Article (refereed) - postprint

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Is freshwater macroinvertebrate biodiversity being harmed by synthetic chemicals in municipal wastewater?

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'Declarations of interest: none'.

KEYWORDS

Wastewater, river, water quality, macroinvertebrate, sensitivity, biodiversity

Abstract: Historically, indices of macroinvertebrate diversity have played a vital role in demonstrating the harmful impacts of poor quality wastewater effluent. The reduction of macroinvertebrate diversity in the past was associated with high organics, low oxygen and high ammonia. There is a current hypothesis that the profusion of micro-organic contaminants escaping in wastewater from modern society are harming macroinvertebrates. Whilst evidence exists for some reduced biodiversity downstream of wastewater treatment plants, it is unclear if such contaminants are responsible. However, evidence from reviewing long-term monitoring records shows consistent and welcome improvements in diversity since the 1990s in the UK. It

is perplexing that more use is not made of such long-term macroinvertebrate records to address questions of chemical impacts.

1.1 Introduction

There is believed to be a worldwide crises of reducing freshwater biodiversity [1]. There has also been a concern over the past 20 years that many of the synthetic chemicals present in treated wastewater are harming aquatic wildlife. Much of this anxiety has been associated with the plethora of pharmaceuticals and personal care products (PPCPs) whose number has steadily increased since WWII and are now very much part of everyday life [2]. The range of chemicals found to escape in wastewater is extraordinary [3]. Aside from the PPCPs, there are a range of other organic compounds which are emanating from the home such as plasticizers, insecticides and flame retardants which heighten the threat [4]. The current popular term for these combined different chemicals are contaminants of emerging concern (CECs) and the issue raises difficult questions of potentially enhanced toxicity through mixture effects [5]. The way European countries have to report the status of their rivers under the Water Framework Directive (WFD) has given an impression of decline due to chemical pollution. For example, a headline in the British newspaper The Sunday Times for 27th January 2019 says '*Dead in the water -86% of UK Rivers threaten wildlife'*. The WFD reporting system is such that only one indicator (typically phosphate concentration) has to fail a standard for a river to be classified as poor. Thus, there is an impression amongst members of the public and indeed many scientists that the river environment in developed countries, such as in the UK, are struggling if not in decline.

1.2. Macroinvertebrate diversity indices

Historically, studying macroinvertebrate communities and their abundances in rivers has been a powerful tool in establishing the health of resident wildlife communities, particularly with respect to pollution. Unlike fish and birds, individual macroinvertebrates cannot easily escape sections of polluted water. With their small size and limited ability to travel long distances, they are seen as reflecting their locality. Macroinvertebrates encompass a very diverse range of organisms from worms to insects, molluscs and crustaceans. There may be hundreds of different taxa in one sediment sample [6]. They perform a wide range of roles in the food web such as scraper, miner, shredder, filterer, gatherer, predator and parasite and possess very different physiologies [7]. This diversity of lifestyles and tolerances has proved very useful to ecologists in revealing the extent of gross river pollution. Back in 1902, it was noted that the variety of different organisms present could be predicted depending on the degree of decaying organic matter present and vice versa which gave rise to the 'saprobic index' [8,9]. Thus, river reaches receiving the highest proportion of wastewater would be dominated by taxa such as Chironomidae and Oligochaeta [10] thanks to their ability to survive in low oxygen levels and tolerate high ammonia. Such organisms would have a low score on the saprobic index. Therefore, different sites and their level of pollution could be compared according to their saprobic index.

In the past 35 years, further developments have occurred in the development of macroinvertebrate metrics to give greater precision in the assessment of pollution stress in a river. The Biological Monitoring Working Party (BMWP) score is the sum of adding the sensitivity scores of all the taxa found at a site [11]*. Thus, hundreds of different macroinvertebrate taxa are each given a score of from 1 to 10 based on observations of their apparent organic pollution tolerance. This can be further broken down into the average score per taxon (ASPT), which may be seen as reflecting how attractive the site is to sensitive organisms [11]. A different sub-component is N_{taxa} which offers the numbers of scoring taxa present. In this case, the score gives an impression of the breadth of organisms and diversity present. A critical aspect is the use of the RIVPACS system where the scores of the nearest unpolluted reference site are given as the reference condition [12]. The strength of this method is that the reference site is selected based on the geological, and elevation similarity to the site of interest, thus, natural regional differences in the presence or absence of certain taxa are allowed for. WHPT, the recent development of BMWP, incorporates abundance weighting as well as taxon presence at a site. This type of sensitivity scoring approach has been further developed for other stressors such as acidification, low flows and sedimentation. A different approach is offered with the Species at risk Index for pesticides (SPEAR) which is based on the theoretical understanding of life-traits that might make a macroinvertebrate more vulnerable to pollution impacts such as those taxa not readily able to recolonize or only reproducing once per year [13]. This has been further developed for habitat degradation [14]. Another approach, coming from the chemical side, is that by knowing the concentration of a range of hazardous chemicals present and hence the potentially affected fraction of species likely to be harmed by these chemicals at those concentrations (msPAF), one could predict the extent of macroinvertebrate diversity depletion [15,16].

2.1 Our less than golden past

Before considering the current situation of the 21st Century, it is instructive to review our past history of river pollution and its impacts on aquatic wildlife. The UK was one of the first countries to industrialize, and big cities often became established along rivers thanks to their associated energy and transportation potential. Unfortunately, it was not long before increasing amounts of both industrial and human waste found its way into rivers. Poor conditions in cities where untreated waste were discharged into rivers were epitomized by the 'Great stink of London' in 1858 [17]. In London, the untreated wastewater, apart from killing resident aquatic wildlife, also led to the death of many1000s' of local citizens from cholera (since the river was also a source of drinking water) from the 1840s' to 1860s'. Whilst the unpleasant appearance of rivers near cities and the damage to fisheries was recognized and often discussed in the press, attempts to tackle the problem were often inadequate. Several things needed to come together at the same time to achieve success including; political will; finance; suitable technology; responsible sewerage undertaker; suitable legal standards and finally a regulatory authority entirely separate from the sewerage undertaker [18]*. Whilst assembling the right infrastructure, legal instruments and institutions was hard enough, the problem itself was continually growing and changing. Technology became unsatisfactory, new polluting industries were set up, such as coal gas power generation which produced particularly harmful waste, whilst population growth constantly outstripped capacity [19]. It is a shock to realize that in the UK, in 1960, almost a 1/3 of rivers contained no fish [10] with improvements only starting to become apparent towards the end of the 1970s [20,21]*. Parts of major European rivers were characterized by very low dissolved oxygen throughout the 1960s' and 70s' [22,23]. Even in the 1980s, authors were concerned that the hard won improvement in water quality may only be temporary [20]. A welcome development that affected European countries came from the introduction of the Urban Waste Water Directive in 1991 (UWWD, Council Directive 91/271/EEC) where advanced treatment was required for sensitive waters (generally leading to activated sludge replacing trickling filter in towns over 10,000 population equivalent). This legal development arrived at a fortuitous moment for the UK, as the sewerage undertakers became privatized in 1989 whilst the regulator remained as a public body [18]. Thus private companies could readily borrow money to improve their infrastructure in response to legal requirements whilst under the scrutiny of an entirely separate regulator. Previously, wastewater treatment was in public ownership and so had to compete for funds in an environment where politicians believed there were ‘no votes in sewage’ and where the regulator was also in effect the polluter [18]!

2.2. Recent short-term studies diagnose an apparent problem

So what can macroinvertebrate diversity tell us about damage being inflicted by the modern cocktail of chemicals, be they PPCPs or CECs of today? Single event (snap-shot) sampling has often revealed a reduced diversity or absence of some sensitive species downstream of waste water treatment plants (WWTPs) or a reduction in some ecosystem process [24-30], although this is not always the case [31]. Many of these authors were tempted to put this reduced diversity down to the presence of the mixture of chemicals escaping in wastewater. But it must be remembered that wastewater effluent also has the potential to change the downstream environment with the introduction of more fine sediments, more nutrients, salts and organic materials too (Fig. 1). This enrichment favours the growth of different benthic algae, and perhaps fewer (or different) macrophytes compared to upstream sites [30,32,33]. If the micro-organic chemicals present in wastewater are the problem, then it might be assumed that taking away the wastewater effluent entirely or using an advanced tertiary treatment process would lead to a recovery of the macroinvertebrate diversity. A laboratory study showed gammarid feeding rate in treated wastewater was apparently improved when activated charcoal was introduced to the experimental tanks [29]. The examples of a small river in France and the White River in the

USA, where closing a poorly functioning WWTP or replacing it with a dramatically improved process led to the return of some sensitive taxa within the limits of a degraded habitat [34,35]. A potentially more valuable study to test the micro-organic contaminant hypothesis was that of the impact of introducing tertiary ozonation to eliminate all organic contaminants from a WWTP in Switzerland which had an existing, acceptably functioning, biological treatment stage [36,37]. Unfortunately, whilst this study did appear to show a benefit as measured by the SPEAR index, the trial was only run for one year. In summary, many authors have and still do call for improvements in wastewater micro-organic contaminant removal on the assumption that this would boost macroinvertebrate diversity [27,29].

There are problems in interpreting the results of short-term studies on local macroinvertebrates and wastewater issues. These can include; the variable rate of recolonization following a previous toxic episode (Fig. 1); flow issues such as if there is or has been a recent drought [38]; and very local issues of river bed morphology which could be influencing the biodiversity [39]. A comprehensive spatial but short-term study of 68 sites along the 2,850 km Danube River, found macroinvertebrate diversity was much more closely linked to habitat features than measured levels of synthetic chemicals including pesticides [33]*. Wastewater quality itself is generally improving over time, so this too represents a moving target [21,40]. Many of the short-term studies have an uncertain reference condition or control sites. This makes it difficult to assess what macroinvertebrate diversity should be for that locality. Not having a long time series of prior and post disturbance leaves uncertainty in assessing the level of recovery, if such it is, of the macroinvertebrate community. Without a long time series, we cannot tell if things are getting worse or better over time. As the numbers and diversity of PPCPs and CECs have apparently increased over recent decades, so it might be assumed that the situation is getting steadily worse.

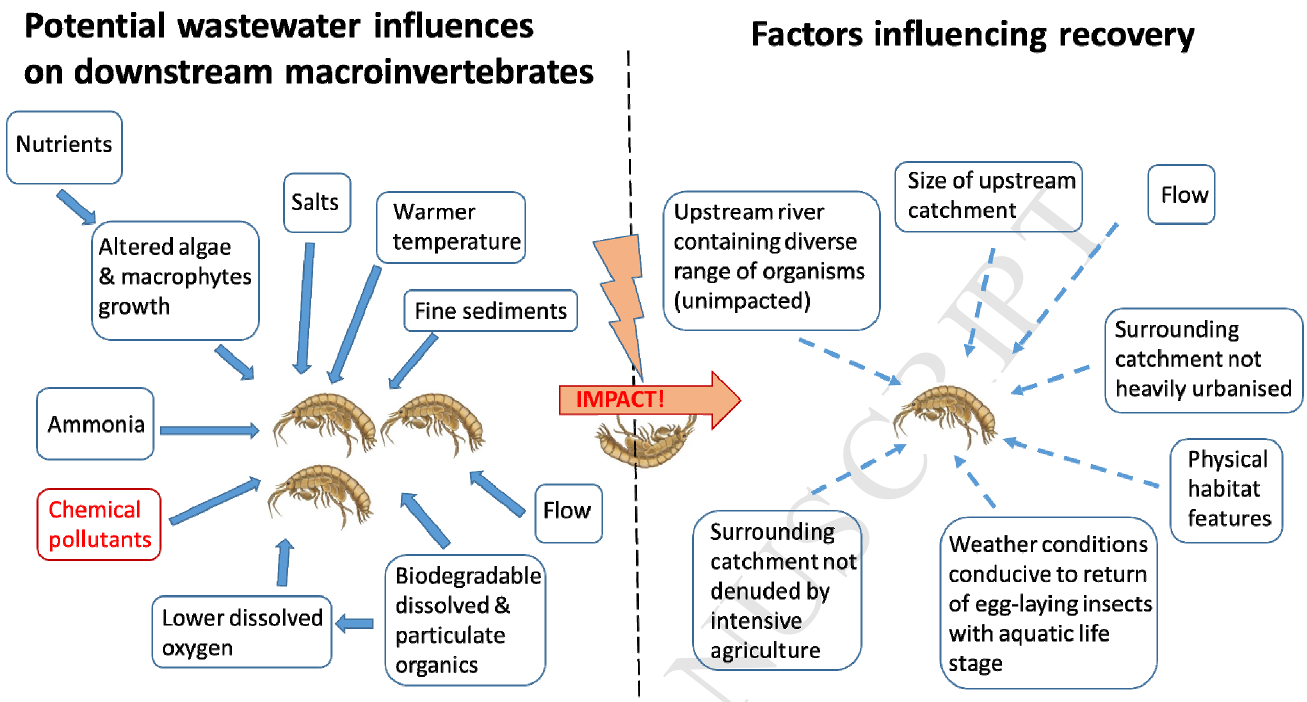

Figure 1. Examples of different features of wastewater potentially influencing downstream macroinvertebrate diversity. On the right, factors that might influence the rate of recovery after an episode which has reduced diversity

2.3. What long-term data sets tell us about wastewater and chemicals

Fortunately, there are some studies which have looked at macroinvertebrate diversity associated with wastewater exposure over several years. For example, a study of macroinvertebrate diversity using data from 1990-1996 in Ohio, USA, found poor diversity in urbanized wastewater receiving sites compared to more rural sites with similar dilution [41]. The authors speculated that WWTPs in more urban centres may be discharging uniquely harmful chemicals due to industries not present in their more rural locations, although such locations tend to have more modified channels. An extensive review of 50 years of broad water quality indicators and macroinvertebrate diversity in 3 locations on the River Trent, UK, starting back in 1952, revealed consistent macroinvertebrate community improvements with better basic wastewater treatment and the disappearance of highly polluting industries from the late 1970s and 1980s [21]*. A similar type of study which examined a wider range of environmental factors (including flow, temperature and metal concentrations) also revealed consistent improvements of macroinvertebrate diversity following dramatic improvements in BOD, DO and NH_3 in 1991 in a wastewater dominated river over 40 years [40]. These observations may go some way to explain the general improvement observed across the UK for macroinvertebrate diversity in Southern England [42] and urban areas reported from the 1990s [43]* which coincide with the UWWD introduction. Thus, despite an increasing use of chemicals, such as those we describe as PPCPs and CECs, this has not inhibited long-term recoveries of macroinvertebrates in the UK.

3.0 Conclusions

So what have we learnt?

- Macroinvertebrate diversity is a superb resource to indicate river health.
- If long-term recording is maintained, in association with chemical monitoring, we have an excellent opportunity to assess chemical impacts on a vital component of a functioning river ecosystem. Such investigations are possible when coupled with information on physical habitat, hydrology and basic chemical quality data
- In the past, impoverished macroinvertebrates diversity has reflected disastrous pollution of rivers downstream of WWTPs. To our shame, this poor condition remained in some rivers into the 1980s.
- Many scientists still report some reductions in diversity and function associated with locations downstream of wastewater effluent

- The evidence from long-term studies showing consistent improvements in macroinvertebrate diversity could be seen as contradicting the view point that the contaminating PPCPs and CECs, still present in effluent, represent a significant threat to such organisms
- It is unclear why scientists have not made more use of long-term macroinvertebrate data. Either very few countries possess it, or there is a lack of imagination in using such information?

Note references highlighted with an asterisk (*) are particularly important

Acknowledgement- This work was supported by the Natural Environment Research Council [NERC grant reference number NEC06550]. The author is grateful for advice and comments from Francois Edwards of CEH. A heartfelt thank you is offered to the many staff of Environment Agency staff and their predecessors in the UK and similar organisations abroad who diligently carry out monitoring in rivers to help protect our environment.

Disclaimer- The views expressed here are those of the author alone.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: