Management of Biological Invasions (2014) Volume 5, Issue 3: 303–307
doi: http://dx.doi.org/10.3391/mbi.2014.5.3.13

Open Access

Proceedings of the 18th International Conference on Aquatic Invasive Species (April 21–25, 2013, Niagara Falls, Canada)

Short Communication

"The pump don't work, 'Cause the vandals took the handles"; why invasive amphipods threaten accurate freshwater biological water quality monitoring

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Received: 30 May 2014 / Accepted: 4 July 2014 / Published online: 12 July 2014

Handling editor: Vadim Panov

Abstract

The 2010 invasion of Great Britain by the eastern European 'killer shrimp' *Dikerogammarus villosus* (Crustacea: Amphipoda) was just the latest of several amphipod invasions of British freshwaters and just one of many amphipod invasions occurring on a global scale. Using examples of previous invasions of other amphipods, *Gammarus pulex* and *Crangonyx pseudogracilis* in The Isle of Man and Northern Ireland, I show that these invaders have the potential to undermine the accuracy of ecological assessment programmes of freshwater, such as those employed in the Water Framework directive (WFD) in Europe and similar schemes used by environmental protection agencies all over the world. Such assessment programmes invariably rely on biological water quality monitoring using biotic indices derived from resident macroinvertebrate assemblages. All three amphipod invaders can greatly undermine accurate water quality biomonitoring in river systems. This can be by invasive amphipods predating upon and/or outcompeting resident macroinvertebrates and thus radically altering resident biodiversity and assemblage structure. This can also occur because these invaders tend to be more physico-chemically tolerant than the resident taxa they are replacing and this greater tolerance of poor organic chemical water quality is not acknowledged in biotic scoring indices. A way forward would be to measure the biological pressure invaders may exert in a biocontamination index or similar, while simultaneously carrying out routine water quality monitoring using biotic indices.

Key words: biocontamination, biological water quality monitoring, *Crangonyx pseudogracilis*, *Dikerogammarus villosus*, *Gammarus*

Introduction

Amphipod crustaceans feature in invasions of inland waters on a global scale (Conlan 1994; MacNeil et al. 1999). They are capable of surviving rigorous introduction mechanisms, such as being transported in poor quality ballast water of ships, allowing them to enter river systems where environmental degradation has diminished resident macroinvertebrate assemblages (Conlan 1994; MacNeil et al. 1999). The amphipod superfamily Gammaroidae contains many species with widely differing physiological tolerances (Walley and Hawkes 1996; Vainola et al. 2008) and *Gammarus* spp. feature in many invasions because of accidental and deliberate introductions connected to shipping, aquaculture, angling and 'ecological experiment' (MacNeil et al. 2012). *Gammarus* spp. possess traits typical of successful invaders such as broad environmental tolerances, diverse diet and rapid reproduction (MacNeil et al. 1997, 1999, 2000a). Invasive *Gammarus* spp. can be more aggressive and predatory than native amphipod species, often replacing them through intraguild predation (IGP – Polis et al. 1989). They are also often more pollution tolerant than the native species they replace (MacNeil et al. 2004).The aim of this paper is to highlight the potential threats such invasive amphipods pose to reliable biomonitoring, wherever in the world such methods are employed.

A well-studied amphipod species replacement in British waters is that of the replacement of the native *Gammarus duebeni celticus* by invading *Gammarus pulex* (Dick 2008). *G. pulex* was introduced from England and Wales to a small

British island, The Isle of Man, by H.B.N. Hynes, between 1949 and 1956 as an 'ecological experiment' (Hynes 1950). This was to see if and how the invader could replace the native and if *G. pulex* was capable of surviving in streams devoid of *G. d. celticus* (MacNeil et al. 2009). *G. pulex* was also introduced from England into Northern Ireland in 1958–59, in order to bolster the salmonid fish food base in angling waters (MacNeil et al. 1999). *G. pulex* was consequently found capable of surviving lower water quality river sites than *G. d. celticus* in both The Isle of Man and N. Ireland (MacNeil et al. 2004, 2009). Invasive *G. pulex* was also found to be more predatory than *G. d. celticus* to a wide range of co-occurring macroinvertebrates (Kelly et al. 2002). A field study found that macroinvertebrate assemblage composition, biomass and diversity differed markedly between *G. pulex* and *G. d. celticus* dominated areas in contiguous reaches of a Northern Irish river, where water chemistry remained constant (Kelly et al. 2006). These differences were ascribed to increased competition and predation by the invader relative to the native (Kelly et al. 2006). *G. pulex* has also been found in 'super-abundance' within invaded sites, for instance, in sites in the Killymoon River, Northern Ireland (near the original introduction points) it constitutes 85% of all the macroinvertebrates present in terms of relative abundance, whereas the native *G. d. celticus* rarely exceeds 10% in physico-chemically similar sites (MacNeil 1997; MacNeil et al. 2000b). Similarly, in the Isle of Man, *G. pulex* greatly dominates kick samples taken for river water quality monitoring purposes and in these monitoring sites, biological monitoring is disregarded and water quality assessment is solely dependent on chemical monitoring (MacNeil pers. obs.).

Crangonyx pseudogracilis is a North American amphipod that has invaded both Northern Ireland and The Isle of Man in the last few decades (Dick et al. 1997; MacNeil et al. 2000b). Although mainly herbivorous (MacNeil et al. 1997), river field bioassay experiments and surveys have indicated this invader can survive much lower organic water quality than either *G. d. celticus* or *G. pulex* (Holland 1976; MacNeil et al. 2000a, 2009).

The purpose of this study is to use data sets of British macroinvertebrate assemblages to investigate if *G. pulex* and *C. pseudogracilis* presence is currently undermining the accuracy of biotic indices used to assess water quality, as these measures still assume both invaders are equivalent to native amphipods in terms of physico-chemical tolerance and they have the same competitive / predatory impact on all other taxa used within indices. In the context of the recent invasion of British freshwaters by a far more predatory amphipod invader, the 'killer shrimp' *Dikerogammarus villosus* and its current British range expansion (MacNeil et al. 2010, 2013), this study aims to assist management decisions which depend on the reliability of biological water quality measures when invaders are present.

Methods

The Biological Monitoring Working Party (BMWP) score, number of BMWP taxa and the derivative Average Score Per Taxon (ASPT) score are the main established indices used to assess biological water quality in the U.K. and The Isle of Man (see Biological Monitoring Working Party 1978; Armitage et al. 1983 and for BMWP taxa list and calculation of indices). The BMWP score is an additive index based on the presence/absence of scoring macroinvertebrate taxa (usually identified to family level) rated 1–10 based on perceived sensitivity to organic pollution, 1 being most tolerant, 10 being most sensitive. *G. d. celticus*, *G. pulex* and *C. pseudogracilis* are all assigned the same score in the BMWP system (6) and assumed to have the same sensitivity to organic pollution. In this study I used combined data sets from Island wide surveys of both N. Ireland (MacNeil 1997; MacNeil et al. 2000b, 2001) and The Isle of Man (MacNeil et al. 2009, 2010) and data sets from the Isle of Man Government water quality monitoring programme.

I calculated ASPT values for macroinvertebrate assemblages co-occurring with each of these three amphipod species (single amphipod species sites), with the amphipod score not included in the calculation to remove its influence on the final score (see MacNeil 1997; MacNeil et al. 2000a,b, 2001, for N. Ireland site details – 30 single species *G. d. celticus* sites, 25 *G. pulex* sites and 8 *C. pseudograclis* sites and see MacNeil et al. 2009 for Isle of Man site details, 20 *G. d. celticus* sites, 18 *G. pulex* sites and 7 *C. pseudogracilis* sites). Samples were all taken in the autumn / winter sampling season. In all surveys, macroinvertebrate assemblages were collected via a standardised 3 minute kick sampling technique, the established field protocol for BMWP biological monitoring (Armitage et al. 1983). Because index data defied normalisation, a separate Kruskal-Wallis test was used for N. Ireland and The Isle of Man, to examine if the three amphipod species co-occurred with macroinvertebrate assemblages with similar or different sensitivities to organic water quality.

To ascertain if an invader amphipod presence may have a different impact on co-occurring taxa than a native, the number of BMWP taxa (Armitage et al. 1983) co-occurring with either the native or invader were compared in river sites which were not significantly different physico-chemically from one another. Such systems are available in N. Ireland. This was done in respect of *G. pulex* and *G. d. celticus* single amphipod species sites in the Killymoon/Ballinderry river system network (10 *G. pulex* sites and 6 *G. d. celticus* sites; sites ranging between U.K. O.S. grid references H799721 and H835764, MacNeil 1997; MacNeil et al. 2000a). Samples were taken during the spring and a Mann-Whitney U-test was used to examine if the natives and invaders occurred with a similar or different number of resident BMWP scoring taxa.

Results

There was a significant difference in mean ASPT values for assemblages co-occurring with different amphipod species ($P < 0.01$ for both N. Ireland and Isle of Man; Figure 1). For both countries, the pattern was the same, with the lowest ASPT values, indicating the assemblages most tolerant of organic pollution, occurring with *C. pseudogracilis* and significantly higher ASPT values indicating the least tolerant, most sensitive assemblages occurring with the native *G. d. celticus*. In both cases, intermediate ASPT values, indicating moderately sensitive/tolerant assemblages, occurred with *G. pulex*. In the Killymoon/Ballinderry River system, less than half the mean number of BMWP scoring taxa were found when *G. pulex* was present compared to sites containing only the native ($U = 8.5$, $P < 0.05$; Figure 2).

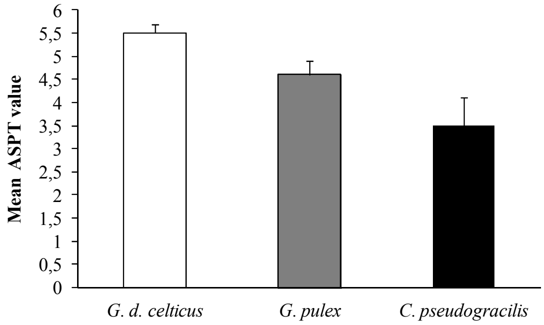

Figure 1. ASPT values (mean ± SE) for macroinvertebrate assemblages co-occurring with either the native *G. d. celticus* or the invader *G. pulex* or the invader *C. pseudogracilis* in river sites in Northern Ireland and The Isle of Man (data sets combined).

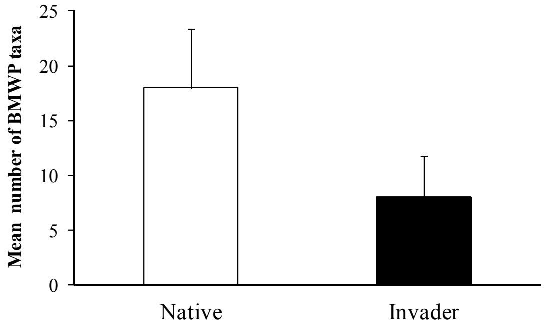

Figure 2. Number of BMWP scoring taxa (mean ± SE) co-occurring with either the native *G. d. celticus* or the invader *G. pulex* in river sites in the Killymoon-Ballinderry system, Northern Ireland.

Discussion and Conclusions

This study clearly shows that invasive amphipods such as *G. pulex* and *C. pseudogracilis* are already undermining the reliability of established biotic indices. Field and laboratory studies have repeatedly indicated that *G. pulex* is more tolerant of lower organic water quality and accompanying dissolved oxygen levels than *G. d. celticus* (MacNeil et al. 2004, 2009). Additional studies have indicated that *C. pseudogracilis* is far more tolerant than either of these *Gammarus* spp. (MacNeil et al. 2000a).

Holland (1976), Walley and Hawkes (1996) and MacNeil et al. (2000a) have all recognised that some invasive amphipods in Britain are more pollution tolerant than natives and both suggested downgrading their values in indices such as the BMWP scoring system relative to the native amphipods they may be replacing. Survey data from Northern Ireland and The Isle of Man shows that *C. pseudogracilis* are found with assemblages containing taxa such as oligochaetes, isopods, chironomids reflecting poor water quality while *G. d. celticus* occurs in assemblages containing mayfly, stonefly and caddis reflecting much higher water quality. However both amphipod species score the same (6) in the BMWP system. This means if included in the ASPT index *C. pseudogracilis* presence will have a disproportionately 'boosting' effect on an ASPT score in such sites, as the rest of the score will have been generated by mostly very low scoring, highly tolerant taxa. This 'boosting' effect may well not be present in *G. d. celticus* sites as scores here will have been generated by similarly relatively high scoring taxa.

Greater physico-chemical tolerance is just one confounding factor linked to invader presence and water quality assessment. Another important aspect shown here is the higher competition / predation pressure exerted by invaders on resident assemblages. Within many sites in N. Ireland and The Isle of Man *G. pulex* is the dominant macro-invertebrate in terms of both relative abundance and biomass (MacNeil 1997; MacNeil et al. 1999) and consequently taxa such as mayfly, stonefly and caddis may be subject to far higher predation than when a scarcer, less predatory *G. d. celticus* is present (Kelly 2002). An additive taxa presence / absence index such as the BMWP may thus be severely impacted if certain BMWP taxa are simply wiped out by an invader and they can obviously no longer contribute to an index.

Dikerogammarus villosus, the 'killer shrimp' is a Ponto-Caspian amphipod invader that has spread rapidly throughout Central Europe and was first detected in the British Isles in 2010 (MacNeil et al. 2010). The 'super-abundance' of *D. villosus*, as it establishes itself dominating the resident macroinvertebrate assemblage, can simplify assemblage structure and trophic links (Dick et al. 2002; van Riel et al. 2006). These latter are probably already well under way within invaded sites in Britain (C. MacNeil, personal observation). In The Netherlands, rapid declines in both native and previously successful invasive *Gammarus* spp. have been attributed to IGP by *D. villosus*. (Dick et al. 2002). Many studies indicate it is far more predatory of macroinvertebrate taxa than any amphipod species currently resident in Britain (Dick et al. 2002; MacNeil et al. 2013). Given that *D. villosus* is currently expanding its U.K. range and is predicted to have a much greater impact on freshwater assemblages than either of these two invaders (Dodd et al. 2014), this study may indicate the degree of caution needed when assessing water quality. Preliminary laboratory studies have already shown that *D. villosus* will probably have a major deleterious effect on BMWP taxa and therefore the reliability of water quality assessments based on such assemblages (MacNeil et al. 2013).

This study joins an increasing number questioning the credibility of established biological water quality monitoring programmes when potentially damaging invaders are present. Realising the need to integrate this biological pressure into monitoring programmes Arbačiauskas et al. (2008) proposed a 'biocontamination index'. This simple method is designed to utilise routine monitoring data and so should require minimal extra effort, expense or expertise to that already expended in routine water quality programmes. This then grades monitoring sites into classes ranging from no biocontamination (no invaders present) up to severe biocontamination (invaders dominating assemblage richness and/or abundance). A general rule may be that the greater number of invader taxa and invader individuals present in a monitoring site, the greater the scrutiny any water quality index used should be subjected to. Whatever the method employed, managers should routinely establish some method of recording the relative importance of an invader in a biological water quality monitoring program. Only then can one decide on the reliability of indices to actually reflect water quality and not some biological pressure and hence make sound management decisions based on such data.

Acknowledgements

Thanks to Prof. Jaimie Dick of Queens University, Belfast, Dr. Dirk Platvoet and staff at the Isle of Man Government Laboratory. Thanks to two reviewers whose comments improved this manuscript.

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