The ARMI aims for an ecology contact from the appropriate regulatory body (Environment Agency in England; Scottish Environment Protection Agency; Natural Resources; or Northern Ireland Environment Agency) to set a trigger level for each site based upon either the regulator’s own data or ARMI volunteer data. The trigger level represents the score below which an acute pollution event is likely to have occurred - and ARMI monitors reporting a score below the trigger level would prompt an investigation by the regulatory body to identify the reason(s) for that low score.

The Riverfly Partnership data repository was launched in July 2014 to establish a UK online dataset for the ARMI. Records captured by trained ARMI volunteer monitors at regulatory body approved river sites are submitted online, then checked and verified by group coordinators. The live dataset currently comprises 30861 records from 2500 sites across the UK and is publicly accessible for use under the terms of the UK Open Government Licence for public sector information (interoperable with Creative Commons' Attribution 4.0 licence; <http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/>). Although the data repository is used by the majority of ARMI participants, the live dataset is incomplete because a substantial number of submitted records remain unverified and because some hubs and groups chose to retain data locally pending further development of the national system. Significant upgrades were completed by the Freshwater Biological Association in March 2020 but the subsequent launch was stifled as a result measures put in place across the UK in response to the global Covid-19 pandemic.

ARMI scoring records presence and abundance of a selection of moderately tolerant to pollution sensitive BMWP families from the three insect orders (BMWP values 4-10), plus the crustacean *Gammarus spp.* (also widely used as an indicator of organic and chemical pollution; Mason, 2002), placed into 8 groups for simplified identification in a live sample (Riverfly Partnership, <http://www.riverflies.org> ; Di Fiore & Fitch 2016; Brooks et al., 2019). The ARMI is therefore a simplified version of the established BMWP-based statutory monitoring system, in the same way that the miniSASS citizen science approach in South Africa is a simplified version of the South African Scoring System used by the regulatory bodies (Graham et al., 2004).

The ARMI index does not distinguish between pollution tolerances of the 8 groups (each is treated equivalently in the scoring formula) but does place a weighting on the abundance of each group, estimated as logarithmic categories. The ARMI score is the total of the abundance scores for the eight groups: zero individuals of a group scores 0; 1-9 scores 1; 10-99 scores 2; 100-999 scores 3; and 1000 or more scores 4. ARMI groups are identified according to presence and number of tails and pairs of legs, appearance of the gills, and (for cased caddisfly larvae) the presence or absence of a case. Species level identification is not needed for the ARMI - broad taxonomic groups are recognized as making little difference to biotic indices scoring compared to species-level identification and accepted as the only option for citizen science monitoring where taxonomic expertise, time, and equipment are limited (Hilsenhoff 1988; Lenat & Resh 2001; Jones 2008). Brooks et al. (2019) compared BMWP and ARMI scores for 4,798 archive macroinvertebrate samples from across England and Wales, concluding that (with r = 0.86) the two systems give broadly equivalent results and that “the ARMI system can provide a comparable approach for assessing river water quality”.

The simplified target groups, live sorting and broad abundance categories make riverside sampling and processing accessible to non-scientist trainees. Kick samples taken of macroinvertebrates are readily scored on the riverside following the ARMI protocol: identification is straightforward; equipment requirements are simple; no preservatives are needed; and estimate of numbers is quicker and easier than counts to the last individual. ARMI citizen science volunteers undertake a one-day course delivered by a Riverfly Partnership accredited trainer (Brooks et al., 2019) during which they are trained in how to complete a semi-quantitative kick sample of macroinvertebrates, as per statutory monitoring in the UK (UKTAG 2008), and how to score the macroinvertebrate assemblage collected in a kick sample using the bespoke ARMI index. Training involves familiarization with macroinvertebrate taxonomy (supported by a Riverfly Partnership accredited trainer and regulatory body ecology contact) using the Riverfly Partnership’s ARMI-specific guide “Riverfly monitoring”, practise on a river, and certification that each volunteer participant is able to correctly take and sort a sample, then identify and record an accurate ARMI score.

Volunteers reporting ARMI scores must be trained and accredited to contribute data to the Riverfly Partnership. However, there is an important role for interested volunteers in shadowing accredited ARMI citizen scientists. Working in pairs or larger groups is important for safety, has a social aspect that aids enjoyment and motivation, and importantly cultivates a cohort of people motivated to take the ARMI training who have experience and realistic expectations (which anecdotally appears to reduce participant drop out). Additionally, there are a number of other roles that citizen scientists can play within Riverfly Partnership groups suited to the varying needs, circumstances and availability of volunteers - for example, as activity coordinators, data managers, or accredited trainers.

***1.3. The context of Greater Manchester’s rivers***

Manchester, recognized as the world’s first industrial city, has a long history of polluted rivers (Burton 2003). The influence of its industrial past is still seen today with continuing leachate of heavy metal contaminants into the River Irwell (Hurley et al. 2017), which is 63 km long and drains a catchment of 701 km2 including much of Greater Manchester. Water quality improvements during the 20th Century along the River Irwell and the River Mersey into which it flows downriver of Manchester were boosted from 1985 when the UK government initiated the Mersey Basin Campaign (Gregory et al., 2011; Struthers, 1997; Williams et al., 2010; Wood et al., 1999).

However, continuing episodic pollution events by raw sewage released by combined sewer overflows following heavy rainfall plus industrial discharges remain an ongoing concern of local recreational anglers in close contact with the rivers in and around the Greater Manchester conurbation. Incidences of fish kills suspected to be connected with sewage and industrial discharges led to the Salford Friendly Anglers’ Society (SFAS) joining the Riverfly Partnership’s ARMI citizen science programme in September 2011. Citizen science activity together with broader engagement in environmental work at the SFAS led to the foundation of the Mersey Basin Rivers Trust in 2015, which then merged with the successor to the Mersey Basin Campaign, the Healthy Rivers Trust, to form the Mersey Rivers Trust, which continues to engage with regulators, angling clubs and local communities to help clean up the catchment’s rivers ([www.healthywaterwaystrust.org.uk](http://www.healthywaterwaystrust.org.uk)).

The SFAS was founded in April 1817 and is an example of the “friendly societies” of 18th and 19th Century Britain, which were social and insurance clubs usually for people sharing common interests such as angling (Cordery 1995; Gorsky 1998). Legislative changes in the 1890s meant the financial support role ceased but the SFAS continued as a fishing club; it is today an organized group of anglers focused on fishing the River Irwell and its tributaries. Free membership, free fishing, and other free activities are a central tenet of the SFAS, enabling it to maximize engagement and ensure accessibility for socially deprived communities around the urban stretches of the river. Rather than an interest in ecological "restoration", understood as being to return something to the state it was at a defined past time, the SFAS aims to "rehabilitate" the Irwell by enhancing its fishing and other public amenity values, cultural role within surrounding communities, water quality, and habitat features.

***1.4. Aims of the study***

The aims of this study are to evaluate: (1) the effectiveness of the Riverfly Partnership and the Salford Friendly Anglers’ Society in establishing a long-term citizen science monitoring network; (2) the effectiveness of the network in responding to a major river pollution event; and (3) the impact of the programme on wider environmental action beyond macroinvertebrate citizen science.

**2. Methods**

***2.1. Macroinvertebrate sampling, biotic indices and laboratory methods***

Macroinvertebrate kick samples were taken for a cumulative three minutes, moving upriver and sampling habitats and substrates proportional to their abundance, plus a one-minute search of larger stones for attached macroinvertebrates. Riverfly Partnership ARMI scoring (Riverfly Partnership, <http://www.riverflies.org>; Di Fiore & Fitch 2016) recorded presence and abundance of 8 groups in the samples: 7 macroinvertebrate groups plus the freshwater shrimp (*Gammarus* spp.). The 7 groups of macroinvertebrate are: cased caddis (Trichoptera); caseless caddis (Trichoptera); true mayfly (Ephemeridae); flat-bodied mayfly (Heptageniidae); blue-winged olives (Ephemerellidae); olives (Baetidae); stoneflies (Plecoptera). To generate an ARMI score for a sample, each of the 8 groups are first given an abundance score (zero individuals of a group scores 0; 1-9 scores 1; 10-99 scores 2; 100-999 scores 3; and 1000 or more scores 4). The 8 group’s abundance scores are then totaled resulting in the ARMI score (maximum ARMI score possible with 8 groups at 4 = 32). Autumn was defined for data handling following UKTAG (2014) as 1st September to 30th November.

***2.2. Sampling sites***

Local knowledge of anglers interested in becoming ARMI monitors was used to identify potential monitoring sites while final selection was then informed by accessibility for safe sampling and proximity to regular fishing locations (for convenient long-term monitoring alongside angling), and approved by the Environment Agency ecologist contact. Eleven sites along the River Irwell from Rawtenstall in the upper reaches (13.5 km from source) to Strangeways adjacent to Manchester city centre (56.5 km from source) and two additional sites on the River Roch and Eagley Brook tributaries were selected to cover a range of putative clean and polluted waters and semi-rural to urban locations across the Irwell catchment (Figure 1). Sites were sampled monthly in September, October and November 2011 to establish a baseline of Riverfly Partnership ARMI scores across the catchment. Sampling on 8 sites did not continue after 2011 due to lack of volunteer availability but sampling continued for nearly 4 years (2011-15) on the River Roch and to August 2017 (6 years of data) at Ewood Bridge on the River Irwell and at the Eagley Brook tributary. Trigger levels at which “low” ARMI scores would initiate an investigatory response by the Environment Agency were not set because baseline scores were below the normal range of trigger levels used elsewhere. Additional sites were sampled in April 2017 between the Chatterton Country Park and Ewood Bridge reference sites in response to a suspected pollution event to constrain the upriver location at which the macroinvertebrate kill began.

***2.3. Mapping and data analysis***

Maps were generated and distances along the river measured using ArcMap and QGIS software. Statistical analysis and graphs were produced using Minitab and Microsoft Excel software.

**3. Results**

***3.1. Sites, baseline scores and long-term records***

For 11 sites along the River Irwell and two additional sites on the Eagley Brook and River Roch tributaries (Figure 1) an autumn (September to November) baseline of ARMI scores was established (Figure 2). The ARMI baseline of 5.7 at Rawtenstall (13.4 km from the source) increases to 9.7 at Springwater Park 22.2 km downriver; then decreases to 5.3 at Sion Street 3.9 km below Springwater Park. The baseline continued to fall as the Irwell flows through the increasingly urbanised conurbation towards the city center, with low scores of 2.7, 2.0 and 2.0 at Clifton Country Park, Agecroft and Strangeways, respectively (14.4 km, 8.7 km and 0.6 km from the edge of the city center, respectively). Autumn baseline ARMI scores for sites on Irwell tributaries were 7.7 for Eagley Brook and 6.5 for the River Roch (8.7 and 12.0 km from the boundary of the city center, respectively).

Near continuous long-term monthly ARMI records were compiled from 2011 until at least 2015 for 3 sites (Figure 3): Ewood Bridge on the upper River Irwell (September 2011 to August 2017; mean 4.41, SD 1.43, range 2-8, n=61); Eagley Brook (August 2011 to August 2017; mean 6.98, SD 1.92, range 4-13, n=58); and the River Roch (November 2011 to May 2015; mean 8.03, SD 2.07, range 3-12, n=37). All three sites show no long-term inter-annual trend, indicating that 2011 when baseline data was collected for the 11 reference sites was a typical year and so reflects the normal state of the macro-invertebrate community.

Combined annual data for individual months January to December (Figure 4) showed significant seasonal influence on the ARMI score (P<0.01) using one-way ANOVA, with highest scores recorded in summer (June to August) and lowest in winter (December to February). Of the 7 reference sites monitored in the investigation of the April 2017 pollution event, 6 had monthly baseline records only from autumn 2011 (September, October, November) whilst Ewood Bridge had near-continuous records from September 2011 to April 2017. The validity of using autumn 2011 ARMI scores as a baseline for the pollution event investigated in April 2017 was therefore tested by comparing multi-year April scores with autumn (September to November scores) for the three long-term monitoring sites. Paired t-tests showed no statistical difference for Ewood Bridge (April mean 4.17, SD 0.75, range 3-5, n=6; autumn mean 4.22, SD 1.31, range 3-7, n=18; P=0.76), Eagley Brook (April mean 5.75, SD 2.06, range 4-8, n=4; autumn mean 6.81, SD 1.22, range 4-9, n=16; P=0.11), or the River Roch (April mean 9.00, SD 0.82, range 8-10, n=4; autumn mean 7.38, SD 2.50, range 3-12, n=8; P=0.66).

***3.2. Macroinvertebrate loss in April 2017***

On 4 April 2017 an angler fishing on the River Irwell upriver of Manchester noted large numbers of dead crayfish, suggesting a pollution incident, and contact was made with the SFAS citizen science monitors. A kick sample was carried out the same day to investigate the macroinvertebrate community at the nearest reference site at Burrs Country Park (see Figure 1) and no macroinvertebrates were found in the sample.

The next day, volunteers carried out further kick samples at existing reference sites upriver to Ewood Bridge, where a healthy macroinvertebrate population was found, and downriver to Agecroft (see Figure 1) to localize the source of pollution and how far the macroinvertebrate kill extended (Figure 5). No macroinvertebrates were found in samples taken at Nuttall Park or Chatterton 6.2 km and 10.0 km upriver of Burrs Country Park respectively but at Ewood Bridge 14.8 km upriver a healthy macroinvertebrate population was found with an ARMI score of 4 typical for the site (April 2012-16 records at Ewood Bridge mean 4.2, SD 0.84, range 3-5, n=5; all records September 2011 to August 2017 mean 4.41, SD 1.43, range 2-8, n=61).

Macroinvertebrates were absent at the first reference site downriver of Burrs Country Park (Warth Fold, 4.4 km along the river). A limited population of macroinvertebrates was found at Springwater Park 7.4 km downriver of Burrs Country Park and 330 m below the confluence of the River Roch; but with an ARMI score of 1 significantly below the baseline of 10 (range 7-13, n=3) recorded from autumn 2011 (P<0.01). Continuing downriver, the reference site at Agecroft had an ARMI score of 2, which is comparable to the low baseline score established for this site in autumn 2011 (mean 2, range 1-3, n=3).

**3.3. Citizen science identification of the putative pollution site with reactive sampling**

Volunteers carried out a responsive survey at short distance interval additional sites downriver of the healthy macroinvertebrate population at Ewood Bridge on the River Irwell, a section which includes a discharge point from a wastewater treatment works, and on the River Ogden tributary (Figure 6).

Healthy macroinvertebrate samples (ARMI score 4) were found upriver of the wastewater treatment works at the two railway bridge crossing sites, with the downstream railway bridge approximately 25 m upriver of the discharge point. Macroinvertebrates were, however, absent at the Stables site immediately below the wastewater treatment works discharge and at Aitken Street 110 m downriver of the wastewater treatment works discharge. The sample from Meadow Park 490 m downriver of the wastewater treatment works discharge and 380 m downriver of the confluence of the River Ogden also contained no macroinvertebrates. The River Ogden sampled immediately above its confluence with the River Irwell displayed an abundance of macroinvertebrate groups (ARMI score 9).

The location of the start of the macroinvertebrate kill was therefore constrained to an approximately 30 m stretch of the River Irwell alongside the discharge point of the wastewater treatment plant. The Environment Agency was immediately contacted with the information to request an investigation.

**4. Discussion**

***4.1. Pollution vigilance: responsiveness of the citizen science network***

For use in citizen science, a sampling method must be easy to use and require minimal equipment and training (Pocock et al., 2014). Kick sampling, the semi-quantitative approach of both Riverfly Partnership citizen science and UK statutory monitoring, is favored for statutory biomonitoring globally over complete and quantitative sampling methods such as Surber sampling because it is quick and easy to carry out (Everall et al. 2017). Field sorting becomes practical when using live samples and identification to broad taxonomic groups without optical aids (Haase et al. 2004; Growns et al. 2016). The Riverfly Partnership ARMI satisfies these requirements through simple bankside identification of live samples with broad groups of readily identifiable taxa and minimal equipment requirements. Experienced monitors can score a kick sample spread out in a small tray by eye for the ARMI index without any sorting needed. Even for beginners, scoring for abundance is straightforward after separating the 8 target groups by live sorting into a compartmentalized tray (although this is relatively time consuming). Exact counts are difficult with moving live individuals but logarithmic estimates of numbers suffice for the Riverfly Partnership ARMI abundance categories.

The rapid response and immediate results obtained at the time of sampling is a key advantage of the Riverfly Partnership citizen science ARMI index over the BMWP, ASPT and WHPT indices used by trained professionals. Regular monitoring and the presence of anglers ready to raise the alarm and to take reactive samples with immediate results if pollution is suspected means large-scale macroinvertebrate kills have a high likelihood of detection. Further investigations by the citizen science group can then be instigated and, if appropriate, be reported to the Environment Agency along with clear data on impacts, as happened in April 2017. In this case, it was not the routine ARMI monitoring that instigated the investigation but the presence of numerous dead crayfish noticed by an angler that was then reported through to the citizen scientists group that is a visible and active part of the local community on the river. Existing reference sites with known baselines allowed volunteers to quickly identify (by the end of the day following the initial report) that thepollution event had occurred between the Chatterton and Ewood Bridge reference sites. Reactive identification of additional sampling sites was able to identify the short stretch of river where the pollution impact began. Reference sites downriver indicated that macroinvertebrate life was absent until the confluence of the River Roch where macroinvertebrates were present at Springwater Park 330 m downriver of the confluence, albeit with an ARMI score of 2 that was significantly below the baseline of 10; P<0.01. This evidence of a substantial pollution event destroying the macroinvertebrate community along an estimated 19 km stretch of the River Irwell was then passed by the chairperson of the local citizen science group to the Environment Agency requesting an investigatory response.

However, other than the loss of macroinvertebrates, there were no visible indicators of pollution such as water discolouration, oil streaking, foaming, smell of sewage, or dumped material. Therefore, the chairperson of the local citizen science group was informed by the Environment Agency that the type and source pollution could not be identified. Given the absence of other plausible explanations, we tentatively suggest that the release of a large quantity of pesticide into the River Irwell may account for the complete loss of macroinvertebrate life. This would have similarities to the chlorpyrifos pesticide pollution events recorded by Raven & George (1989) in the River Roding and by Thompson et al. (2016) in the River Kennet, both tributaries of the River Thames in southern England. The latter incident was also identified by Riverfly Partnership ARMI citizen scientists following a large-scale macroinvertebrate kill (Brooks et al., 2019).

The Chatterton, Nuttall Park and Burrs Country Park sites with zero macroinvertebrates in April 2017 were monitored for recovery on a monthly basis after the pollution event on the River Irwell. No macroinvertebrates were found in May but the pollution-tolerant olives (Baetidae) were found in small numbers (10 or less, equivalent ARMI score 1-2) in June and July, increasing to 100 or more in September samples (equivalent ARMI score 3). The typical macroinvertebrate community dominated by olives (Baetidae), stone clingers (Heptageniidae) and caddis (Trichoptera) returned to the site by spring 2018.

***4.2. Broad awareness but limited records***

The SFAS was only able to engage citizen science volunteers to continue monitoring for 5 of the initial 13 sites used in the autumn 2011 baseline survey. Of these 5, monitoring ended at Rawtenstall after 20 months (data last collected April 2013) and at Clifton Country Park after 23 months (data last collected June 2013). Monitoring continued on the 3 remaining sites, giving long-term records, to May 2015 on the River Roch and to September 2017 for both the Eagley Brook tributary and Ewood Bridge on the upper River Irwell.

As of June 2020 there are a total of 22 volunteer Riverfly Partnership citizen scientists active across 38 monitoring sites on the River Irwell and broader Mersey catchment, coordinated now by the Mersey Rivers Trust which has taken over the citizen science of the Salford Friendly Anglers’ Society. In total 80 trainees have been certified over four courses with 22 still active as citizen science monitors (20 trainees in 2010, of which 7 are still active; 10 in 2015, 2 still active; 30 in 2018, 12 still active; 10 in 2019, 1 still active). Four of the original Irwell reference sites are now being monitored again (Nuttall Park, Burrs Country Park, Springwater Park, Agecroft) along with two further Irwell sites (in Bury, between the 2011 reference sites at Warth Fold and Springwater Park, and Peel Park in Salford). The spatial extent of monitoring sites has expanded to further Irwell tributaries (2 sites on the River Croal, 3 on Moston Brook, 3 on the River Irk) and across the wider Mersey catchment (1 site on the River Mersey, 4 sites on the River Sett, 8 on the River Bollin, 10 on the River Goyt, 11 on the River Tame).

The potential for geographic coverage and temporal resolution that the ARMI index gives would be unattainable using the more discriminatory professional scoring methods such as BMWP or ASPT, a major advantage of citizen science approaches (Kobori et al. 2016; Shupe 2016). However, monitoring activity is irregular and patchy and, with the informal and devolved organization of citizen science activity, it has proven difficult to capture this data and the volunteer group’s central database is far from comprehensive. It has therefore been difficult to translate citizen science activity into a resilient long-term monitoring programme. Volunteers that have remained active are typically those that have developed active working or social relationships with external “professional” partners involved as coordinators, academic collaborators, or Riverfly Partnership staff. The 3 sites of the original 11 established in 2011, for example, were monitored by such volunteers.

***4.3. Approaches for an effective citizen science monitoring network?***

When planning long-term monitoring, consideration needs to be given to the non-random factors influencing volunteer retention and drop out, in which the quality of relationships developed and sharing of perspectives plays a major role (see for example: August et al., 2019; Groulx et al., 2019; Marsh & Cosentino, 2019). Approaches to sustaining volunteer engagement should be reappraised considering the importance of maintaining links between the data collectors, the accumulating data, and the monitoring outcomes as stressed by Roy et al. (2012) and Pocock et al. (2014).

A major pollution event needs to be detected with minimal delay so that action can be taken to remedy the source and for the statutory authorities to obtain further investigatory evidence. Realistically, monitoring activity once a week is the maximum temporal resolution for even the most vigorous volunteer group. In addition, a point source pollution event will only be detected if a sample is taken from a site downriver. An effective monitoring network therefore depends on appropriate coverage across the catchment and a coordinated roster of sites for weekly samples. This would offer the opportunity to coordinate the three goals competing for the finite time of citizen science monitors: frequent monitoring able to detect major pollution events with minimum delay; breadth of coverage; and specific sites with long-term records. This coverage and frequency is only possible with volunteers (Latimore & Steen 2014; Kobori et al. 2016) but also depends on individual monitors being effectively supported, which has proven a time and resource challenge for volunteer-managed Riverfly Partnership citizen science programme in Manchester.

One possibility to establish durable monitoring sites might be to engage a coordinated network of existing local environmental volunteer groups active along rivers, for example those associated with parks, woodlands and other green spaces. The Mersey Rivers Trust and similar organisations nationwide could also assume a coordinator role within the Riverfly Partnership and perhaps host their own locally managed databases with formal mechanisms to interface with the national database. The Mersey Rivers Trust works closely with the Environment Agency and regional water company, United Utilities in the Catchment Partnerships it leads and could therefore be a viable conduit for flagging chronic and acute pollution concerns raised by citizen scientists and facilitate dialogue with regulators.

***4.4. Deciding pollution alert trigger levels in urban river catchments with low and variable macroinvertebrate diversity***

Unless a pollution event causing large-scale macroinvertebrate mortality also results in fish kills, unusual odours, water discolouration, debris or dying fish it is likely to be unseen, and hence not reported or investigated without ARMI activity. The ARMI methodology is designed specifically to enable trained citizen scientists to detect severe changes in water quality. However, the ARMI assesses a selection of taxa found in clean to moderately polluted water only, rather than all macroinvertebrates including those that can live in highly polluted water as with the BMWP, ASPT and WHPT indices. The ARMI is therefore not sensitive to differences between highly and severely polluted water as scores would simply be zero – whilst BMWP, ASPT and WHPT indices retain sensitivity within more polluted water. It is also interesting to note that, despite anecdotal reports from anglers of less macroinvertebrate life, the extensive winter floods of 2015-16 across northern Britain (Marsh et al. 2016) had no discernible impact on ARMI scores in the monitoring records for the two Irwell catchment sites which cover this period (Ewood Bridge and Eagley Brook). This could be because broad identification groups miss subtler changes (Lenat & Resh 2001). It certainly highlights that the variability of ARMI scores means only severe pollution impacts on macroinvertebrate life are identifiable in the Irwell catchment. The ARMI index was of course explicitly designed to detect acute pollution incidents but this highlights that more detailed monitoring and investigation work would be required to identify subtler chronic pollution and to assess its impacts.

ARMI scores in the urban catchment of the River Irwell are low (ranging from 2 to 9 as typical scores across the sites reported here; see Figure 2) by comparison to other catchments monitored by the Riverfly Partnership (for example, typical ARMI scores of 15-16 for the River Kennett and 10-12 for the River Aire in case studies discussed by Brooks et al., 2019). A challenge therefore has been the inability to set trigger levels to justify an investigatory response by the Environment Agency to lower than usual ARMI scores, particularly when these are only localized drops in macroinvertebrate abundance. Based on 6 years’ data, for example, Ewood Bridge (River Irwell) has a mean ARMI score of 4.41 (SD 1.43, range 2-8) so an ARMI score of 1 would be the realistic trigger level - and that would be insensitive to anything less than a catastrophic macroinvertebrate kill. This is not an issue confined to the River Irwell catchment. as volunteers monitoring urban sites on the River Churnet in Derbyshire became demotivated when using the ARMI method because several of the eight target invertebrate groups do not occur there, as is true of most urban rivers in the West Midlands (Fitch et al., 2018).

This highlights a wider problem at urban river sites with ongoing issues impacting water quality (for example domestic misconnection outfalls), which is that pollution incidents could go undetected and volunteer effort may be wasted should a trigger level be set too low. One solution proposed by Environment Agency staff is to set a default minimum trigger level for all sites that may be suitable for a broad range of river types - but this approach would result in heavily urbanised sections of rivers such as the Irwell consistently failing to achieve this minimum level. For urban catchments we would need to also look beyond ARMI scores to specific changes, for example a sudden drop of a particular invertebrate group, which cannot be attributed to seasonality or normal variation for a site and suggest a pollution event or other incident. The possibility of detecting this type of change in an urban catchment using the ARMI method, however, may be greatly reduced if several of the eight target groups do not occur, as discussed by Fitch et al., (2018), hence why trigger levels cannot be effectively set at River Irwell sites.

The importance of a baseline for specific sites is highlighted by the baseline drop, for example, between Springwater Park (ARMI score 10) and Agecroft (ARMI score 2) 16.5 km downriver. The April 2017 ARMI score of 2 for Springwater Park indicates an impacted macroinvertebrate community, whereas the ARMI score of 2 for Agecroft is consistent with the baseline for this site closer to Manchester city centre. Whether that means the pollution impact of the April 2017 event was negligible at Agecroft we are unable to judge, given the lack of sensitivity of such a low baseline and already markedly degraded community.

In response to observations on urban catchments across the UK, the Environment Agency ecology contact for West Midlands area, Nicola Edgar, has developed an Urban Riverfly index that extends the ARMI by adding a further six invertebrate groups commonly found in urban and modified rivers (worms, snails, beetles, leeches, blackfly larvae (Simuliidae) and freshwater hoglouse (Asellidae)). Pollution sensitive and mildly pollution sensitive invertebrate groups within this Urban Riverfly index score positively according to abundance. Scores for groups such as leeches, worms and freshwater hoglouse that are pollution tolerant (and also populous in slow flowing and canalised urban rivers due in part to depositional sediment rich in organic material), however, become negatively weighted as abundance increases beyond expected levels that occur in unimpacted rivers (Fitch et al., 2018).

There are further pilot studies ongoing within the Riverfly Partnership for “Riverfly Plus” indices of greater complexity that would provide citizen scientists with a monitoring platform sensitive to specific water quality stressors beyond the scope of the existing ARMI index. These are discussed in more detail by Brooks et al. (2019) and include an Extended Riverfly Scheme with additional taxa (extended to 33 invertebrate groups in total) and a River Invertebrate Identification and Monitoring (RIIM) index enabling species-level identification by trained volunteers using a smartphone app. The Urban Riverfly and Extended Riverfly Scheme approaches, with their extended range of pollution tolerance, have the advantage of being more broadly relatable to the UK's statutory WHPT approach, which is also the approach taken by the miniSASS citizen science version of the South African Scoring System (SASS) developed by Graham et al. (2004). All the new Riverfly Partnership indices continue to use the same riverside sampling method of the original ARMI approach.

**4.5. Citizen science as a catalyst for public engagement and change**

The involvement of volunteers and local communities allows monitoring to transcend the limitations of research and monitoring by academics or regulatory bodies and provides scope for implementation of community-led environmental improvement projects (Kobori et al. 2016). This is very much the case with the Riverfly Partnership citizen science programme in Greater Manchester. The Riverfly Partnership group at the SFAS galvanized interest in wider environmental action, community clean up events along the riverside in public green spaces, and in outreach engaging schoolchildren with their local rivers. This community engagement led to media interest, which raised the profile of events and encouraged more people to get involved. As was typical for friendly societies (Cordery 1995), the SFAS has held its regular meetings in public houses for 200 years and this history led to the group and the citizen science work being featured on the British Broadcasting Corporation (BBC) television series “Pubs That Built Britain” in April 2015. The BBC’s Countryfile magazine has also featured the SFAS’ citizen science, wider environmental work and schools outreach (Griffiths 2016).

As has been observed elsewhere (Nerbonne & Nelson 2008), conflicts of volunteer goals, however, were quickly apparent with some anglers not wanting the group to move in an environmental direction and non-anglers wanting to get involved but being discouraged by the SFAS being an “anglers’ society”. The divergence of goals and interest outside the SFAS led to the establishment in 2015 of the Mersey Basin Rivers Trust as a free membership umbrella organization that would be the face of the wider environmental work. This group has now become part of the Mersey Rivers Trust that leads the Upper Mersey (covering the Irwell and tributaries) and Lower Mersey catchment partnerships under the UK government’s catchment-based approach (CaBA) framework for EU Water Framework Directive compliant river basin management plans (Cascade Consulting, 2013; Robins et al. 2017).

As well as 22 ARMI volunteers active (of 80 trained) and 48 sites intermittently monitored, there are a minimum 12 river clean up events per year and further projects and funding from various sources for tackling invasive non-native species such as Giant Hogweed *Heracleum mantegazzianum*, Himalayan Balsam *Impatiens glandulifera* and Japanese Knotweed *Fallopia japonica* along the Irwell and tributaries. Twelve volunteers have been formally trained in Giant Hogweed removal by herbicide spraying, of which 6 are still active, working an average 2 days per year alongside Mersey Rivers Trust staff memberswho carry out invasive species control regularly. Group events removing Himalayan Balsam from specific sites take place typically 15 times per year with an average attendance of 8 people. The programme of trained Riverfly Partnership volunteers has now been subsumed within a volunteer title of “River Guardian” to recognise the broader range of work with which citizen scientists are involved - including the regular testing of water for nitrates and phosphates using test strips for instant, if approximate, field measurements. In that sense, the community engaged with the SFAS and Mersey Rivers Trust have gone beyond the ARMI "collaborative" form citizen science (in which participants help refine the project, analyze results and/or disseminate findings as well as collect data; Thornhill et al., 2019) to co-created citizen science in which participants lead in project design.

Some of the current shortfalls in ARMI records discussed above therefore could be addressed by the Riverfly Partnership and academic collaborators recontextualising macroinvertebrate sampling within a broader appreciation of local communities' interests and extending involvement beyond macroinvertebrate monitoring to a wider programme of community-based environmental monitoring and action. Putting the interests, capacity and motivations of the community first is key to trust and partnership of citizens and for effective community-based environmental monitoring and action (see for example by Gérin-Lajoie et al., 2018). Informing community-based environmental monitoring and action for the Irwell could take a formal engagement with communities, such as done using focus groups and semi-structured interviews by Weber & Ringold (2019) to determine detailed publicly relevant river metrics, or in the first instance by working with existing volunteers and staff at the Mersey Rivers Trust.

**5. Conclusion**

The Riverfly Partnership citizen science network enables the detection of riverine pollution incidents throughout the UK that would otherwise likely go unseen and unreported. Anglers and conservation volunteers trained as citizen scientists provide day-to-day coverage whilst fishing that cannot be matched for awareness and local knowledge by cost- and labor-intensive professional assessments of water quality. Riverfly Partnership citizen science in Manchester and surrounding areas, led by the Salford Friendly Anglers’ Society and now the Mersey Rivers Trust, has established a broad long-term monitoring network with 22 volunteers intermittently active across 38 monitoring sites. However, patchy coordination of records and monitoring activity with the Riverfly Partnership has limited the extent to which citizen science activity has resulted in a resilient long-term monitoring programme and data source. Addressing that should consider citizen science within broader approaches to community-based environmental monitoring centered on the interests of local communities and anglers. The ability of citizen science networks to provide pollution vigilance across a river catchment was demonstrated in April 2017 by detecting a major pollution event and rapidly identifying the location of the pollution source. Work is continuing on how to make the ARMI more appropriate to urban and polluted rivers such as the Irwell with derivatives such as the Urban Riverfly index. Importantly, Riverfly Partnership citizen science has here catalyzed broader environmental engagement, further funding, and led to genuine grassroots environmental action. Challenges remain in terms of coordination, centralized record-keeping and reconciling different goals with limited resources but this case study shows the potential of citizen science to play an important role in the protection and improvement of river catchments.

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**Authors’ contributions**

Adam Moolna (A.M.) designed the study; A.M. and Mike Duddy (M.D.) collated and analysed data; M.D. coordinated training and volunteer activities and led the sampling in April 2017; Ben Fitch (B.F.) and Keith White (K.W.) contributed contextual knowledge, aided in interpreting results and worked on the manuscript.

**Declaration of interest statement**

A.M. is accredited as a trainer for the Riverfly Partnership and has received past consultancy for Riverfly training. M.D. is Projects Manager for the Mersey Rivers Trust. B.F. is the Anglers’ Riverfly Monitoring Initiative Project Manager for the Riverfly Partnership. Initial funding for volunteer training and equipment was provided by a UK National Lottery Awards for All grant of £9800 to the Salford Friendly Anglers’ Society.

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**Figure 1.** Riverfly Partnership reference sites on the River Irwell and tributaries

**Figure 2.** Baseline ARMI scores for 13 sites on the River Irwell and tributaries

**Figure 3.** Long-term records of individual month ARMI scores from 2011: to 2017 for (a) Ewood Bridge on the River Irwell; to 2017 for (b) Eagley Brook; and to 2015 for (c) the River Roch

**Figure 4.** Individual ARMI scores (grey-filled circles) and multi-year mean for each month (solid line) for all samples taken for: (a) Ewood Bridge on the River Irwell 2011 to 2017 (range 2-8, n=61), (b) Eagley Brook 2011 to 2017 (range 4-13, n=58), and (c) the River Roch 2011 to 2015 (range 3-12, n=37).

**Figure 5.** ARMI scores in April 2017 for 7 reference sites along 37 km of the River Irwell from Ewood Bridge (15 km from the source) to Agecroft (52 km from the source) in comparison to autumn (September, October, November) 2011 baseline scores and spring 2012-17 (March, April, May) and autumn 2012-17 scores for Ewood Bridge.

**Figure 6.** Map of sites sampled downriver of the Ewood Bridge reference site on the River Irwell to identify the stretch within which the April 2017 macroinvertebrate kill occurred. Grey-filled circles = sites with no macroinvertebrates and white-filled circles = sites with healthy macroinvertebrate samples (ARMI scores of 4 or more)