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A test of the association between Lake Habitat Quality Assessment and macroinvertebrate community structure

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ABSTRACT

1. Lake Habitat Survey (LHS) provides a standard method for characterizing the physical habitat of lakes and reservoirs, but has not been tested for its relevance to the composition and abundance of macroinvertebrates. This study investigated the relationship between the metrics used in LHS and components of macroinvertebrate communities found in the littoral zone of a shallow calcareous lake in the west of Ireland.
2. A scoring system, the Habitat Quality Assessment (HabQA), developed from the Lake Habitat Quality Assessment (LHQA) of the LHS, was used to assess the relationship between habitat quality based on physical structure within 10 LHS 'habplots' and metrics of the macroinvertebrate community.
3. Macroinvertebrate taxon richness, both of adults found in the riparian zone and larvae found in the littoral zone, correlated positively with the HabQA score. Macrophytes within the littoral zone, and complexity of riparian vegetation within the riparian zone, were particularly important in driving the HabQA score. While overall abundance of macroinvertebrates did not vary with HabQA score, that of particular genera did.
4. The HabQA score was a useful surrogate of taxon richness for adult and larval aquatic macroinvertebrates, suggesting that, in general, LHS provides a useful conservation assessment tool relevant for macroinvertebrates. However, in some circumstances, such as wave-washed stony substrates devoid of macrophytes, the HabQA score may not capture the quality of a site for macroinvertebrates, and the importance of natural but low diversity sites should not be neglected in conservation assessment of lakes. Similarly, while the LHS method notes the presence of alien species, further work on how these could be incorporated into the method would be useful.
5. Reliance on a single, or overall combined, metric score across quality elements, whether based on biotic or structural assessment, has some potential limitations. It is clear that for conservation management a holistic assessment of naturalness, representativeness and species rarity needs to be made in conjunction with scoring systems.

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KEY WORDS: lakes; hydromorphology; macroinvertebrates; Lake Habitat Survey

INTRODUCTION

The link between hydromorphology and aquatic biotic communities should be self-evident. The text of the European Water Framework Directive (Directive 2000/60/EC) requires the use of freshwater biota for determining the quality and status of fresh and marine waters, and recognizes hydromorphological alteration as a potential impact on the composition and abundance of those communities. The Water Framework Directive has been an important driver for the development of survey tools such as Lake Habitat Survey (LHS), which provides a method for characterizing and assessing the physical habitat of lakes and reservoirs (Rowan *et al.*, 2004, 2006). LHS includes quantitative descriptions of canopy, macrophytes along the lake shore, the amount of shoreline affected by human activities, and the dominant littoral substrate. The usefulness of LHS as a metric of general relevance to macroinvertebrates is, however, untested.

The UK River Habitat Survey (RHS) applied the concept of mesohabitats, readily identifiable patches of habitat types at the scale of 10^1–10^2 m (Raven *et al.*, 1997). Mesohabitats were not a usual feature of lake assessment (White and Irvine, 2003), until the LHS method, drawing from the US EPA Field Operations Manual for Lakes (FOML) (Kaufmann and Whittier, 1997), adapted the RHS mesohabitat approach.

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LHS surveys a number of units, or habplots, within the ecotone between land and lake. An ecotone is generally defined as the area of transitional land in between vegetation types (Risser, 1990), and in this case is the area incorporating the riparian and the littoral zone of a lake. The littoral zone of lentic water bodies is functionally important, providing shelter against predation and wave action, feeding zones and habitat (Schiemer *et al*., 1995). It can provide the zone of highest productivity in a lake (Wetzel, 2001).

LHS attempts to measure many attributes that may be important for macroinvertebrates. For example, habitat diversity is a well recognized driver of species diversity, with a greater number of species found in more diverse and physically complex habitats (Menge and Lubchenco, 1981; Cheruvelil *et al*., 2002), with taxon richness and total density of animals increasing with increasing complexity and abundance of macrophytes in the littoral zone (Tolonen *et al*., 2003; Taniguchi and Tokeshi, 2004). Disturbance of the riparian zone, caused by erosion, deposition, inundation and desiccation, contribute, furthermore, to spatial heterogeneity of the ecotone (Giudicelli and Bournaud, 1997). Bankside vegetation has been found to be important for distribution and abundance both of macroinvertebrate larvae and their adult terrestrial phase in streams and rivers (Harrison and Hildrew, 1998). The more structurally complex marginal macrophytes may also provide numerous sites for insect pupation, emergence and oviposition, leading to a greater supply of recruits to all habitats (Harrison and Harris, 2002).

This study tested the usefulness of LHS as a surrogate of taxon richness and abundance for both aquatic and terrestrial macroinvertebrate phases, within a single lake. If found to be a useful surrogate of macroinvertebrate taxon richness and abundance, LHS could be useful for predicting occurrence of macroinvertebrates in lakes, similar to PSYM (Williams *et al*., 1998) and RIVPACS (Armitage *et al*., 1983) for ponds and rivers, respectively. Macroinvertebrates were sampled within their adult riparian phase and their larval littoral phase within each of the habplots surveyed using the LHS method. A scoring system was developed from the established Lake Habitat Quality Assessment (LHQA) score to describe and score the quality of the habitat within each habplot and relate it to the macroinvertebrates present.

METHODS

Study site

Benthic macroinvertebrates were sampled within the littoral and riparian zones at 10 approximately evenly spaced sites within the upper two basins of Lough Carra, a shallow, polymictic, and calcareous lake covering approximately 1610 ha in the west of Ireland (Figure 1). The upper two basins divide naturally from the lower basin, being connected by just a narrow inflow channel during the summer; the study focused on these owing to time constraints, and as habplots are treated independently for the HabQA method. There are no major centres of population on the lake, and the main land use in the catchment is grass production and sheep farming (King and Champ, 2000). The lake has a mixed substrate comprising marl, sand, cobbles, pebbles and boulders. Recent work

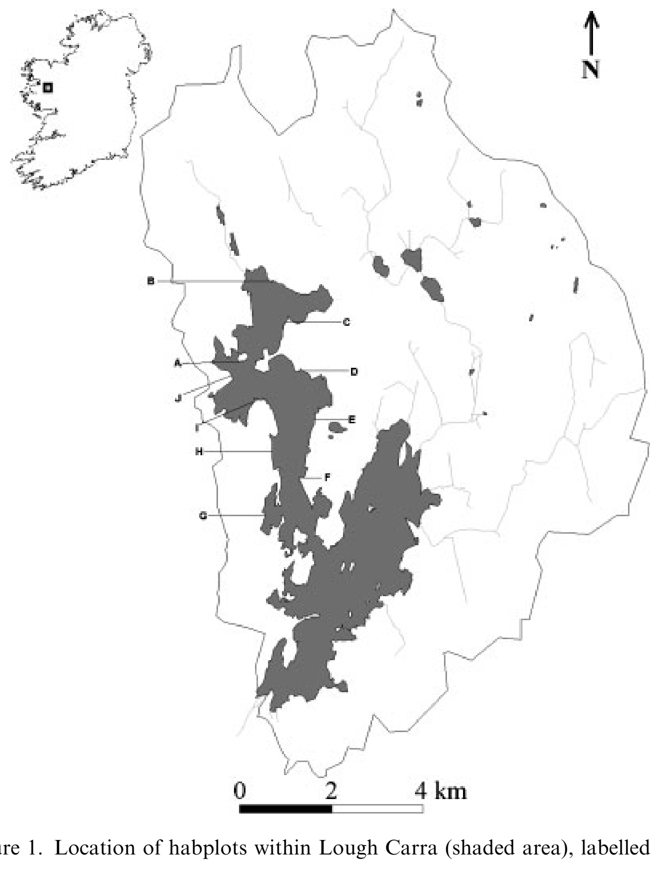

Figure 1. Location of habplots within Lough Carra (shaded area), labelled A–J.

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indicates recent, and probably increasing, nutrient enrichment (Hobbs *et al*., 2005).

Lake Habitat Surveying

LHS requires that the shoreline and riparian habitat are assessed at random and evenly spaced locations (habplots); and that the macroscale riparian and littoral habitats are described for the lake as a whole. The first habplot is chosen randomly and the remainder are approximately evenly spaced around the lake perimeter. These are designed to record the main lake-shore habitat characteristics over 15 m wide plots which extend from within the riparian zone to within the littoral zone. It is based on binomial theory, and if a feature is present in over 10% of the lake, it should be accounted for within 10 habplots (Rowan *et al*., 2006). The riparian zone extends 15 m landwards from the edge of the bank, the littoral zone is the area from the waterline to 10 m offshore, and the shore zone is the region between the edge of the bank and the current waterline. A detailed questionnaire is filled out at each of the habplots scoring features of habitat in the shore, riparian and littoral zones (Rowan *et al*., 2005). Human pressure on each habplot is assessed up to 50 m back from the waterline. A whole lake assessment is undertaken within which the perimeter features up to 50 m back from the waterline are assessed.

The Lake Habitat Quality Assessment (LHQA) of LHS provides an index of lake habitat quality based on diversity, physical structure and the presence of habitat features considered to be of ecological value (Rowan *et al*., 2004, 2006). The scoring system of LHQA is outlined in Table 1. For more information on the details and development of the method see Rowan *et al*. (2004, 2005, 2006).

Habplot Quality Assessment score (HabQA)

In order to link the habitat within the individual habplots with the macroinvertebrate community, a modified scoring method was developed for individual habplots (Table 1). The LHQA of LHS is based mainly on proportional scoring over the habplots, whereas the modified HabQA used either a dichotomous presence/absence score (e.g. if a trashline was present in a habplot it scored 1, if not it scored 0), or a 4-point proportional score, with maximum value of 1, for (a) the overall extent of macrophyte cover; (b) diversity of macrophyte structural types; and (c) diversity of littoral features. For the LHS score for 'Diversity of special habitat features' the modified system retained the modified ratio of 4:1 between LHQA:HabQA, allowing for a maximum HabQA score of 5 (see Table 1), and for HabQA this feature was referred to as 'Number of wetland habitats'. The HabQA is further simplified compared with the LHQA by not considering whole lake features which are only useful for among-lake comparison. Hence, while the LHQA is based on 21 features, the modified HabQA is based on 13 (Table 2). The maximum HabQA score achievable per habplot is 16, indicating the highest habitat quality, and the minimum is 0. The scoring variables of the HabQA were compared across the 10 habplots for association with metrics of macroinvertebrate community structure.

Sampling of macroinvertebrates

At each habplot, macroinvertebrates were sampled within the littoral zone at 1.5 m, 5 m and 10 m from the shore lakewards, ensuring adequate representation of the littoral habplot, extending 10 m out from the shoreline. Sampling was done in August 2006. Benthic sampling was carried out using a bilge pump suction sampler (Whale® Gusher 30) with a stiff 38 mm bore tube (after Tolonen *et al*., 2001, 2005). At each distance from shore, suctioning was carried out for 30 s in a transect across the habplot. The sample was then passed through a standard Freshwater Biological Association (FBA) pond net of 1 mm mesh size. Each of the samples was preserved in industrial methylated spirits on site. Field trials were carried out within the lake comparing kick sampling with suction sampling. ANOVA found no difference for taxon richness or abundance between the methods.

Emerging animals were sampled over the same period using emergence traps, constructed from electrical piping and polythene, enclosing an area of 0.5 m^2 and standing approximately 1 m tall. Two traps were placed and weighed down on the sediment within each habplot in approximately 50 cm of water, and left in place for 7 days. Emerging animals were caught within the collecting head of the trap.

Sticky traps collected macroinvertebrates in the riparian zone of each habplot. The traps comprised two acetate sheets stapled to form a cylinder, and coated on the outside in all-weather sticky tangletrap paste (Tanglefoot®) (after Collier and Smith, 1995), representing an area of approximately 0.12 m^2. Six traps were deployed within each habplot, with one trap at each distance of 2 m, 4 m, 8 m, 16 m, 32 m and 50 m from the waterline landwards, representing the full extent of the riparian habplot surveyed within the LHS method. The traps were stapled to riparian trees, or to wooden posts, approximately 1 m off the ground. Trap height was not found by Collier and Smith (1995) to have a significant effect on numbers of animals caught in a previous study in New Zealand. Traps were left in place for 5 days, after which many were fully coated with insects. Traps were wrapped in polyethylene film and frozen for later sorting. Sub-sampling of the traps was necessary owing to the number of animals on each acetate; five 3 cm^2 pieces were chosen randomly from each trap for sorting. Specimens were removed from the tangletrap paste using Citroclear, which released the animals without damage.

All individuals sampled by each method were identified to the lowest practicable level, generally species. Littoral larval macroinvertebrates were identified to family level for the Diptera, Coleoptera and Odonata. Oligochaete and dipteran pupae were not identified further. Adult macroinvertebrates were identified to species level in most cases and to family level for Diptera. Identification was carried out using an Olympus binocular microscope $\times 40$ magnification. An ANOVA was carried out using SPSS on taxon richness and abundance at different distances from shore for littoral macroinvertebrates across habplots.

Statistical analyses

Spearman rank and Pearson product moment correlations were carried out within SPSS. The PRIMER program was used for multivariate analyses, and for cluster, non-metric

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Table 1. LHQA scores following Rowan *et al*. (2006) compared with HabQA score per habplot developed in this study. Max LHQA = 108, Max HabQA = 16

Lake Zone	Characteristic measured	Measurable feature	Whole lake LHQA score	Max Score	Individual habplot HabQA score	Max score
Riparian	Vegetation structural complexity	Proportion of habplots with complex or simple riparian vegetation structure	1 for 1–3, 2 for 4–6 3 for 7–8, 4 for 9–10	4	Complex or simple riparian vegetation structure- present/absent	1
	Vegetation longevity/ stability	Proportion of habplots with > 10% cover of trees with DBH > 0.3m	1 for 1–3, 2 for 4–6 3 for 7–8, 4 for 9–10	4	Trees > 10% cover of trees with DBH > 0.3m–present/absent	1
	Extent of natural land-cover types	Proportion of habplots with either natural/ semi-natural woodland, wetland, moorland heath or rock, scree and dunes	1 for 1–3, 2 for 4–6 3 for 7–8, 4 for 9–10	4	Does the habplot have natural/semi-natural woodland, wetland, moorland heath or rock, scree and dunes - present/absent	1
	Diversity of natural land-cover types	Number of natural cover types recorded	1 for each type, maximum of 4	4	Not applicable to individual habplots	0
	Diversity of bank-top features	Number of bank-top features recorded	1 for each type, maximum of 4	4	Not applicable to individual habplots	0
Shore	Shore structural habitat diversity	Proportion of habplots with an earth or sand bank > 1 m	1 for 1–3, 2 for 4–6 3 for 7–8, 4 for 9–10	4	If it has an earth or sand bank > 1 m- present/ absent	1
	Bank naturalness	Proportion of habplots with trash-line	1 for 1–3, 2 for 4–6 3 for 7–8, 4 for 9–10	4	If it has a trash line- present/absent	1
	Diversity of natural bank habitat	Number of natural bank materials recorded	1 for each type, maximum of 4	4	Not applicable to individual habplots	0
	Beach naturalness	Proportion of habplots with natural beach material	1 for 1–3, 2 for 4–6 3 for 7–8, 4 for 9–10	4	Natural beach material - present/absent	1
	Diversity of natural beach habitats	Number of natural beach materials recorded	1 for each type, maximum of 4	4	Not applicable to individual habplots	0
Littoral	Hypsographic variation	Coefficient of variation for depth at 10m from shore over all plots	1 for > 25, 2 for > 50 4 for > 75	4	Not applicable to individual habplots	0
	Extent of natural littoral zones	Proportion of habplots with natural littoral substrate	1 for 1–3, 2 for 4–6 3 for 7–8, 4 for 9–10	4	Natural littoral substrate- present/absent	1
	Diversity of natural littoral zone types	Number of natural littoral substrate types recorded	1 for 1–3, 2 for 4–6 3 for 7–8, 4 for 9–10	4	Not applicable to individual habplots	0
	Extent of macrophyte cover	Average of total macrophyte cover over all habplots	1 for a '1', 2 for a '2' 3 for a '3', 4 for a '4'	4	Total of macrophyte cover for each habplot 0.25(0–10%), 0.5 (> 10–40%), 0.75 (> 40–75%), 1 (> 75%)	1
		Number of habplots where macrophyte cover extends lakewards	1 for 1–3, 2 for 4–6 3 for 7–8, 4 for 9–10	4	If macrophytes extend lakewards - present/ absent	1

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Table 1. *Continued*

Lake Zone	Characteristic measured	Measurable feature	Whole lake LHQA score	Max Score	Individual habplot HabQA score	Max score
	Diversity of macrophyte structural types	Number of macrophyte cover types recorded (not including filamentous algae)	1 for each type, maximum of 4	4	No of macrophyte types recorded in a habplot, 0.25 for each type, maximum of 1	1
	Extent of littoral habitat features	Average of total cover for fish over all plots	1 for a '1', 2 for a '2' 3 for a '3', 4 for a '4'	4	Not applicable to individual habplots	0
	Diversity of littoral habitat features	Number of littoral habitat feature types recorded	1 for each type, maximum of 4	4	No different habitat features present in the habplot, 0.25 for each type, maximum of 1	1
Whole Lake	Diversity of special habitat features	Number of special habitat features (excl. diseased alders)	5 for each type, maximum score of 20	20	Number of wetland habitats adjacent to habplot up to 50m inland from lake shore, score 0.625 for each type, maximum of 8	5
		Number of islands	2 for 1, 5 for 2–4, 10 for 5 or more	10	Not applicable to individual habplots	0
		Number of deltaic depositional features recorded (excl. unvegetated sand and silt deposits)	2 for each type	6	Not applicable to individual habplots	0

multi-dimensional scaling (MDS) and bubble plot analysis. The PRIMER BEST method was used to search for high rank correlations between matrices. A full search of all combinations of variables of one matrix (usually a suite of variables considered to be 'driving' the assemblage structure) was searched against another fixed matrix to find a subset which best maximizes the rank correlation between the two. Rho falls in the range (-1 to 1), where values around zero indicate no match. However, the rho cannot be referred to standard statistical tables, as the ranks are not mutually independent variables, and are based on a number of interdependent similarity calculations. GLOBAL BEST, a non-parametric form of Mantel test, was used to test the statistical significance of the BEST results, but only where the two matrices were independently derived. This is a permutation test, where, within one of the matrices, one set of labels was randomly permuted relative to the other. Rho was recalculated for successive permutations to test the null hypothesis of 'no agreement in multivariate pattern' between the matrices. If less than 5% of these values were greater than the real rho, then the null hypothesis can be rejected at $P<0.05\%$.

RESULTS

LHS metrics and HabQA score

The LHMS and LHQA calculated for the lake were 12/42 and 59/108, respectively (Table 3). Some variables of the HabQA scoring were the same across all habpots (Table 2). Nine of the original 13 variables varied among habplots. Three variables were significantly correlated with HabQA score (Spearman correlation, $P\leqslant0.05$, $n=10$): (1) number of wetland habitats ($r=0.82$); (2) extension of macrophytes lakewards ($r=0.66$); and (3) macrophyte PVI ($r=0.70$). With decreasing HabQA, the macrophyte PVI decreased, the number of wetland habitats decreased and macrophytes did not extend lakewards. Variables that showed a weak trend of increase with overall HabQA were complex riparian vegetation ($r=0.52$, $P=0.12$), and natural bank material ($r=0.57$, $P=0.09$).

Littoral taxon richness and abundance

Distance from shore was not related significantly either to taxon richness or abundance of macroinvertebrates. Counts for the three distances from shore were, therefore, pooled for further analysis. A significant correlation was found between HabQA score and taxon richness (Pearson, $r=0.62$, $P\leqslant0.05$) (Figure 2), but not abundance (Figure 3). However, taxon richness would have increased if chironomids were identified to a lower taxonomic level.

In order to explore the mechanisms driving these patterns, the community composition of littoral macroinvertebrates was organized into taxonomic groups (Table 4). A species list of macroinvertebrates found in Lough Carra is given in the Appendix (Table A.1). The habplots with higher HabQA scores generally contained the taxonomic groups found within the lower scoring habplots, suggesting taxon loss rather than substitution with declining habitat quality. An MDS graph (Figure 4) of community composition among habplots indicated five groups at 65% similarity: group 1 containing habplots D, C, E and F, group 2 containing habplots I, H and J, group 3 containing habplot B, group 4 containing habplot A and group 5 containing habplot G. Abundance of the taxonomic groups was searched against the full species abundance matrix in order to determine which of the groups were driving the MDS clustering pattern. Five groups (Trichoptera, Corixidae, Ephemeroptera, Aranea and Tricladida) were found to best explain the overall variation among habplots with a rho of 0.761 (Figure 4(b)–(f)). Further significance testing was not possible owing to the non-independence of the two matrices.

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Table 2. Variables making up the scoring system for the HabQA for each habplot. Letters A–J refer to individual habplots

HabQA habitat variables	A	B	C	D	E	F	G	H	I	J
Complex/simple vegetation	1	1	1	1	1	1	0	1	1	1
> 10% trees over 5 m tall	0	0	0	0	0	0	0	0	0	0
Natural or semi-natural habitat present	0	0	1	1	1	0	0	0	0	0
Does it have an earth sandbank?	0	0	0	0	0	0	0	0	0	0
Is the trash line visible?	0	1	0	0	1	1	1	1	1	1
Does it have natural bank material?	1	1	1	1	0	1	0	0	0	1
Natural beach material	1	1	1	1	1	1	1	1	1	1
Natural littoral substrate	1	1	1	1	1	1	1	1	1	1
Macrophyte PVI (0.25 = 0–10%, 0.5 = 10–40%)	0.25	0.5	0.25	0	0.25	0.25	0.25	0.25	0.5	0.5
Do macrophytes extend lakewards?	1	1	0	0	0	0	0	1	1	1
Number of macrophyte types (0.25 for each type)	0.25	0.5	0.5	0.25	0.75	0.5	0.25	0.5	0.5	0.5
Number of littoral habitat features present, 0.25 for each type	0.25	0	0	0	0	0	0	0.5	0	0
Number of wetland habitats in the zones adjacent to each habplot	3.75	3.75	3.13	1.25	0.63	1.88	1.88	1.25	1.88	3.13
Total HabQA score	9.5	10.75	8.88	6.5	6.63	7.63	5.38	7.5	7.88	10.13

Table 3. Allocation of scores for LHQA in Lough Carra, score allocated according to Table 1

Feature number	Zone	Measurable LHS feature	Counts of features across lake, or number of habplots with a feature	Score allocated
1	Riparian	complex or simple veg.	9	4
2		>10% large trees	0	0
3		natural/semi natural veg.	3	1
4		no. natural types	1	1
5		no. banktop features	2	2
6	Shore	earth/sand bank	0	0
7		trashline	7	3
8		natural bank material	6	2
9		no. natural types	1	1
10		natural beach material	1	1
11		no. natural types	3	3
12	Littoral	coefficient variation	0	0
13		natural littoral substrate	10	4
14		no. natural types	4	4
15		total macrophyte cover	1	1
16		extend lakewards?	5	2
17		no. macrophyte types	4	4
18		total fish cover	0	0
19		no. littoral features	1	1
20	Whole lake	no. wetland habitats	3	15
21		no. islands	16	10
22		no. deltaic deposits	0	0
Total				59

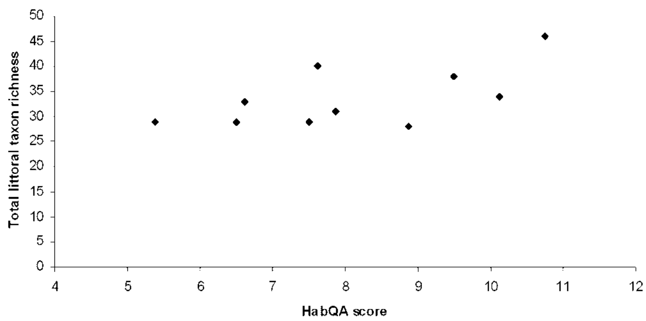

Figure 2. Pooled littoral taxa richness per habplot compared with HabQA score ($r = 0.62$, $P \leqslant 0.05$, $n = 10$).

GLOBAL BEST indicated five HabQA variables important for structuring the biotic data: presence of complex riparian vegetation, presence of natural bank material, macrophyte PVI, extension of macrophytes lakewards and number of wetland habitats. However, the significance level was just $P = 0.27$. Bubble plots were again used to visualize the differences in the variables among habplots, with some indicating only presence/absence, and others indicating increasing amounts per habplot (Figure 5).

Ephemeroptera abundance increased with decreasing score (Table 5). Trichoptera abundance increased within mid-scoring habplots and decreased at both high and low scores.

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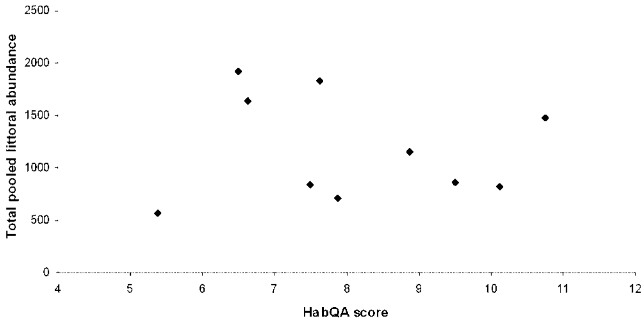

Figure 3. Total pooled littoral abundance per habplot compared with HabQA score ($r = 0.04$, $n = 10$).

Table 4. Taxon richness within taxonomic groups for each of the habplots, ordered in decreasing HabQA score

	B	J	A	C	I	F	H	E	D	G
Diptera	2	4	4	2	3	4	3	3	3	3
Oligochaeta	1	1	1	1	1	1	1	1	1	1
Amphipoda	2	1	2	1	2	2	2	1	2	2
Isopoda	2	1	1	1	1	2	1	2	2	1
Coleoptera	7	4	2	2	5	6	3	4	3	3
Trichoptera	8	11	12	10	7	9	9	9	8	6
Hemiptera	9	1	1	1	1	0	0	0	0	1
Odonata	1	0	1	0	1	2	1	0	1	2
Gastropoda	7	3	5	3	4	8	3	5	5	4
Hirudinea	3	3	2	2	2	2	3	3	2	3
Tricladida	1	1	2	2	0	1	0	1	2	1
Ephemeroptera	2	2	3	2	2	1	1	2	0	1
Aranea	1	1	1	1	1	1	1	1	0	0
Megaloptera	0	1	1	0	1	1	1	1	0	1
Taxon richness	46	34	38	28	31	40	29	33	29	29
HabQA score	10.75	10.13	9.50	8.88	7.88	7.63	7.50	6.63	6.50	5.38

Hemiptera and Aranea both decreased in abundance with decreasing score. Tricladida showed no discernible trend (Table 5). These trends can be followed within the groups indicated by the MDS. Group 3 contained habplot B, which was the highest scoring habplot. This was followed by group 4 containing habplot A, group 2 containing H, I and J, group 1 containing C, D, E and F, and group 5 with habplot G being the lowest scoring habplot and group. In terms of HabQA variables, the highest scoring three groups all had macrophyte extension lakewards, and generally had high macrophyte PVI, and a higher number of wetland habitats, which all decreased within the lower scoring groups, as indicated by the correlations detailed earlier. Subsequent Spearman rank correlation of taxonomic groups and HabQA variables showed that Hemiptera correlated positively with number of wetland habitats and overall score; Ephemeroptera, comprising 80–100% *Caenis luctuosa* in all of the habplots, correlated negatively with macrophyte PVI, extension of macrophytes lakewards, the number of wetland habitats and the overall score; and Trichoptera correlated negatively with macrophyte PVI (Table 6). The main Trichoptera genera, comprising 70% abundance, were *Oecetis, Mystacides* and *Tinodes*. Aranea were not correlated with any HabQA variables, although they were completely absent from the two lowest scoring habplots. Tricladida did not correlate with any HabQA variables.

Emergence abundance and taxon richness

The majority of individuals caught by the emergence traps comprised Diptera (84% of all of the animals) and Trichoptera (16%). Within the traps taxon richness increased with increasing HabQA score (Figure 6), although non-significantly (Pearson correlation, $r = 0.55$, $P = 0.10$, $n = 10$). Using the BEST method, Trichoptera was the most indicative group of overall emergence assemblage structure (Figure 7), with a rho of 0.425.

GLOBAL BEST on emergence abundance and HabQA variables showed that the three variables that best described the emergent macroinvertebrate assemblage were complex riparian vegetation, natural/semi natural vegetation and littoral habitat diversity. The rho was 0.65, with a significance of $P = 0.09$. Trichoptera genera *Tinodes* and *Polycentropus* comprised over 88% of the proportional Trichoptera abundance within the traps. *Tinodes* spp. were absent in the habplot with the lowest score. *Polycentropus* spp. were absent in the habplot with the highest score. These two genera were then correlated with the three variables, and the overall score. *Polycentropus* spp., accounting for 35% proportional abundance of Trichoptera in the traps, correlated positively with the presence of natural/semi-natural vegetation ($r = 0.81$, $P < 0.05$, $n = 10$). *Tinodes* spp., comprising 55% of the proportional abundance of Trichoptera

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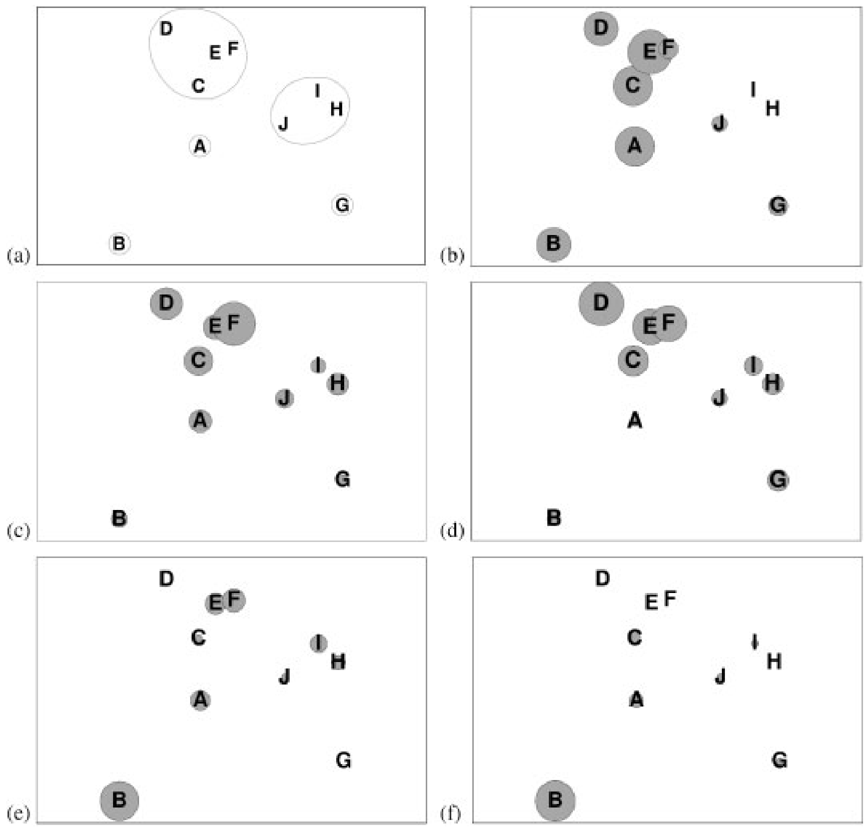

Figure 4. (a) MDS of Bray–Curtis similarities from log $(x+1)$ transformed littoral macroinvertebrate abundance data with cluster analysis overlaid at 65% similarity (stress = 0.08) (b)–(f) same MDS but with superimposed circles of increasing size with increasing abundance of (b) Tricladida, (c) Trichoptera, (d) Ephemeroptera, (e) Aranea and (f) Hemiptera.

within the traps, correlated positively with HabQA score ($r = 0.70$, $P < 0.05$, $n = 10$), but not with any other features.

Sticky trap abundance and taxon richness

Taxon richness on the sticky traps increased with HabQA score (Pearson correlation, $r = 0.50$, $P = 0.14$, $n = 10$) (Figure 8). Abundance was dominated (>98%) by Diptera, with Trichoptera making up 1%, and Ephemeroptera, Odonata and Megaloptera comprising the remainder. Diptera only (comprising 96% Chironomidae abundance) were associated with the two lowest scoring habplots. Sticky trap abundance did not, however, correlate with HabQA score overall (Pearson correlation, $r = 0.31$, $P = 0.39$, $n = 10$). Global BEST highlighted two HabQA variables as important: macrophyte PVI and number of types of macrophyte. However, none of the HabQA variables could be considered to be efficiently describing the sticky trap community composition, with a maximum rho of 0.203, and a significance level of $P = 0.86$. *Tinodes* spp. were the only trichopteran that occurred in more than one habplot, in contrast to emergence and littoral samples. Their abundance was correlated significantly with HabQA score (Pearson correlation, $r = 0.75$, $P \leqslant 0.05$, $n = 10$), and associated with macrophyte PVI (Spearman rank, $r = 0.60$, $P = 0.07$, $n = 10$). Chironomidae correlated positively with the number of macrophyte types (Spearman rank, $r = 0.83$, $P < 0.01$, $n = 10$), but not with macrophyte PVI, or overall score.

DISCUSSION

The lack of standard assessment methods to support judgements of habitat quality of lakes led to the development of LHS (Rowan *et al*., 2006). Underlying the LHS approach is an assumption that parts of the scoring criteria, such as the LHQA, could be useful for evaluating lake conservation status. This study has attempted to test the link between the LHQA and the littoral benthic macroinvertebrates, but because it was confined to one lake, had to adjust the scoring method, which was designed for comparison across lakes. Nevertheless, the modified criteria were based firmly on the original LHS approach and philosophy. Confining the study to one lake and sampling period was a logistical constraint because of time involved in sampling and, particularly, processing samples from 10 habplots. However, it was useful for testing the relationship between the LHS metrics and macroinvertebrates at the scale of the habitat. Although seasonal variation owing to life-cycle strategies can be significant (Rosenberg and Resh, 1993), previous work on Lough Carra has demonstrated that while abundance differs significantly seasonally, the proportional abundance of taxa in the major orders remains relatively constant over time (Little, 2008). However, seasonality should not alter the underlying relationship between macroinvertebrates and HabQA variables.

The work has demonstrated a link between the LHS methodology, which operates at the mesohabitat scale, and macroinvertebrate taxon richness, and abundance of particular

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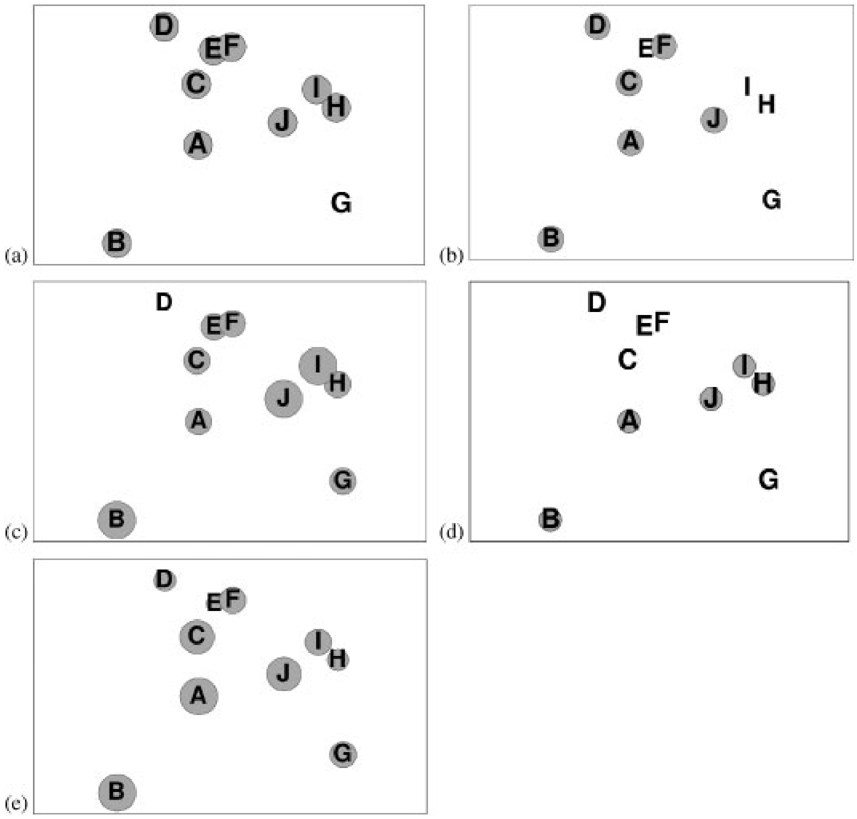

Figure 5. MDS of Bray–Curtis similarities from log(x+1) transformed littoral macroinvertebrate abundance data (stress = 0.08) with superimposed circles of HabQA variables indicating (a) presence/absence of complex riparian vegetation, (b) presence/absence of natural bank material, (c) amount of macrophyte PVI per habplot, (d) presence/absence of macrophyte extension lakewards, and (e) amount of wetland habitats per habplot.

Table 5. Abundance of taxonomic groups within each habplot, arranged in decreasing HabQA score

	B	J	A	C	I	F	H	E	D	G	Proportional abundance over all habplots
Diptera	694	488	319	340	377	645	529	1056	746	328	46.8
Oligochaeta	24	8	17	69	24	68	14	70	99	17	3.3
Amphipoda	33	12	192	45	121	49	18	23	23	15	2.9
Isopoda	44	107	101	175	2	44	1	39	424	1	7.1
Coleoptera	86	17	4	10	11	19	8	32	9	21	2.1
Trichoptera	41	52	99	126	33	289	72	95	157	19	8.4
Hemiptera	33	1	7	3	1	0	0	0	0	1	0.7
Odonata	1	0	3	0	12	24	25	0	1	3	0.6
Gastropoda	434	16	70	84	25	379	3	12	20	12	10.1
Hirudinea	14	14	12	96	16	15	5	14	7	38	2.0
Tricladida	3	1	6	4	0	1	0	5	3	1	0.4
Ephemeroptera	40	54	26	205	78	287	97	281	436	104	13.7
Aranea	31	1	11	1	6	11	4	9	0	0	0.7
Megaloptera	0	46	69	0	0	2	60	1	0	4	1.2
Total Abundance	1478	817	938	1158	706	1833	836	1637	1925	564	100.0
Habplot QA	10.75	10.13	9.50	8.88	7.88	7.63	7.50	6.63	6.50	5.38	

taxa; and has shown the strong influence of macrophytes in the assessment. Both macrophyte PVI and extent of macrophytes lakewards were found to be associated with littoral macroinvertebrate abundance. Dense macrophyte stands support many species of macroinvertebrate, probably through increased habitat complexity, availability of food and refuge from predation (Weatherhead and James, 2001; Tolonen *et al*., 2003, 2005). While not surprising that metrics of littoral macroinvertebrate community richness increase with presence and diversity of macrophytes, it is important that the use of LHS is not weighted in such a way that it is effectively a surrogate for a survey of macrophytes. HabQA score was reduced when devoid of macrophytes, yet many wave-washed shores which are naturally devoid of macrophytes are still good quality, comprising distinct assemblages of macroinvertebrates, albeit with lower taxon richness (White

Table 6. Spearman rank correlations of littoral taxonomic groups versus HabQA variables (significance indicated by bold, $n = 10$)

	Corixidae	Tricladida	Ephemeroptera	Aranea	Trichoptera
Complex riparian veg	$r = -0.06$ $P = 0.87$	$r = 0.18$ $P = 0.62$	$r = -0.06$ $P = 0.87$	$r = 0.47$ $P = 0.17$	$r = 0.52$ $P = 0.12$
Natural bank material	$r = 0.37$ $P = 0.29$	$r = 0.36$ $P = 0.30$	$r = -0.07$ $P = 0.85$	$r = 0.11$ $P = 0.77$	$r = 0.50$ $P = 0.14$
Macrophyte PVI	$r = 0.51$ $P = 0.13$	$r = -0.34$ $P = 0.34$	**$r = -0.69$** **$P = <0.05$**	$r = 0.38$ $P = 0.27$	**$r = -0.64$** **$P = <0.05$**
Extension of macrophytes lakewards	$r = 0.44$ $P = 0.21$	$r = -0.39$ $P = 0.26$	**$r = -0.87$** **$P = <0.001$**	$r = 0.28$ $P = 0.43$	$r = 0.52$ $P = 0.12$
No. wetland habitats	**$r = 0.91$** **$P = <0.001$**	$r = 0.14$ $P = 0.70$	**$r = -0.73$** **$P = <0.05$**	$r = 0.23$ $P = 0.53$	$r = -0.25$ $P = 0.49$
HabQA	**$r = 0.72$** **$P < 0.05$**	$r = 0.03$ $P = 0.95$	**$r = -0.72$** **$P < 0.05$**	$r = 0.48$ $P = 0.17$	$r = -0.13$ $P = 0.73$

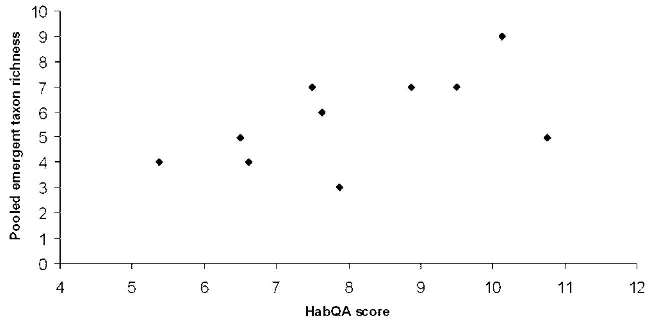

Figure 6. Pooled emergent taxon richness per habplot compared with HabQA score ($r = 0.55$, $P = 0.10$, $n = 10$).

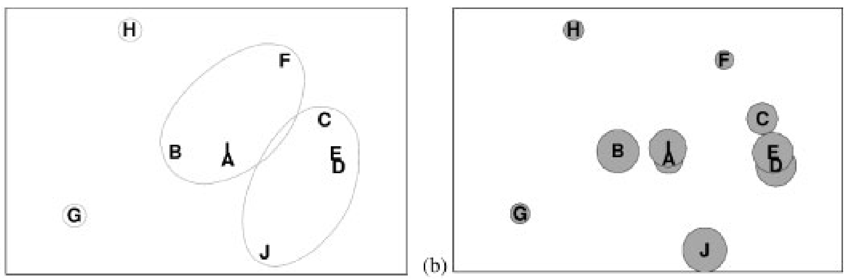

Figure 7. (a) MDS of Bray–Curtis similarities from log $(x+1)$ transformed emergence trap macroinvertebrate abundance data with cluster analysis overlaid at 63% similarity (stress = 0.11); (b) same MDS but with superimposed circles of increasing size with increasing abundance of Trichoptera.

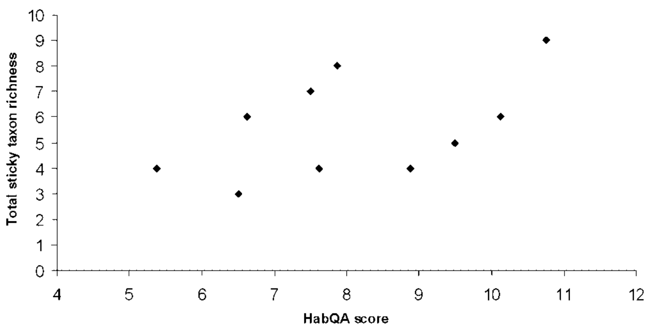

Figure 8. Total sticky trap taxon richness compared with HabQA score ($r = 0.50$, $P = 0.14$, $n = 10$).

and Irvine, 2003). Conversely, features such as rip-rap reduce the HabQA score, but recent work found rip-rap provides useful niche space for macroinvertebrates (Brauns *et al.*, 2007). It is also notable that Aranea (comprising just *Argyroneta aquatica*) was absent from the two lowest scoring habplots, which were the most structurally simple. Aranea are known to be associated with structurally complex macrophyte habitats (Warren, 1989). The difficulty in disentangling naturalness from diversity is not unique to LHS, but bedevils many conservation monitoring programmes. It is, however, noteworthy that the lower scoring habplots in our study comprised fewer, but not essentially different, taxon groups than the higher scoring habplots. This suggests that the gradient described by the HabQA is related to relative increase, rather than replacement, of taxa.

A general increase in larval, emergence and sticky taxon richness was found with increasing HabQA score. Abundance of the trichopteran *Tinodes* spp. found in the emergent and sticky traps, for example, correlated with HabQA; and sticky trap *Tinodes* spp. abundance was positively associated with macrophyte PVI. Larval *Tinodes* spp. are generally grazers, feeding predominantly on epilithic algae and biofilm (Moog, 1995), which would probably be abundant in complex macrophyte beds (Warfe and Barmuta, 2006). However, larval Trichoptera were negatively correlated with macrophyte PVI, but were correlated positively with complex riparian vegetation, and extension of macrophytes lakewards. It is intuitive that habitat structure in both the littoral and riparian zone influences prevalence of species with both aquatic and terrestrial phases. Harrison and Hildrew (2001) found that *Tinodes* spp. larvae had greatest abundance in habitat patches under or near trees, and other studies have found significant associations between adult aquatic macroinvertebrates and riparian features (Harrison and Hildrew, 1998; Winterbourn and Crowe, 2001; Harrison and Harris, 2002). Similarly, in this study, emergent *Polycentropus* spp. were correlated with semi-natural/natural riparian vegetation across habplots but were absent from sticky traps. Certain Trichoptera have been found to fly over or around traps (Bird and Hynes, 1981).

In this study on Lough Carra the dominance of *Caenis luctuosa* among the Ephemeroptera was striking. Ephemeroptera correlated negatively with macrophyte PVI, extension of macrophytes lakewards and the number of wetland habitats, therefore being found predominantly in the lower scoring habplots. *C. luctuosa* are found predominantly in silt (Elliott *et al*., 1988) and are tolerant of low dissolved oxygen concentrations (Thorp and Covich, 2001). Much of the sediment of Lough Carra comprises soft marl, which could explain the high proportional abundance of *C. luctuosa* However, evidence of increased enrichment of the lake (Hobbs *et al*., 2005) and reports of fewer mayfly (*Ephemera danica*) (C.Huxley, pers comm.) are also in keeping with the data. With enrichment, sediment structure may become too loose to support the burrows of *E. danica* (Harris, 1952). Ephemeroptera abundance was also extremely low in both the emergence and the sticky traps, probably because the majority of the emergence occurs earlier in the year. Diptera, comprising mostly Chironomidae, were, overall, the most abundant group found in the suction samples and emergent and sticky traps, and was the only group associated with the low-scoring sites in sticky traps. They occurred across all habplots regardless of score, possibly owing to being less affected by, and sometimes favouring, alteration of habitat (Koel and Stevenson, 2002). However, chironomids span a wide range of habitat preferences, possibly obscuring any association. Littoral Hemiptera, comprising mainly Corixidae, were positively correlated with number of wetland habitats and overall HabQA, and positively associated with macrophyte PVI. Many Irish corixid species have been found to be associated with sheltered, vegetation rich, mud substrates (Tully *et al*., 1991), although the mechanism behind the correlation with number of wetland habitats is not clear.

Overall, the HabQA scoring from the single lake used in this study appears a useful metric that relates habitat complexity to macroinvertebrate taxon richness, and abundance of particular taxa. Although there is noise in the data set, GLOBAL BEST indicated that of the three sampling methods used, the HabQA variables are most useful for describing emergence abundance, followed by littoral abundance. HabQA variables do not seem valid for describing sticky trap abundance assemblage, possibly owing to variation in the data set. Sticky abundance may be affected by other untested factors such as wind and flight direction.

This is the first test of the relevance of LHS as a descriptor of ecological quality, but it is important to recognize the limitations of a study on one lake. It would be highly informative to extend such detailed work across a number of lakes, to enable comparison of the relevance of LHS, especially the whole lake score LHQA, to macroinvertebrates. The study also highlighted a potential limitation of using LHQA as a metric of conservation status in areas or lakes where macrophytes are naturally sparse. For example, small low alkalinity upland lakes will generally have less emergent macrophytes and habitat diversity than large higher alkalinity lakes, hence scoring lower for LHQA, despite their naturalness. In order to address this, a lake typology approach, similar to that used for the Water Framework Directive, or the JNCC lake classification method (Duigan *et al*., 2007), could be useful for calculating the LHS scores, with different habitat features scored differently according to lake type. Identification of littoral Chironomidae to a lower taxonomic level would also increase overall taxon richness of samples.

Lough Carra, while under increasing human pressures (Hobbs *et al*., 2005; Huxley and Irvine, 2008) does not appear to suffer major problems from alien species introductions, although there are reports that roach (*Rutilus rutilus*) now occur in this salmonid dominated lake, and Canadian waterweed (*Elodea canadensis*) occurs in low abundance (C. Huxley, pers comm.). *Gammarus pulex* was also found in the lake, but in low abundance. This study could not, therefore, consider the impact of invasive species on the habplot scores. Hence, while LHS appears useful for describing habitat quality and its association with littoral macroinvertebrates in Lough Carra, this may not be the case in other lakes with alien species. In particular the introduced zebra mussel (*Dreissena polymorpha*) has become a keystone species in many Irish lakes, and there are recent concerns over the spread of African waterweed (*Lagarosiphon major*). The original LHS method (Rowan *et al*., 2006) notes invasive species but does not incorporate these into the overall LHQA scores. Incorporating aliens or, conversely notable national or local rarities, into conservation assessment of lakes is important. Two methods which do take rarity into account are SERCON (Boon *et al*., 1997), a method for evaluating rivers for conservation, and WETSCORE (Foster *et al*., 1989) which allocates site scores according to the average beetle species rarity. Incorporation of such information would, furthermore, contribute to the development of conservation assessment based on community assemblage (Webb and Lott, 2006).

In summary, the development of a HabQA score for individual habplot assessment provides a supplementary method to LHS. In this case it enabled assessment of the relevance of the components of LHS for littoral macroinvertebrates, highlighting the importance of macrophyte structure for macroinvertebrate communities. However, while there was generally good concordance between the assessment of HabQA variables and littoral taxon richness and abundance of some groups, conservation assessment relies on an appreciation of the special features of any one site, including its representativeness, naturalness and importance for supporting local or regional rarities. Reliance on a single, or overall combined, metric score across quality elements, whether based on biotic or structural assessment, has some potential limitations. For conservation management, a holistic assessment of naturalness, representativeness and species rarity needs to be made in conjunction with tested scoring systems.

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APPENDIX A

The species list of invertebrates found in Lough Carra is given in Table A1.

Table A1. Species list of invertebrates found in Lough Carra

Taxomonic group	Family/Species	Taxomonic group	Family/Species
Diptera	Ceratopogonidae	Trichoptera	*Polycentropus kingi/flavomaculatus*
	Chironomidae		*Sericostoma personatum*
	Tabanidae		*Stenophylax permistus*
	Tipulidae		*Tinodes maculicornis*
Oligochaeta	Oligochaeta		*Tinodes waeneri*
Amphipoda	*Gammarus duebeni*	Aranea	*Argyroneta aquatica*
	Gammarus lacustris	Megaloptera	*Sialis lutaria*
	Gammarus pulex	Hydroacarina	Acari sp.
Isopoda	*Asellus aquaticus*	Hemiptera	*Corixa iberica*
	Asellus meridianus		*Corixa iberica/punctata*
Coleoptera	*Cercyon littoralis*		*Corixa panzeri*
	Elmidae larvae		*Glaenocorisa propinqua*
	Haliplus confinis		*Notonecta marmorea viridis*
	Haliplidae larvae		*Sigara distincta*
	Hydrophilidae larvae		*Sigara dorsalis*
	Hydroporus erythrocephalus		*Sigara falleni*
	Hydroporus palustris		*Sigara nigrolineata*
	Hygrotus quinquelineatus	Odonata	*Coenagrionidae* sp.
	Hygrotus sp. larvae		*Enallagma cyathigerum*
	Hyphydrus ovatus		*Sympetrum danae*
	Laccobius biguttatus	Gastropoda	*Bithynia leachi*
	Laccophilus minutus		*Bithynia tentaculata*
	Limnius volckmari		*Radix labiata*
	Noterus clavicornis		*Stagnicola palustris*
	Ochthebius nanus		*Limnaea stagnalis*
	Oulimnius tuberculatus		*Galba truncatula*
	Potamonectes depressus		*Physa fontinalis*
	Potamonectes sp. larvae		*Planorbis carinatus*

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Table A1. *Continued*

Taxomonic group	Family/Species	Taxomonic group	Family/Species
Trichoptera	*Athripsodes albifrons/bilineatus/commutatus*		*Segmentina complanata*
	Cyrnus insolutus		*Sphaerium/Pisidium* spp.
	Cyrnus trimaculatus		*Valvata studeri*
	Halesus radiatus	Hirudinea	*Erpobdella testacea*
	Holocentropus picicornis		*Glossiphonia complanata*
	Limnephilus binotatus		*Helobdella stagnalis*
	Micropterna lateralis	Tricladida	*Dugesia lugubris/polychroa*
	Mystacides azurea		*Planaria torva*
	Mystacides longicornis		*Polycelis felina*
	Neureclipsis bimaculata		*Polycelis nigra/tenuis*
	Oecetis furva	Ephemeroptera	Baetidae sp.
	Oecetis lacustris		*Caenis luctuosa*
	Oecetis ochracea		*Centroptilum luteolum*
	Phryganea bipunctata		*Ephemera danica*