EVALUATION OF THE GAMMARUS PULEX IN SITU FEEDING ASSAY AS A BIOMONITOR OF WATER QUALITY: ROBUSTNESS, RESPONSIVENESS, AND RELEVANCE

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Abstract—Biomonitoring using benthic macroinvertebrates has been used to assess water quality in Europe since the early 20th century. Most methods use community-level measurements, and the use of single-species responses has been limited, despite their potential benefits as sensitive, early warning indicators. Here we evaluate a single-species in situ assay in which the response is feeding inhibition of the freshwater amphipod Gammarus pulex. The assay was deployed in uncontaminated reference sites to quantify background variability in feeding rates and to elucidate sources of this variation. The ability of the assay to detect impacts of point-source discharges was assessed and the ecological relevance of the assay determined by comparing assay responses to aspects of community structure and functioning. Water temperature accounted for 76% of the variation in the feeding rate of animals deployed at uncontaminated sites, and summer deployments had a >90% power to detect a 30% inhibition in feeding. Inhibition of the in situ feeding rate of G. pulex deployed downstream of a variety of point-source discharges ranged from 27 to 99.6%. Gammarus pulex is an important detritivore in stream communities, and a strong positive correlation existed between in situ feeding rate measured over 6 d and leaf decomposition measured over 28 d. A positive correlation also existed between in situ feeding and macroinvertebrate diversity and a biotic index. The G. pulex in situ feeding assay is a short-term sublethal biomonitor of water quality that is indicative of community- and ecosystem-level responses occurring over longer time periods. It is robust, responsive, and relevant.

Keywords—In situ assay Biomonitor Gammarus pulex Feeding inhibition

INTRODUCTION

Monitoring is an important component of environmental management; it is essential for determining the impact of contaminants on natural ecosystems and for assessing the efficacy of pollution control measures. The quality of rivers and streams has been monitored using both chemical and biological measures, the most commonly used biomonitoring approaches being based on benthic macroinvertebrates [1,2]. Biomonitoring has been used to assess water quality in Europe since the early 20th century, and several biotic indices based on the indicator concept have been developed [2–4]. This approach has been developed further in the United Kingdom, where multivariate methods that use site-specific environmental information to predict community structure expected at a site have been employed [5]. Methods based on the indicator concept have been less widely used in North America, where the emphasis has been more on diversity indices and chemical measures of water quality [6]. Recently, however, multimetric indices have been developed that integrate biotic, diversity, and trophic indices [7,8].

The methods referred to previously rely on detecting changes in macroinvertebrate community structure and, as such, require individuals, species, or even families of macroinvertebrates to be eradicated from a site before impact can be detected. An alternative approach is to develop methods based on sublethal responses of single species. Sublethal single-species responses are more sensitive and respond more rapidly than community-based measures and are, therefore, particu-
proposed as an in situ indicator of water quality [15]. However, the feeding rate of G. pulex is affected by many intrinsic and extrinsic factors. Intrinsinc factors include parasite load [23], source population [17,18], and body size [24]. Extrinsinc factors include temperature [25], dissolved oxygen concentration [25], and pH [26]. Feeding rate will therefore vary, depending on the status of the organisms and the environmental conditions to which they are exposed. To be useful as a general indicator of water quality, this variability must be characterized and its causes identified. Gammarus pulex is a detritivore, feeding primarily on coarse particulate organic matter, but it will also consume other food sources, including algae and other animals [27]. It plays an important role in detritus processing in streams and is an important prey species for fish [28]. Inhibition of the feeding rate of G. pulex is correlated with reduced growth and reproduction [29]. Correlations between feeding inhibition and community structure and functioning (detritus processing) are investigated in this study.

METHODS

Collection and maintenance of G. pulex

Adult male G. pulex (mean size = 8.24 mg dry wt, standard error = 0.1) were collected from Crags Stream, Derbyshire, United Kingdom (National Grid Reference SK 497 745), and maintained in the laboratory for 5 to 10 d prior to deployment. Animals were maintained in 20-L aquaria containing aerated artificial pond water [30] and fed an ad libitum diet of alder leaves (Alnus glutinosa) inoculated with the fungus Cladosporium sp. [26]. Aquaria were kept in a temperature-controlled room (15 ± 1°C) under a 12:12-h light:dark cycle.

Deployment sites

Thirty-five deployments at 24 reference sites and 22 deployments at 15 contaminated sites were performed over the period July 1997 to September 1998 (Table 1). Rivers in England and Scotland were selected to cover a range of physicochemical characteristics and geographical locations. Deployments were repeated in winter and summer/autumn at six reference sites and five contaminated sites to assess temporal variability in response. Contaminated sites were 100 to 1,000 m downstream of point-source discharges and had a corresponding reference site 100 to 1,000 m upstream of the discharge. No known diffuse inputs existed between the reference and contaminated sites. The exception to this deployment strategy was the September 1998 deployment on the River Aire (United Kingdom). The River Aire receives a large number of point-source discharges, and therefore animals were deployed at four sites along the river, two reference and two contaminated.

Environmental measurements

A suite of environmental variables was measured on each deployment occasion. Conductivity, pH, dissolved oxygen concentration, and water temperature were measured using handheld meters (Jenway Models 4071, 3150, and 9071, Dumnow, Essex, UK). Flow rate was measured using an Ott Current Meter (Model C2, Kempten, Germany), and 1-L water samples were collected in food-quality polyethylene terephthalate containers for determination of alkalinity. In addition, river width and depth were measured and bed substrates characterized. These variables, along with altitude and distance from source, both of which were obtained from maps, were used as input values for River Invertebrate Prediction and Classification System (RIVPACS) [31]. The RIVPACS software uses site-specific environmental data to predict what macroinvertebrates should be present at a site assuming it is uncontaminated. Deviations from the predicted assemblage and associated biotic indices are then used as a measure of impact.

In situ feeding rate measurements

In situ deployments followed the methods described previously [15,25]. Thirty adult male G. pulex were deployed for 6 d in individual polyvinyl chloride cages (5 cm long, 5 cm diameter), the ends of which were capped with 1-mm mesh. Each animal was provided with a known weight of presoaked (24 h) Cladosporium-inoculated alder leaf material as a food source. Five cages, containing leaf material only, were deployed per site to control for leaf weight gain or loss in the field. Cages were randomly allocated in groups of 17 or 18 to 2.5-cm-mesh holding baskets and positioned with the bore of the cage parallel to the direction of water flow. Holding baskets were secured to the streambed using bricks.

Cages were retrieved after 6 d, and the number of live and dead animals was recorded. Cages containing dead animals were discarded. Animals alive at the end of the deployment period were killed before being dried in an oven at 60°C for 4 d and weighed. Food material remaining in each cage was removed, gently rinsed in clean water, dried in an oven at 60°C for 4 d, and weighed. Feeding rate (FR, mg dry wt food/mg dry wt animal/d) of each G. pulex surviving the 6-d deployment was calculated using Equation 1:

\[ FR = \frac{(L_i \times C_i) - L_s}{W \times 6} \]  

where \( L_i \) is the dry weight of food material initially supplied (mg), \( L_s \) is the dry weight of leaf material remaining after 6 d (mg), \( W \) is the dry weight of G. pulex (mg), and \( C_i \) is the leaf weight change correction factor given by the mean of the quotient of the final (6 d) to initial weight of control leaves.

Benthic macroinvertebrate community structure

The benthic macroinvertebrate community was sampled at 14 reference sites and 11 contaminated sites over the period July to September 1997 and July to September 1998. At most sites, 25 benthic samples were taken using a Hess sampler (basal area: 700 cm²). The exceptions were the Barlow Brook and Coombes Brook sites, where 3-min kick samples were taken because the water depth was too low for Hess sampling. Samples were preserved in 70% ethanol and all macroinvertebrates identified to species, where possible, and enumerated. Site-specific species lists were used to calculate Shannon diversity (H' [32]) and the average score per taxon (ASPT) biotic index, which is derived from the biological monitoring working party (BMWP) score [33,34]. The ASPT ranges from 0 (no scoring macroinvertebrate present) to 10 (all scoring macroinvertebrates are pollution sensitive). In contrast, the BMWP score has no upper limit. The ASPT expected at a site (assuming it is uncontaminated) can be predicted using RIVPACS and the observed-to-expected quotient used as an ecological quality index (EQI ASPT [35]). Similarly, an ecological quality index based on the number of taxa observed and expected at a site can be calculated (EQI N-taxa). The EQI ASPT and EQI N-taxa are used in the Environment Agency's biological general quality assessment to classify rivers in England and Wales [35].
Table 1. Details of deployment sites in the United Kingdom used for the in situ *Gammarus pulex* feeding assay

<table>
<thead>
<tr>
<th>Site (river, county)</th>
<th>National grid reference</th>
<th>Deployment date (no.)</th>
<th>Discharge source</th>
<th>Contaminants</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Aire, West Yorkshire</td>
<td>SD944537 R</td>
<td>9/9/97 (1)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Barlow Brook, Derbyshire</td>
<td>SK366751 C</td>
<td>7/17/97 (8)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>River Chess, Buckinghamshire</td>
<td>SP954014 R</td>
<td>8/20/98 (9)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Chew Brook, Greater Manchester</td>
<td>SE012038 R</td>
<td>7/29/97 (10)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>River Conder, Lancashire</td>
<td>SD499576 R</td>
<td>8/12/97 (12)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Coombe Brook, Oxfordshire</td>
<td>SD496573 C</td>
<td>8/12/97 (13)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Coombes Brook, Derbyshire</td>
<td>SK009023 C</td>
<td>8/13/97 (15)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Crags Stream, Derbyshire</td>
<td>SK497745 R</td>
<td>8/26/98 (—)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>River Don, South Yorkshire</td>
<td>SE212030 R</td>
<td>7/15/97 (17)</td>
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<td>None</td>
</tr>
<tr>
<td>River Esk, Dumfrieshire</td>
<td>NY355853 R</td>
<td>9/19/97 (21)</td>
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<td>None</td>
</tr>
<tr>
<td>River Evenlode tributary, Oxfordshire</td>
<td>SP285263 R</td>
<td>8/5/98 (—)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>River Goyt, Derbyshire</td>
<td>SK008798 R</td>
<td>8/27/97 (28)</td>
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<td>None</td>
</tr>
<tr>
<td>Limb Brook, South Yorkshire</td>
<td>SK318818 R</td>
<td>1/28/98 (—)</td>
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<td>None</td>
</tr>
<tr>
<td>River Loxley, South Yorkshire</td>
<td>SK323694 R</td>
<td>1/24/98 (—)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>New Mill Dyke, West Yorkshire</td>
<td>SE164074 R</td>
<td>1/27/98 (—)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Pinch Beck, West Yorkshire</td>
<td>SE174005 R</td>
<td>1/27/98 (—)</td>
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<td>None</td>
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<tr>
<td>River Rib, Cambridgeshire</td>
<td>TL398232 R</td>
<td>8/20/98 (—)</td>
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<td>None</td>
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<tr>
<td>Strines Dike, South Yorkshire</td>
<td>SK219908 R</td>
<td>8/26/98 (—)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>River Tame, Greater Manchester</td>
<td>SE992044 R</td>
<td>9/23/97 (35)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>River Test, Hampshire</td>
<td>SU516500 C</td>
<td>9/24/97 (—)</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

* R = reference sites, C = contaminated site.
* STW = sewage treatment works.
* OP = organophosphorus pesticides, OC = organochlorine pesticides.

Leaf litter processing

The processing of leaf litter was quantified at 18 sites (nine reference and nine contaminated) over the period January to March 1998 and coincided with deployments of the in situ feeding assay. Alder leaf material, collected in the autumn after abscission but before leaf fall, was air dried and stored until use. Two types of leaf bags were deployed at each site. Coarse-mesh bags (5- × 4-mm mesh) allowed macroinvertebrates to feed on the leaf material and were used to estimate total processing rates due to macroinvertebrate feeding, microbial decomposition, and, to a lesser extent, physical abrasion. Fine-mesh bags (1-mm mesh) prevented macroinvertebrates feeding
on the leaf material and reduced loss of leaf material due to physical abrasion. These bags were used to determine microbially mediated leaf processing rates. The difference in weight loss between coarse- and fine-mesh bags was used as a measure of macroinvertebrate-mediated leaf processing rates.

Approximately 1 g of alder leaf material was placed in each mesh bag (mean = 1.004 g, standard error = 0.003). Each bag was uniquely labeled and weighed prior to deployment. Ten coarse- and 10 fine-mesh bags were deployed per site. They were secured to bricks using fishing line and left in situ for 28 d. On retrieval, the remaining leaf material was carefully removed from each bag, washed gently to remove accumulated silt, dried in an oven at 60°C for 5 d, and weighed.

Data analysis

Between-deployment site variation in feeding rate was assessed using one-way analysis of variance, and within-deployment site variation (between seasons) was assessed using paired t tests. The mean and variance for each deployment were used to perform a power analysis assuming 30 replicates and α = 0.05. The relationship between feeding rate and site-specific environmental factors was investigated using stepwise multiple regression.

The ability of in situ feeding rate to assess changes in water quality was evaluated by comparing the feeding rate of animals deployed upstream and downstream of point-source discharges. Feeding rates were tested for normality, and the significance of between-site comparisons was evaluated using Mann–Whitney or two-sample t tests. Pearson product moment coefficients and least-squares regression procedures were used to explore the association between in situ feeding rate and survival, ecosystem functioning (leaf litter processing), or community structure (H', ASPT). Statistical analyses were performed using Minitab® Release 13, and the significance level was p < 0.05.

RESULTS

Variability in in situ feeding rates at reference sites

Significant variation was observed in the in situ feeding rate of G. pulex deployed at uncontaminated reference stations over the period July 1997 to September 1998 (F<sub>35,901</sub> = 40.6). Mean (standard error) feeding rates ranged from 0.43 (0.03) mg/mgd for animals deployed in the River Esk in July 1998 (deployment 22) to 0.03 (0.006) mg/mgd for animals deployed in Strines Dike in August 1998. With the exception of Strines Dike, the lowest feeding rates were recorded for animals deployed in the winter months (Fig. 1), and for all sites where animals were deployed on more than one occasion, feeding rates for animals deployed in summer/autumn (July–September) were significantly higher than those for animals deployed in winter (January–February) (t<sub>24</sub> > 8.1).

Survival of deployed animals was greater than 73% except for animals deployed at Strines Dike (57%). Strines Dike is an acid (pH = 4–6) moorland stream, the natural community of which is devoid of crustaceans [36]. Results from Strines Dike were omitted from subsequent analyses. No significant correlation was observed between the survival and the feeding rate of G. pulex deployed at reference sites (r = 0.18, n = 35).

Regression analysis indicated that 79% of the between-deployment variation in feeding rate could be accounted for by between-deployment variation in water temperature and alkalinity (Eqn. 2) and 76% by water temperature alone (Eqn. 3). The maximum amount of variation that could be accounted for by the environmental variables recorded (pH, temperature, alkalinity, conductivity, flow, and dissolved oxygen) was 82%:

\[ \log(\text{FR}) = 0.072T - 0.002\text{Alk} - 1.47 \quad (r^2 = 79\%) \]  
\[ \log(\text{FR}) = 0.065T - 1.49 \quad (r^2 = 76\%) \]  

where FR is in situ feeding rate (mg dry wt food/mg dry wt animal/d), T is water temperature (°C), and Alk is alkalinity (mg/L CaCO<sub>3</sub>). Water temperature at reference sites ranged from 1.8 to 18.3°C, and alkalinity ranged from 6.9 to 157 mg/L CaCO<sub>3</sub>.

Seasonal variation in feeding rate was reflected in seasonal variation in the statistical power of the assay. Mean power of the assay (n = 30) to detect a 20, 30, or 50% change in feeding rate was 20, 38, and 66%, respectively, for the winter deployments compared to 64, 91, and 99.8% for summer/autumn deployments. A sample size >100 would be required to achieve a power of 90% to detect a 30% reduction in the feeding rate of animals deployed in winter.

Responsiveness of in situ feeding rate to changes in water quality

Survival of G. pulex deployed for 6 d at contaminated sites ranged from 53 (deployment 6) to 100% (deployment 27). In situ feeding rate of G. pulex deployed at contaminated sites was less than the feeding rate of animals deployed at reference stations, but no significant correlation was observed between the survival and feeding rate of animals deployed at contaminated sites (r = 0.03, n = 21).

An inhibition of feeding was observed for animals that were deployed in summer/autumn and winter (Fig. 2, W<sub>25,32</sub> > 820, t<sub>2,25</sub> > 2.5), and the inhibition in feeding rate ranged from 99.6 (deployment 11) to 16.5% (deployment 26). Feeding inhibition was generally greater for animals deployed at a site in winter than in summer/autumn (Fig. 2), the exception being the River Esk, where animals deployed in summer/autumn (deployment 24) exhibited a similar feeding inhibition as those deployed in the same site in winter (deployment 25).

Reference and contaminated sites differed in a number of environmental factors, including water temperature and alkalinity, and between-site differences in feeding rate may not, therefore, be a result of contamination. Equation 2 was used to predict the feeding rate expected at a site in the absence of contaminants. Figure 3 compares feeding rates predicted for

Fig. 1. Mean (±1 standard error) in situ feeding rate of adult male Gammarus pulex deployed at reference sites in England and Scotland for 6 d.

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animals deployed at contaminated sites to those measured in situ in summer/autumn. For only three of the 13 downstream deployments (deployments 15, 19, and 26) could the inhibition in feeding rate be possibly explained in terms of site-specific differences in environmental factors, and for only one deployment (River Esk, deployment 26) was the measured in situ feeding rate greater than that predicted.

Relationships between in situ feeding rate and macroinvertebrate community structure and functioning

Over 100 taxa were identified in benthic samples from 25 sites, and summary statistics are presented in Table 2. Taxon richness ranged from 50 to 24 at reference sites and from 30 to 7 at contaminated sites. Shannon diversity ranged from 3.9 to 1.6 for reference sites and from 3.0 to 0.9 for contaminated sites. A significant positive correlation was observed between in situ G. pulex feeding rate measured over 6 d and Shannon diversity \( (r = 0.7; \text{Fig. 4}) \). A significant positive correlation was also observed between in situ G. pulex feeding rate and ASPT \( (r = 0.6; \text{Fig. 4}) \).

The RIVPACS was used to predict the benthic macroinvertebrate assemblage expected at each site, and ecological quality indices were calculated for taxon richness (EQI N-taxa) and a biotic index (EQI ASPT). The ecological quality indices were used to grade sites according to the Environment Agency’s biological general quality assessment scheme \[35\]. Mean feeding rate differed significantly among grades \( (F_{428} = 2.8; \text{Fig. 5}) \) and ranged from a mean of 0.3 mg/mg/d for grade b sites (good quality) to 0.001 mg/mg/d for grade e sites (bad quality).

A significant positive correlation was observed between G. pulex feeding rate measured in situ over 6 d and total leaf decomposition measured in situ over 28 d \( (r = 0.83; \text{Fig. 6}) \). Moreover, a significant positive correlation was observed between in situ feeding rate and macroinvertebrate-mediated leaf decomposition.

![Graph of feeding rate and Shannon diversity](image)

**Fig. 4.** Relationship between mean in situ Gammarus pulex feeding rate and average score per taxon (open symbols) or Shannon diversity (closed symbols) at reference and contaminated sites.

![Graph of feeding inhibition](image)

**Fig. 2.** Inhibition of in situ feeding rate of Gammarus pulex deployed downstream of point-source discharges for 6 d in summer/autumn (solid bars) or winter (open bars). Feeding inhibition is given by \( \left( FR_u - FR_d \right)/FR_u \times 100 \), where \( FR_u \) is the mean feeding rate of animals deployed upstream of the discharge and \( FR_d \) is the mean feeding rate of animals deployed downstream of the discharge. Deployment numbers are defined in Table 1, and underscoring of deployment numbers indicates sites at which animals were deployed in both summer/autumn and winter.

![Graph of predicted feeding rate](image)

**Fig. 3.** Predicted (open bars) and mean measured (solid bars) in situ feeding rate of Gammarus pulex deployed at contaminated sites for 6 d in July to September 1997 and July to September 1998. Error bars denote 95% confidence interval. Note that the feeding rate of animals deployed at site 11 was very low (0.0012 mg/mg/d).
decomposition by the natural benthic community (r = 0.7; Fig. 6).

DISCUSSION

The aim of this study was to evaluate the usefulness of the G. pulex in situ feeding assay as a biomonitor of water quality. Three aspects of the assay were investigated: background variability and statistical power (statistical robustness), sensitivity of the assay to point-source discharges (responsiveness), and relationship between assay response and macroinvertebrate community structure and functioning (relevance).

Statistical robustness was assessed by conducting 35 deployments at 24 uncontaminated sites. Significant between-site variation was observed in the in situ feeding rate of G. pulex, but 79% of this variation could be accounted for by between-site differences in water temperature and alkalinity, and 76% of the variation could be accounted for by water temperature alone. Water temperature has been shown previously to have a major influence on G. pulex feeding rate, the feeding rate of 8 to 10 mg animals being reduced by 90% at 2°C compared to 15°C [24]. It has been demonstrated that a 25 to 30% reduction in G. pulex feeding rate can result in significant reductions in individual growth rate and reproduction (L. Maltby, unpublished). In summer/autumn deployments, the assay had a greater than 90% power of detecting a 30% depression in feeding rate using a sample size of 30 animals. The lower feeding rates of animals deployed in winter were associated with a reduction in the power of the assay, power to detect a 30% reduction in feeding rate being only 38%. Therefore, if this assay was to be deployed in low-temperature waters, the sample size would have to be increased substantially to compensate for the reduction in power.

The G. pulex in situ feeding assay was deployed upstream and downstream of a number of point-source discharges in order to assess its responsiveness to a range of effluents. The effluents studied were from sewage treatment works, dye manufacturers, food processors, paper product manufacturers, paper processors and recyclers, and disused coal mines. Consequently, animals deployed in situ were potentially exposed to a variety of contaminants, including metals, organophosphorus, organochlorine and pyrethroid pesticides, chloride, and ammonia. Feeding rate inhibition was detected for animals deployed downstream of all point-source discharges in summer/autumn and winter. Feeding inhibition, relative to animals deployed upstream of the discharge, ranged from 16.5 to 99.6%. These results support those of previous field [15–17,20,37] and laboratory [25,26,29] studies that have demonstrated that the feeding rate of G. pulex is inhibited by a variety of environmental contaminants.

It would appear, therefore, that the in situ feeding assay would be a suitable general biomonitor of water quality. However, as discussed previously, feeding rate is also affected by environmental factors other than contaminants, in particular water temperature. It is therefore possible that between-site differences in feeding rate were not related to between-site differences in water quality. This was assessed by comparing the feeding rate observed for animals deployed downstream of point-source discharges in summer/autumn with that predicted using site-specific temperature and alkalinity information. For only three of the 13 summer/autumn deployments could the inhibition of feeding rate downstream of the discharge possibly be explained in terms of site-specific environmental factors (temperature and alkalinity), and for only one deployment was the predicted feeding rate less than that observed. The use of site-specific environmental factors to predict in situ assay responses is potentially a very powerful tool. The reference database used to generate the predictive relationships contained information from 24 reference sites, and, although sites were selected to cover a range of physicochemical characteristics and geographical locations, most sites were streams in northern England or southern Scotland. Whereas the predicted feeding rates presented here are relevant to the contaminated sites used in this study (streams in northern England or southern Scotland), further research would be required in order to assess fully the validity and generality of predicted site-specific feeding rates over a wider range of sites [38].

The final issue that was addressed in this study was relevance. What is the wider ecological significance of the in situ feeding rate assay, and to what extent is a reduction in G. pulex feeding rate indicative of community- and ecosystem-level responses? A strong positive correlation was observed between G. pulex feeding rate measured in situ over 6 d and total leaf decomposition measured at the same site over 28 d, suggesting that the in situ feeding assay can be used as an indicator of this important ecosystem process. A significant positive correlation was also observed between G. pulex feed-
ing rate and benthic macroinvertebrate diversity. Gammarus pulex is an important shredding detritivore in many stream systems where it feeds on leaf material, among other things [27]. Reductions in shredder abundance have been shown to have consequences for detritus processing [39], and it is not unreasonable, therefore, to suggest that reductions in shredder feeding activity will also translate into reductions in detritus processing rates. The extent to which reductions in G. pulex feeding rate are indicative of stress-induced reductions in total shredder activity will depend on the species present in the community as well as on the degree of functional redundancy [40]. Of the 25 benthic communities studied, one reference site community (Barlow Brook) and six contaminated site communities did not contain G. pulex. The shredders in these communities were isopods (Asellus aquaticus), stonefly larvae (Tipulidae), cased caddis larvae (Limnephilidae), and dipteran larvae (Tipulidae). Interestingly, no evidence from this study was found that the correlation between in situ G. pulex feeding rate and leaf decomposition was weaker for sites lacking G. pulex than for sites with G. pulex.

In conclusion, the G. pulex in situ feeding assay has use as a short-term sublethal biomonitor of water quality that is indicative of community- and ecosystem-level responses occurring over longer time periods. It is robust, responsive, and relevant.

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