BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE, BIOLOGIE, 76: 111-123, 2006
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN, BIOLOGIE, 76: 111-123, 2006

Freshwater Ostracoda (Crustacea) from the Assynt region, NW Scotland: new Scottish records and a checklist of Scottish freshwater species

by Ian BOOMER, David J. HORNE & Robin J. SMITH

Abstract

Collections of living ostracods from lochs, pools, streams, springs and seepages in the area around Loch Assynt, Sutherland, NW Scotland, provide the first detailed record of these calcareous-shelled crustaceans from the Scottish mainland north of the Great Glen, and the most detailed regional study for any part of Scotland. Surface conditions in the area are often dominated by acidic *Sphagnum* bogs and peatlands, usually inimical to the survival of ostracods. The unusual occurrence of abundant and relatively diverse ostracod populations in the area is made possible largely by the local outcrop of the Middle Cambrian Durness Limestone which provides not only a buffering capacity to the pH of the surface water but also a significant karst system with which many of these records are hydrologically connected. From a total of more than 60 samples of living ostracods recovered during field visits in 2001-2003, 21 species were identified and a further 10 taxa, mostly represented only by juveniles, were identified to genus level. The chemical and physical properties of many of the water samples are also reported. A checklist of 53 species is provided for all freshwater ostracods recorded in Scotland. Three species are recorded for the first time in Scotland: *Cavernocypris subterranea, Cytherissa lacustris* and *Potamocypris arcuata.* These records include the most northerly occurrences of *C. lacustris* and *C. subterranea* in the UK and the presence of Britain's only presumed endemic freshwater ostracod, *Psychrodromus robertsoni*. Two more species, *Cyclocypris serena* and *C. laevis* are confirmed from Scotland for the first time. The distributions of key taxa in this study are compared with existing biogeographical records using the NODE (Nonmarine Ostracod Distribution in Europe) database.

Key words: Ostracoda, freshwater, springs, Loch Assynt, Scotland.

Introduction

The Ostracoda are a diverse group of microscopic aquatic Crustacea that inhabit both non-marine and marine habitats worldwide. Non-marine ostracods belong exclusively to the Order Podocopida and include representatives of three superfamilies, the Darwinuloidea, Cytheroidea and Cypridoidea (of which the last is by far the most diverse). The distribution of individual ostracod species is determined by a range of environmental factors, particularly water chemistry, temperature, substrate, dissolved oxygen levels and food supply (SMITH & HORNE, 2002).

Despite a long history of British freshwater ostracod studies there are few detailed records of faunas from Scottish localities, particularly from the area to the north of the Great Glen. The present study aims to fill this geographical gap in our knowledge of British freshwater ostracods, largely on the basis of collections from a single hydrological catchment, Loch Assynt. The closest areas for which detailed ostracod distribution data are available are in northern England: the English Lake District (HORNE, 1988; HORNE *et al.*, 1990; WOOD, 1992) and Yorkshire (FRYER, 1993). A total of 21 ostracod species are recorded herein from the Assynt region, of which at least three are new to the Scottish fauna. A further 10 taxa (typically represented only by juveniles) are identified questionably to species level or to genus level only.

The earliest Scottish records of freshwater Ostracoda are those of BRADY (1868; localities in the Southern Uplands and the Midland Valley) and BRADY & NORMAN (1889; various localities in the Southern Uplands, Midland Valley, Highlands and the Hebridean islands of Skye and Lewis) which simply listed the occurrence of species with little geographical or ecological detail. More recently FRYER & FORSHAW (1979) recorded 10 ostracod species on the Isle of Rhum in the Hebrides. BENZIE (1989) described the relationship between a number of freshwater ostracods and their preferred substrate type in a coastal freshwater lagoon from the Loch of Strathbeg, NE Scotland. Two papers have focused on the ostracods from Loch Ness (GRIFFITHS *et al.*, 1993; GRIFFITHS & MARTIN, 1993), concentrating on species from deep-water habitats. Recent work on the Hebridean islands of Harris and Barra has resulted in the discovery of ostracod species new to the British fauna (HORNE & SMITH, 2004; SMITH & HORNE, 2004). Stygophylic ostracods from the Isle of Skye and the Assynt region have been listed by DJH (*in* PROUDLOVE *et al.*, 2003).

The NODE (Non-marine Ostracod Distribution in Europe) GIS database (HORNE *et al.*, 1998) contains 184 records of freshwater ostracods for the whole of Scotland, totalling 44 species, compared with 944 records of 86 species for the British Isles as a whole (figures as of April 2006). With the addition of data from PROUDLOVE *et al.*, (2003) and the present study (not yet entered in NODE) a total of 53 species have now been recorded in Scotland. A species checklist based on NODE and the present study is given in Appendix 1.

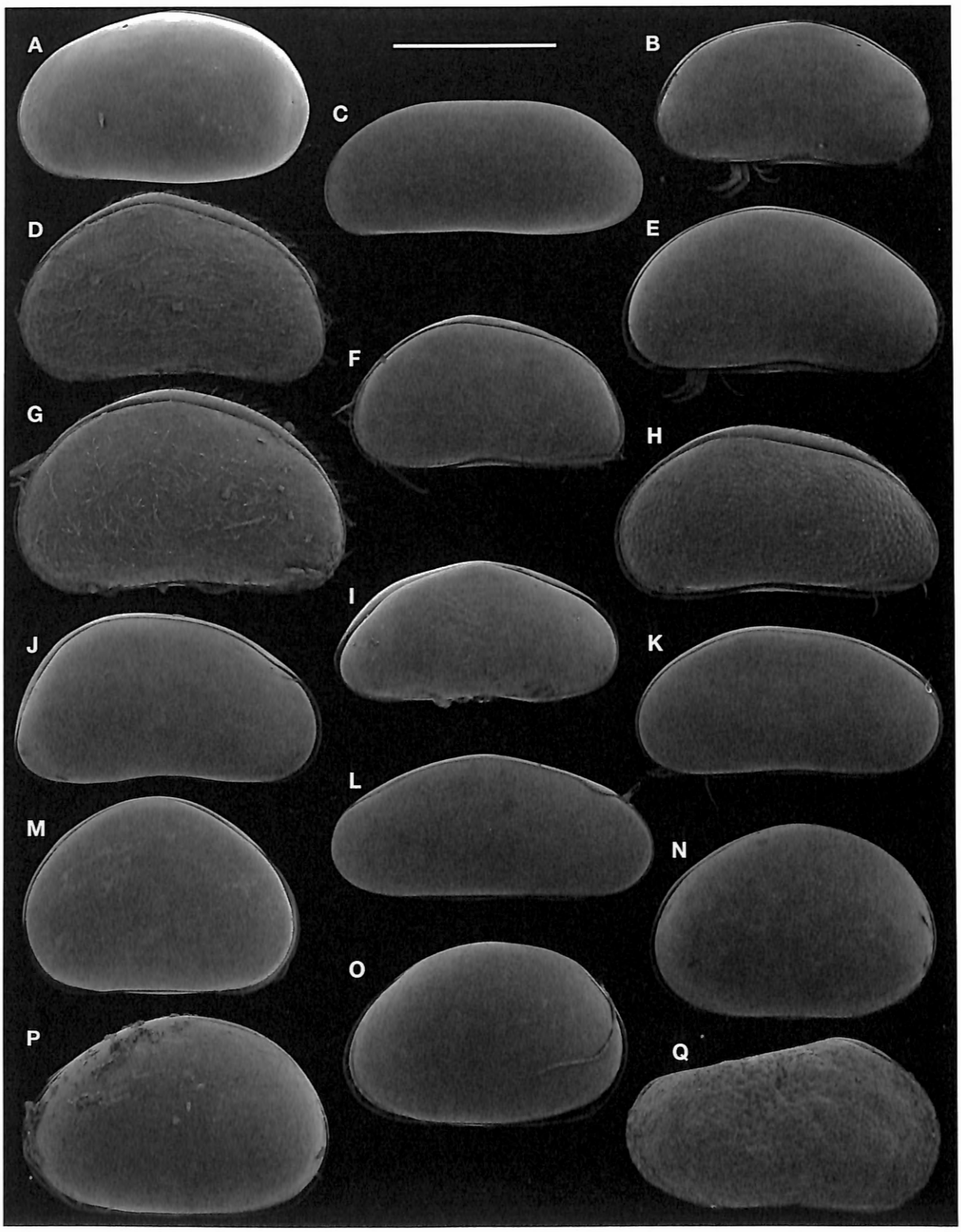

Plate 1. A: *Heterocypris incongruens* (scale bar = 880μm), female carapace, left side; **B:** *Psychrodromus olivaceus* (scale bar = 700μm), female carapace, right side; **C:** *Herpetocypris chevreuxi* (scale bar = 1150μm), female carapace, left side; **D:** *Potamocypris variegata* (scale bar = 375μm), female carapace, left side; **E:** *Psychrodromus robertsoni* (scale bar = 880μm), female carapace, right side; **F:** *Potamocypris pallida* (scale bar = 375μm), female carapace, left side; **G:** *Potamocypris villosa* (scale bar = 375μm, female carapace, left side; **H:** *Potamocypris zschokkei* (scale bar = 375μm), female carapace, left side; **I:** *Cavernocypris subterranea* (scale bar = 375μm), female carapace, right side; **J:** *Candona candida* (scale bar = 570μm), female carapace, right side; **K:** *Cryptocandona vavrai* (scale bar = 480μm), female carapace, right side; **L:** *Cryptocandona reducta* (scale bar = 480μm); **M:** *Cypria ophtalmica* (scale bar = 375μm), female carapace, right side; **N:** *Cyclocypris serena* (scale bar = 375μm), female carapace, left side; **O:** *Cyclocypris globosa* (scale bar = 480μm), female carapace, left side; **P:** *Cyclocypris ovum* (scale bar = 290μm), female carapace, left side; **Q:** *Cytherissa lacustris* (scale bar = 480μm), female carapace, right side.

Regional setting

The geology of the Assynt and Coigach region of NW Scotland has been studied in great detail due to its complex structure (see GOODENOUGH *et al.*, 2004 for a recent summary). The area contains a wide variety of rock types, both acidic and alkaline (e.g., sandstones, shales, limestones, schists, gneisses and igneous intrusions). They include some of the oldest rocks in Britain, many of which have suffered significant alteration, folding and faulting. The complex nature of the local geology can be seen on British Geological Survey's Solid Geology Sheet (1:50,000) for the Assynt District (GEOLOGICAL SURVEY, 1965). The high annual rainfall of the Assynt region today has resulted in the widespread development of blanket bog and numerous surface water flows overlying the solid geology. Recent research has shown that the local rainfall has a high correlation with North Atlantic Oscillation state (PROCTOR *et al.*, 2002) and that this connection may have persisted for at least the last few millennia.

The local surface hydrology is modified by the presence of a karst system within the partly-dolomitised Middle Cambrian Durness Limestone in the eastern part of the catchment, with an extensive network of seasonal streams, springs and seepages. Many surface exposures of the Durness Limestone in this region are disjointed due to its complex structural history, resulting in multiple repetitions of the geological sequence (GOODENOUGH *et al.*, 2004).

The modern landscape is termed 'Knock and Lochan', derived from Gaelic and referring to the many small hills and lakes which can be observed throughout much of the area (LAWSON, 1993). Upland bogs are often oligotrophic habitats, with low pH levels, containing specialist biota. It is known that with increasing acidity, aquatic crustacean species diversity declines (FRYER, 1980). Ostracods, possessing a bivalved carapace mineralised with low-magnesium calcite, are generally rare in such habitats, particularly where water pH falls below about 5; where they do live in such acid waters the *post-mortem* preservation of their shells is rarer still.

In the Assynt region, the buffering capacity of the Durness Limestone, local tills (unconsolidated glacial deposits) and other sediments means that the pH levels of many surface waters and most springs are suitable for ostracods to survive. However, the low ionic concentration of HCO_3^- and Ca^{2+} in these waters means that most carapaces dissolve shortly after death. This is particularly noticeable in the sedimentary records of the small lochans and in Loch Assynt itself where, although living ostracods are found in the surface sediments (even at profundal depths), no sub-fossil carbonate remains are recorded in the bottom sediments; chitinous "soft-part" remains of ostracods have been observed occasionally but these are usually not suitable for specific identification or subsequent palaeoecological study.

This study is largely confined to surface water bodies, springs and seepages usually associated with the karst system in the eastern catchment of Loch Assynt (figure 1). Occasional opportunistic sampling within the local cave systems has not yet yielded any living ostracods although one of us (IB) has recovered a few well-preserved shells of *Potamocypris* sp. (late juvenile or adult) from a shallow pool in the 'Grotto' of Uamh an Tartair, approximately 2 km southeast of Inchnadamph.

Loch Assynt has a maximum depth of about 100-115m, with the deepest areas in the eastern half. It is one of the largest water bodies in the region and receives inflow from two main rivers: the Lonan, draining a large area to the south-east of the loch, and the Traligill, a smaller catchment to the east of Inchnadamph (figure 1); there are also many relatively small inflows along its length. The loch outflows at its north-eastern end. The catchment is delimited in figure 1; most of our samples were taken within this area, including five surface-sediment samples from the deep parts of the loch, between 26-76 m water depth. A single additional sample was also taken from a roadside spring at Elphin, on a 6 m high roadside cliff face approximately 12 kilometres south of Inchnadamph, outside the Loch Assynt catchment.

Material and methods

The results presented herein are the product of three field seasons (2001-2003) by the three authors and these have been combined to establish a single dataset. The considerable variation in sampling techniques used, rendered necessary by the great differences in habitat type, water depth, flow rates, etc., renders quantitative analyses meaningless, and even approximate abundances are not comparable between samples, therefore only presence/absence data are recorded (for living taxa only). Similarly, the different methods of field and laboratory measurements of water quality make it difficult to quantitatively assess the entire dataset in terms of species-environment relationships. Notwithstanding these points, this remains the most extensive and detailed ecological record of non-marine ostracods from Scotland.

Springs, seepages and other small waterbodies such as temporary ponds were sampled using a hand-net or a fine-mesh sieve (typically 125 µm). In the majority of cases samples were examined under a low-power binocular microscope within 24 hours of collection so that living ostracods could be picked out and preserved in alcohol. In view of the variety of waterbodies being sampled, any attempt to take quantitative samples would have been futile, and efforts were focused simply on trying to obtain representative samples of the ostracod fauna from each habitat.

A total of 69 sample sites (including a small number of inter-annual replicates) were studied for ostracods, of which only 61 yielded living specimens. Sites, shown in figure 2, were generally chosen on an opportunistic basis following extensive field-walking. Peat pools and peat flows proved the least productive environment; no living ostracods were obtained from these water bodies, which often exhibited pH values <5.

The samples which yielded ostracods have been classified into one of six habitat groups based on water depth, rate of water flow and permanence: Deep Loch, Littoral Loch, Spring, Stream, Ditch/Pool and Temporary Pool, these are described further in Table 1.

The maps from the NODE database were produced using ArcGIS at Queen Mary, University of London.

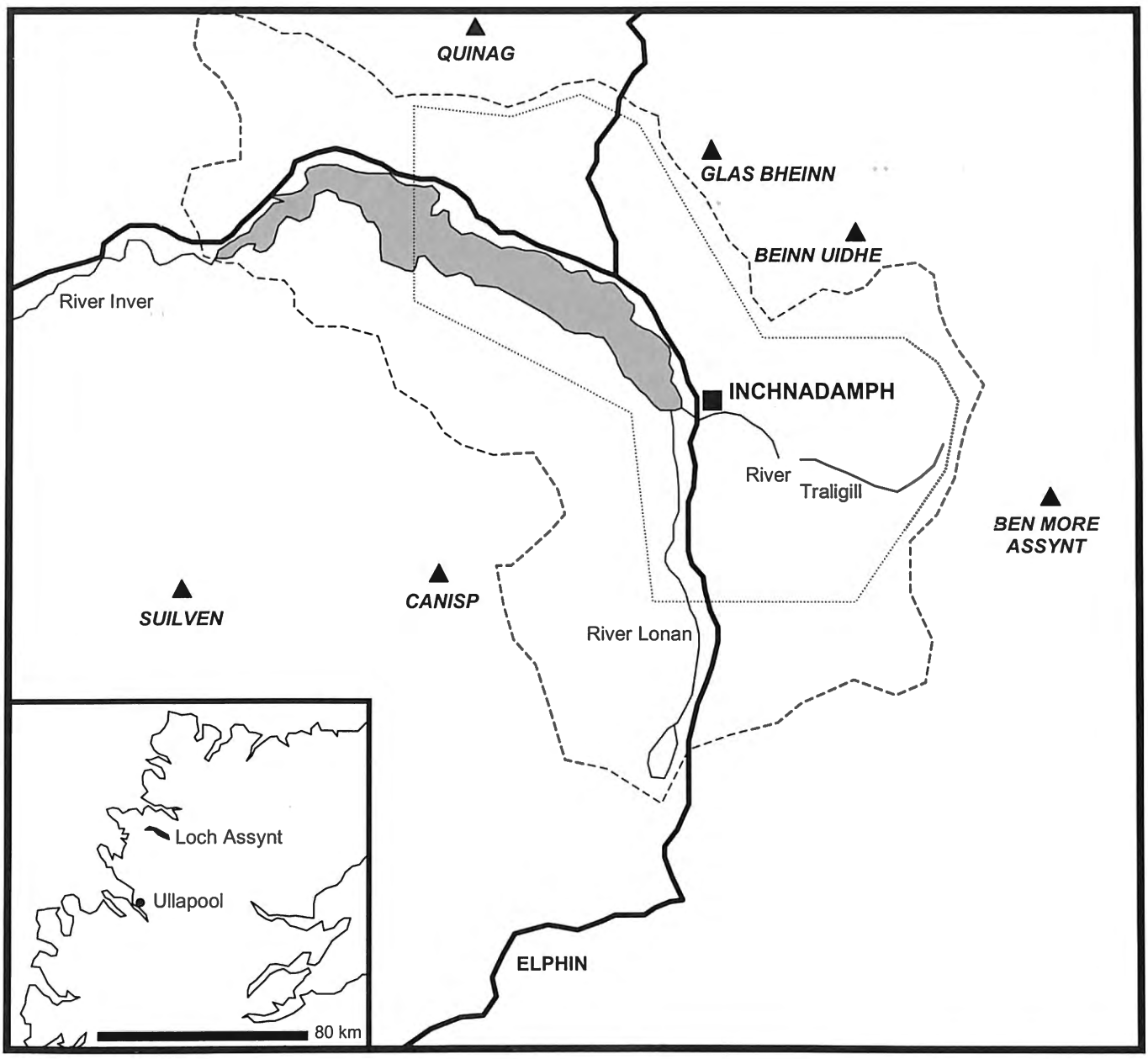

Fig. 1. Location map of Loch Assynt, Northwest Scotland, with local mountain peaks marked. Dotted line marks approximate catchment boundary and solid line indicates the major area of sampling. An additional opportunistic sample was recovered from a roadside spring with tufa deposits at Elphin, 12 km south of Inchnadamph.

Results

Environmental properties

The range of environmental properties of all water samples are illustrated in figure 3, although not all ostracod samples have environmental values recorded at the time of collection. The range of pH values shows a bi-modal distribution, the lower modal group of samples at about 5.0–5.5 are generally associated with flows coming off peatland or waters which have not been in significant contact with the local limestone or other carbonate bearing sediments. Conversely the majority of samples, in the range 7.0–8.5, reflect waters that are intimately connected to the local karst system, such as springs.

The temperature of the sampled waters at the time of collection ranged from about 5°C to 18°C. While many of the temperature readings in shallow surface waters reflect local air temperatures at the time of collection (generally in the range 10–15°C) the karst system ensures that most waters are at a relatively constant 6.0–9.0 °C when they emerge at springs and seeps.

The conductivity measurements are dominated by samples with very low concentrations of ions and this plays a major role in the *post-mortem* dissolution of the carbonate ostracod shells, values are mostly in the <150 µS range.

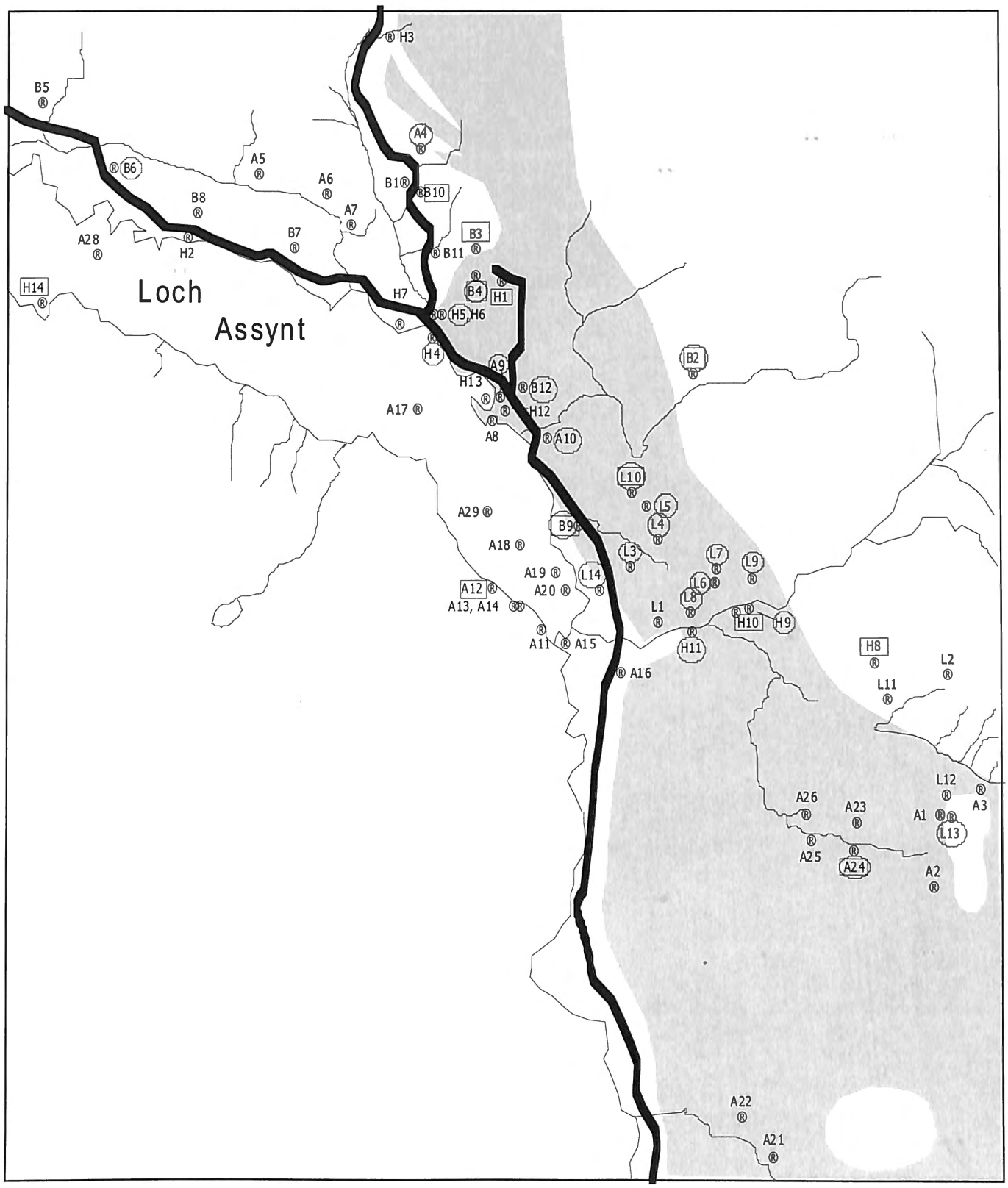

Fig. 2. Location map of all sites containing ostracods studied in this survey. Samples in circles contain *Psychrodromus olivaceus*, those in boxes, *P. robertsoni*. The grey stippled area indicates the local outcrop of the partly dolomitised Durness Limestone.

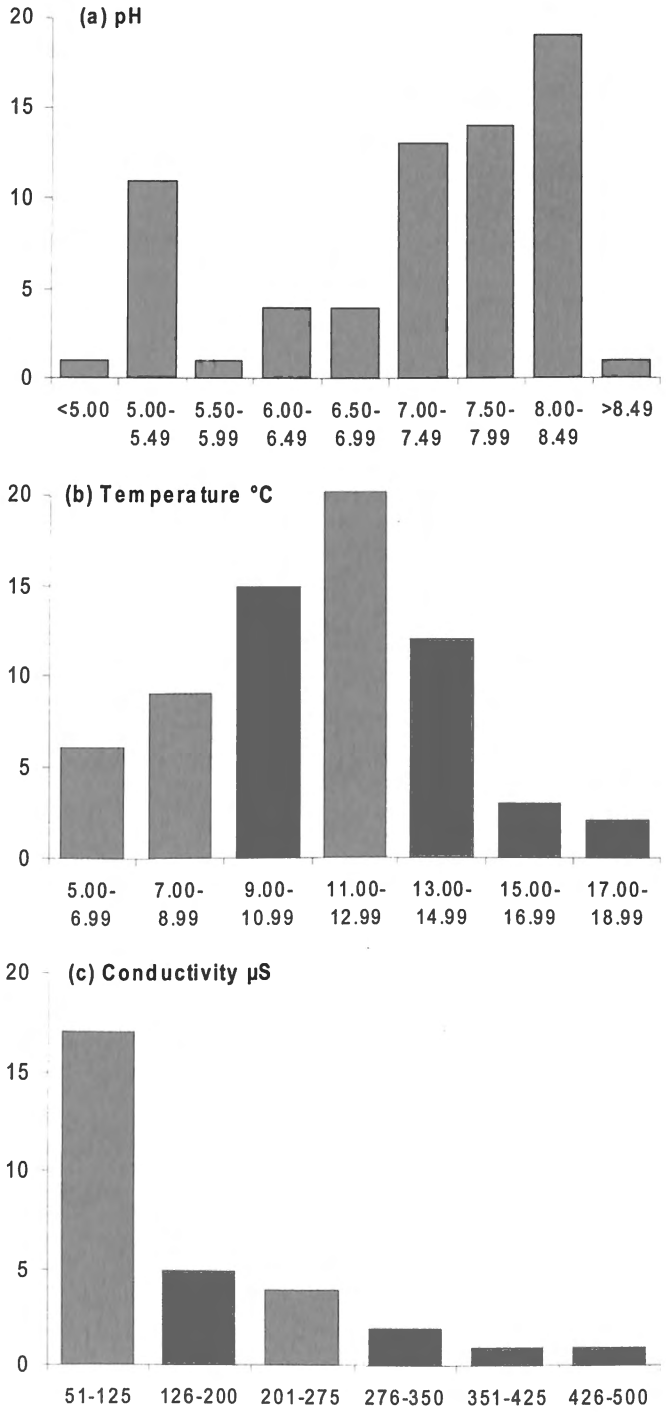

Fig. 3. Range of pH, temperature (°C) and conductivity (µS) values observed in Assynt water samples.

The main Loch Assynt surface waters in May 2003 had a pH of about 8.3, surface water temperatures of 10.5 °C and conductivity of 84 µS. A single bottom-water sample at the same time, from a depth of 53 metres, yielded a temperature of 9.8 °C, pH 8.5 and conductivity at 93 µS indicating little differentiation between surface and bottom waters of the loch at this time of year.

The average water temperatures for each habitat (for those samples where it was recorded at collection, late spring-summer) are illustrated in figure 4 together with an indication of

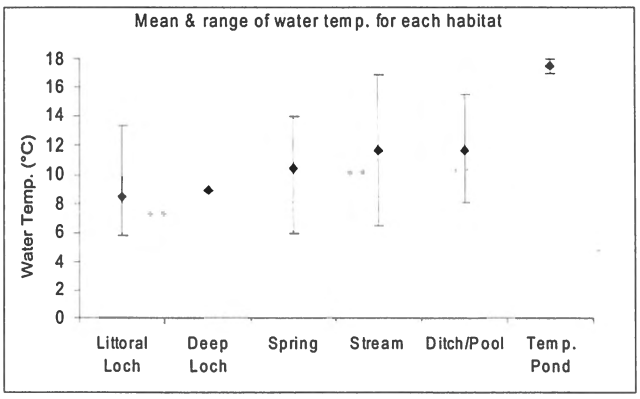

Fig. 4. Mean and standard deviation water temperature values for the six classified habitats.

the total range and the number of readings available. The Loch samples, both littoral and deep, are the coolest at 8.5–9.0 °C. The springs are the next warmest with an average of about 10.5 °C. The ditch and stream samples, both of which are largely derived from spring waters and seepages, are just a little warmer, still both averaging just over 11.5 °C. The warmest habitats are the relatively shallow temporary ponds at about 17.5 °C.

Table 2 lists the occurrence of all species recovered in the samples, with the samples grouped using the habitat classification given in Table 1. A number of summary observations can be made from this table regarding the relationship between species and habitats.

OSTRACOD SPECIES

In total 21 taxa were identified to specific level, two more were questionably assigned to species and a further 8 were identified only to generic level (the latter being juveniles in many cases, not attributable with certainty to identified adults). Our taxonomic determinations follow the scheme of MEISCH (2000); the most important taxa are illustrated in plate 1. Species occurrences in samples detailed in Table 2.

Table 1. Habitat classification for ostracod samples recovered in the Assynt region.

Code	Habitat	Description
ST	Stream	Small surface streams with no obvious spring source within about 10 metres
SP	Spring	Immediately adjacent to emerging spring/ seepage
DP	Ditch/Pool	Non-flowing water body, generally shallow and small area. May be seasonal.
TP	Temporary Pool	Temporary pool related to seasonal bank overflow or direct rainfall
LL	Littoral Loch	Shallow (<1 m) littoral region of major lochs
DL	Deep Loch	Deep (generally >10 m) profundal region of major lochs

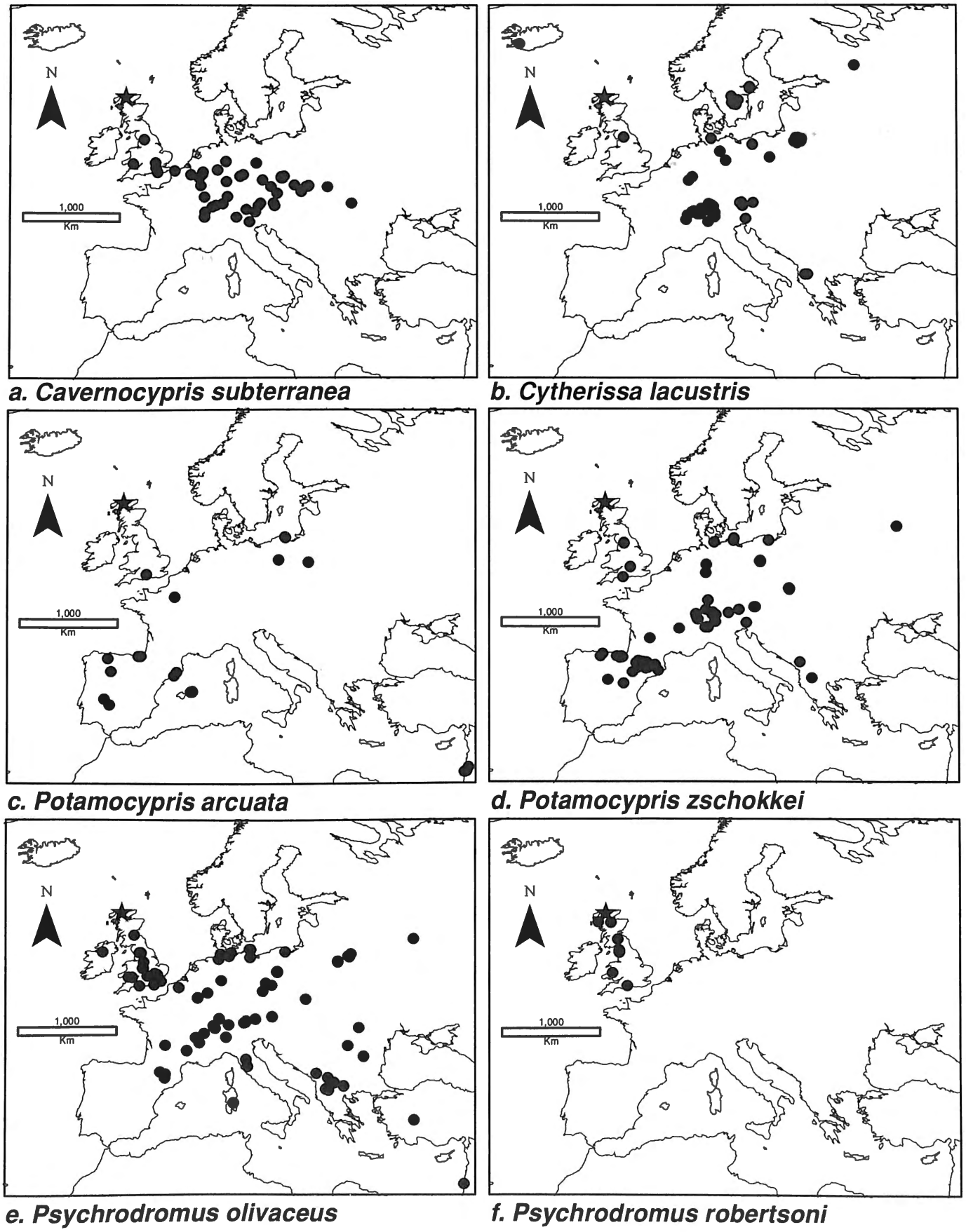

Fig. 5. Geographical distribution of living ostracod records in Europe (Mollweide projection) based on the NODE database (as of April 2006). (a) *Cavernocypris subterranea*, (b) *Cytherissa lacustris*, (c) *Potamocypris arcuata*, (d) *Potamocypris zschokkei*, (e) *Psychrodromus olivaceus*, (f) *Psychrodromus robertsoni* . Star indicates Assynt region records.

The characteristic ostracod faunas from the different habitats are described below.

Deep Lake (DL)

The deep lake habitat (DL) is characterised by low diversity assemblages with consistent species composition (*Cytherissa lacustris, Cypria ophtalmica, Candona candida, Cryptocandona reducta*). Of these species, only *C. lacustris* is particularly linked with deep lake settings while the others are found in shallow water habitats throughout Europe. This is also the northernmost recorded occurrence for *C. lacustris* in Britain and the first from Scotland, the next most northerly British occurrences being a questionable one from Windermere in the English Lake District (Horne *et al.*, 1990) and reliable one from Semerwater in Yorkshire (Fryer, 1993).

Springs and Seepages (SP)

The next most readily identifiable habitat, the springs and seepages (SP), is dominated by epifaunal and infaunal (unable to swim) species of *Psychrodromus* and *Cryptocandona* together with *Potamocypris zschokkei*, indicating their preference for cooler water/stenothermal conditions and spring habitats. Two species of *Psychrodromus* were found: *P. robertsoni* , first described from the Isle of Skye, is possibly the only freshwater ostracod species that is endemic to the British Isles (Meisch, 2000; Proudlove *et al.*, 2003); its congener, *P. olivaceus*, on the other hand, is widespread in Europe (Fig 5).

Littoral Loch (LL)

The shallow-water loch habitat (LL) contains elements of both the deep loch and spring assemblages but in addition often includes crawling /swimming (nektobenthonic) species of *Cyclocypris* and *Potamocypris*, these latter two genera often dominating the assemblages.

Streams (ST)

The flowing-water stream habitat (ST) yields similar taxa to the SP assemblages, which is not surprising given that many of these surface flows are intimately sourced from the karst system in the region. In addition, the stream assemblages include common occurrences of *C. candida* and *C. ovum*, which are perhaps less tolerant of cooler water conditions.

Ditches and Ponds (DP) and Temporary Pools (TP)

Of the final two habitats, the shallow surface ditches and ponds (DP) have a similar composition to the LL assemblages with many small nektobenthonic species but also include *P. olivaceus*, suggesting that some of these habitats may be fed by groundwater. The temporary pools (TP) yielded *Heterocypris incongruens* and *Eucypris virens*, both of which are common and widespread in European temporary waterbodies; their short life-cycles (typically a few weeks) and desiccation resistant eggs (the latter being a characteristic of most, if not all, cypridoidean ostracods) make them well-suited to such ephemeral habitats.

European distribution of key ostracod species

Of the 21 species identified by us in the Assynt region, three have not previously been recorded alive in Scotland: *Cavernocypris subterranea, Cytherissa lacustris* and *Potamocypris arcuata*. *Cavernocypris subterranea* is a stygophilic species known from several English and one Welsh locality and is widespread in western and central Europe (figure 5a); it is also reported from central Asia and North America (Meisch, 2000). *Cytherissa lacustris* is typically found in the muddy-bottom sublittoral and profundal zones of cold, deep lakes (Meisch, 2000). The only previous British record, from Semerwater in Yorkshire (Fryer, 1993), is unusual in being from a shallow sublittoral, vegetated sandy habitat (confirmed by a recent collection by one of us, DJH). It is widely distributed in alpine and prealpine lakes in Europe and further north in Scandinavia, but records south of the Alps seem to be restricted to Balkan lakes (figure 5b; Meisch, 2000). There is only a single previous British record of *P. arcuata*, that of Griffiths & Evans (1992) from a seepage-fed meadow pond in Hampshire; most European records in the NODE database are from mainland Spain but it is also found in the Balearic islands, France and Poland (figure 5c). There are undoubtedly other European records that have yet to be entered in NODE, but according to Meisch (2000) the species remains unknown in Ireland, the Netherlands, Luxembourg, Switzerland and the Czech Republic. Its main distributional area extends from central Asia to the Middle East and the circum-Mediterranean region (Meisch, 2000).

Two other stygophilic species of *Potamocypris*, *P. pallida* and *P. zschokkei*, were thought, initially, to constitute first Scottish records, but according to Meisch (2000) they are both represented in G.S. Brady's collections (Hancock Museum, Newcastle-upon-Tyne) from the Scottish island of Bute, having been misidentified or overlooked by Brady (1868) and Brady & Norman (1889). Both are widespread in Europe (for *P. zschokkei* see figure 5d).

The NODE database does not contain any Scottish records of either *Cyclocypris laevis* and *C. serena*; Henderson (1990) indicated Scottish occurrences of both of these species but gave no locality or publication details (possibly he made use of unpublished records represented by material in the Natural History Museum collections), so ours may be regarded as the first confirmed records from Scotland.

The discovery of a few specimens of *Fabaeformiscandona breuili* near Inchnadamph was reported by DJH in Proudlove *et al.* (2003), who noted that this western/central European stygobitic species was previously unknown in Britain although *Candona wedgewoodii* Lowndes, 1932 (from Wiltshire) may be a synonym. Specimens recovered in the present study are only questionably assigned to this species.

Two species of the rheophilic genus *Psychrodromus* were found, often in considerable abundance, mainly in springs, seepages and streams. *P. olivaceus* (23 sites) is common throughout Europe (figure 5e) but *P. robertsoni* (12 sites) is

Table 2. Species-sample occurrence (species alphabetical, samples grouped by habitat type (see right-hand column)

	Candona candida	*Candona* sp.	*Candonopsis kingsleii*	*Cavernocypris subterranea*	*Cryptocandona reducta*	*Cryptocandona vavrai*	*Cryptocandona* sp.	*Cyclocypris globosa*	*Cyclocypris laevis*	*Cyclocypris ovum*	*Cyclocypris serena*	*Cyclocypris* sp	*Cypria ophtalmica*	*Cypridopsis* sp.	*Cytherissa lacustris*	*Eucypris pigra?*	*Eucypris virens*	*Fabaeformiscandona breuili?*	*Herpetocypris chevreuxi*	*Heterocypris incongruens*	*Ilyocypris* sp	*Potamocypris arcuata*	*Potamocypris pallida*	*Potamocypris variegata*	*Potamocypris villosa*	*Potamocypris zschokkei*	*Potamocypris* sp.	*Pseudocandona* sp.	*Psychrodromus olivaceus*	*Psychrodromus robertsoni*	*Psychrodromus* sp.		
A17					X								X		X																	A17	DL
A18	X				X								X																			A18	DL
A19	X												X		X																	A19	DL
A20		X											X																			A20	DL
A28					X								X		X																	A28	DL
A2									X	X														X	X							A2	LL
A5						X																										A5	LL
A8	X									X	X		X										X									A8	LL
A11	X								X	X	X				X																	A11	LL
A12																											X		X			A12	LL
A14	X																															A14	LL
H13														X																		H13	LL
H14	X							X			X																		X			H14	LL
A16	X					X				X																						A16	DP
B6	X							X					X										X					X				B6	DP
B7						X		X		X																						B7	DP
B8	X							X		X			X																			B8	DP
H4						X														?					X	X			X			H4	DP
H5		X																					X						X			H5	DP
H7								X			X																					H7	DP
L1											X		X																			L1	DP
L4										X	X		X																X			L4	DP
L13																										X			X			L13	DP
H2		X											X							X												H2	TP
H3																				X												H3	TP
H12																	X											X				H12	TP
A4						X																	X						X			A4	ST
A9	X				X				X																	X			X			A9	ST
A15	X						X		X	X									X													A15	ST
A24	X				X					X			X													X			X	X		A24	ST
A25		X								X			X												X	X						A25	ST
A26																										X						A26	ST
B5	X				X			X		X																						B5	ST
B12						X		X																					X			B12	ST
H8					X	X																								X		H8	ST
H9		X			X	X																				X			X			H9	ST
H10						X																								X		H10	ST
H11																X		X								X			X			H11	ST
L3																										X			X			L3	ST
L5	X												X								X	X							X			L5	ST
L6																		X											X		X	L6	ST
L7										X																X			X			L7	ST
L8																					X					X			X			L8	ST
L9										X																X			X			L9	ST
L10			X																							X			X	X		L10	ST
L11	X					X	X																									L11	ST
A3	X					X																				X						A3	SP
A10																										X			X			A10	SP
A22				X																						X						A22	SP
A27																										X						A27	SP
B1																							X			X	X					B1	SP
B2										X																	X		X			B2	SP
B3					X	X				X																X				X		B3	SP
B4										X															X	X			X	X		B4	SP
B9						X																				X			X	X		B9	SP
B10						X																				X	X			X		B10	SP
B11					X					X																				X		B11	SP

Table 3. Location, environmental and Physico-chemical parameters (not all parameters available for all samples, no data marked by " – ").

Date		Type	Location	pH	T (°C)	Cond (µS)	Depth (m)	Latitude & Longitude
Mar-02	**A2**	LL	Loch Mhaolich Coire, 3 km SW Inchnadamph	7.6	5.8	183	0.20	58° 07' 47"N, 004° 55' 40" W
Mar-02	**A3**	SP	Spring at Cnoc-nan-Uamh, 2 km SW Inchnadamph	7.6	6.0	245	0.05	58° 08' 11"N, 004° 55' 38" W
Mar-02	**A4**	ST	Durness Road	8.1	7.3	281	0.20	58° 11' 22"N, 005° 01' 00" W
Mar-02	**A5**	LL	Lochan-an-Duibhe	8.0	9.7	77	0.20	58° 11' 18"N, 005° 02' 25" W
Mar-02	**A8**	LL	Ardvreck Castle	7.8	7.1	85	0.25	58° 10' 19"N, 005° 00' 22" W
Mar-02	**A9**	ST	Allt a' Chalda Beag	7.8	7.6	149	0.15	58° 10' 21"N, 005° 00' 20" W
Mar-02	**A10**	SP	Calda House Spring	7.3	6.4	353	0.05	58° 10' 12"N, 004° 59' 58" W
Mar-02	**A11**	LL	River Lonan mouth	8.8	7.2	161	0.20	58° 09' 20"N, 004° 59' 53" W
Mar-02	**A12**	LL	SW Loch Assynt 1	8.3	6.2	85	0.10	58° 09' 32"N, 005° 00' 18" W
Mar-02	**A14**	LL	SW Loch Assynt 3	7.7	7.6	88	0.10	58° 09' 29"N, 005° 00' 09" W
Mar-02	**A15**	ST	Lonan tributary	7.3	10.8	151	0.20	58° 09' 22"N, 004° 59' 55" W
Mar-02	**A16**	DP	Road Ditch	7.8	8.1	290	0.25	58° 09' 16"N, 004° 59' 14" W
Mar-02	**A17**	DL	Middle Loch Assynt	8.3	9.2	82	75.0	58° 10' 15"N, 005° 00' 58" W
Mar-02	**A18**	DL	Middle Loch Assynt	8.3	8.9	82	55.0	58° 09' 38"N, 005° 00' 10" W
Mar-02	**A19**	DL	Middle Loch Assynt	8.3	9.1	82	36.0	58° 09' 33"N, 004° 59' 52" W
Mar-02	**A20**	DL	Middle Loch Assynt	8.3	9.0	82	26.0	58° 09' 31"N, 005° 00' 13" W
Jul-02	**A22**	SP	Alt nan Uamh Lr Spring	7.5	7.7	115	0.10	58° 07' 12"N, 004° 58' 20" W
Jul-02	**A24**	ST	Alt na Glaic Moire 2	7.1	16.9	202	0.10	58° 08' 25"N, 004° 57' 14" W
Jul-02	**A25**	ST	Alt na Glaic Moire 3	8.1	14.7	220	0.10	58° 08' 27"N, 004° 57' 12" W
Jul-02	**A26**	ST	Alt na Glaic Moire 4	8.1	13.9	221	0.10	58° 08' 31"N, 004° 57' 31" W
Jul-02	**A27**	SP	Elphin layby	8.4	12.5	406	0.01	58° 03' 17"N, 005° 03' 18" W
Jul-02	**A28**	DL	Loch Assynt	8.3	9.0	82	76.0	58° 03' 43"N, 005° 10' 58" W
Sep-01	**L1**	DP	Permanent Pond by Inchnadamph Lodge	6.0	11.0	-	0.10	58° 08' 57"N, 004° 57' 56" W
Sep-01	**L3**	ST	Stream, 80m east from the A837, north of Inchnadamph	6.5	11.5	-	0.03	58° 09' 10"N, 004° 58' 10" W
Sep-01	**L4**	DP	Shallow pool, just north of Inchnadamph	5.0	11.0	-	0.09	58° 09' 22"N, 004° 58' 00" W
Sep-01	**L5**	ST	Stream, 1km north of Inchnadamph	6.0	12.0	-	0.06	58° 09' 30"N, 004° 58' 05" W
Sep-01	**L6**	ST	Stream, north side of Allt Poll an Droighinn	5.0	12.0	-	0.03	58° 09' 08"N, 004° 57' 25" W
Sep-01	**L7**	ST	Streamside wetland, north side of Allt Poll an Droighinn	6.0	11.0	-	0.10	58° 09' 18"N, 004° 57' 25" W
Sep-01	**L8**	ST	Stream pool just below Allt Poll an Droighinn	7.0	12.5	-	0.03	58° 08' 57"N, 004° 57' 33" W
Sep-01	**L9**	ST	Shallow pool, north side of Allt Poll an Droighinn	5.5	14.0	-	0.04	58° 08' 57"N, 004° 57' 10" W
Sep-01	**L10**	ST	Stream, 1km north of Inchnadamph	7.5	10.5	-	0.02	58° 09' 30"N, 004° 58' 10" W
Sep-01	**L11**	ST	Stream, north side Traligill Valley	5.0	10.0	-	0.36	58° 08' 33"N, 004° 56' W
Sep-01	**L13**	DP	Surface flow, south side Cnoc nan Uamh	5.0	11.0	-	0.30	58° 08' 05"N, 004° 55' 30" W
Sep-01	**L14**	SP	Seepage between main road and Loch Assynt	7.0	14.0	-	0.40	58° 090' 05"N, 004° 58' 30" W
Sep-01	**B1**	SP	1 km North of Loch Assynt	6.5	9.0	-	0.10	58° 10' 50"N, 004° 59' 58" W
Sep-01	**B2**	SP	2 km North of Inchnadamph	7.0	11.0	-	0.03	58° 9' 56"N, 004° 58' 30" W
Sep-01	**B3**	SP	Track from A894 to Achmore Farm	6.0	12.0	-	0.09	58° 10' 36"N, 004° 59' 30" W
Sep-01	**B4**	SP	West of Achmore Farm, just to west of B3	7.0	13.0	-	0.30	58° 10' 32"N, 005° 59' 30" W
Sep-01	**B5**	ST	NW shore of Loch Assynt	5.0	13.5	-	0.50	58° 11' 9"N, 005° 03' 7" W
Sep-01	**B6**	DP	By A837, North shore of Loch Assynt	5.0	15.5	-	0.22	58° 11' 0"N, 005° 02' 31" W
Sep-01	**B7**	DP	By A837, North shore of Loch Assynt	4.8	12.0	-	0.14	58° 10' 39"N, 005° 01' 5" W
Sep-01	**B8**	DP	Old quarry by A837, North shore of Loch Assynt	5.0	14.0	-	0.20	58° 10' 39"N, 005° 01' 48" W
Sep-01	**B9**	SP	North of Loch Assynt	7.5	12.0	-	0.62	58° 09' 23"N, 004° 58' 32" W
Sep-01	**B10**	SP	East roadside A894, North of Loch Assynt	6.5	14.0	-	0.01	58° 10' 0"N, 005° 03' 0" W
Sep-01	**B11**	SP	West roadside A894, North of Loch Assynt	7.5	12.0	-	0.06	58° 10' 2"N, 004° 59' 15" W
Sep-01	**B12**	ST	By A837, Ardvreck castle, North shore of Loch Assynt	7.5	12.0	-	0.06	58° 09' 59"N, 004° 59' 12" W
Jul-00	**H1**	SP	Spring near Achmore Farm	7.1	10.0	-	0.50	58° 10' 30"N, 004° 55' W
Jul-00	**H2**	TP	Roadside temporary pond on N side of Loch Assynt	8.4	18.0	-	-	58° 10' 30"N, 005° 02' W
Jul-02	**H3**	TP	Roadside temporary puddle on A894 N. of Loch Assynt	-	-	-	0.20	58° 11' 30"N, 005° 00' 15"W
Jul-02	**H4**	DP	Roadside ditch about 300m E. of Skiag Bridge	6.5	13.0	-	0.15	58° 10' 15.1"N, 004° 59' 53.0"W
Jul-02	**H5**	DP	Spring-fed pool E. of Skiag Bridge	7.0	10.0	-	0.20	58° 10' 15.1"N, 004° 59' 53.0"W
Jul-02	**H6**	SP	Spring E. of Skiag Bridge	7.0	10.0	-	0.20	58° 10' 15.1"N, 004° 59' 53.0"W
Jul-02	**H7**	DP	Pool near Skiag Bridge, N side of Loch Assynt	5.0	11.0	-	0.20	58° 10' 24.4"N, 005° 00' 07.7"W
Jul-02	**H8**	ST	Stream on N side of Gleann Dubh	5.0	11.0	-	0.35	58° 08' 41.0"N, 004° 56' 7.9"W
Jul-02	**H9**	ST	Small stream E of Inchnadamph	8.0	11.0	-	-	58° 09' 30"N, 004° 57' 10"W
Jul-02	**H10**	ST	Small stream E of Inchnadamph	8.0	11.0	-	-	58° 09' 15"N, 004° 57' 15"W
Jul-02	**H11**	ST	Small stream E. of Inchnadamph	7.0	13.0	-	-	58° 09' 20"N, 004° 58' 00"W
Jul-02	**H12**	TP	Temporary pond NE of Ardvreck of Loch Assynt	8.1	17.0	-	0.40	58° 10' 00" N, 004° 59' 00" W
Jul-02	**H13**	LL	Margin of Loch Assynt at Ardvreck	8.2	13.4	81	<2.0	58° 10' 00"N, 004° 59' 00" W
Jul-02	**H14**	LL	South margin of Loch Assynt	7.0	10.0	-	1.75	58° 10' 21.6"N, 005° 03' 14.8"W

known only from the British Isles (figure 5f), the latter was first described from the Isle of Skye (BRADY & NORMAN, 1889) and in recent years has been found in many localities in northern England and Scotland, including the Outer Hebrides (PROUDLOVE *et al.*, 2003; DJH, unpublished data). *Psychrodromus robertsoni* was additionally found at two localities on the margin of Loch Assynt where streams enter the loch, and *P. olivaceus* was found in five ditch / pond sites (DP) fed by springs or seepages. Although the two were found together at four of our sites, most samples with *Psychrodromus* contained only one or the other species, typically in association with *Potamocypris zschokkei*, *Cryptocandona vavrai* and *Cryptocandona reducta*. The distribution of the two species in the study area suggests that *P. olivaceus* may show a preference for waters associated with the Durness Limestone, while *P. robertsoni* tends to occur more on quartzitic sandstones (Fig. 2); how this might relate to pH, water chemistry or temperature (e.g. cool groundwater) preferences remains unclear, however. Our records of *P. olivaceus* from Assynt may be the most northerly in Europe for this species (figure 5e).

Summary

Based on the collections in this study, three species are new records to Scotland (*Cavernocypris subterranea, Cytherissa lacustris, Potamocypris arcuata*) bringing the total number of freshwater ostracod species recorded in Scotland to 53, 33 of them to the north of the Great Glen (see Appendices 1 and 2). The study highlights the potentially important role that ground water emergence, whether associated with karst systems or not, plays in determining the distribution of ostracods. Further investigations of subterranean habitats associated with such systems may lead to a better understanding of their ecology and possibly the importance of troglobytic habitats as refugia during times of environmental crises. It is likely that other invertebrates also rely on the stenothermal ground water emergences in this area.

Acknowledgements

The authors wish to thank Assynt Estates, Alex SCOTT (Scottish Natural Heritage), and Chris RIX and his staff at Inchnadamph Lodge for their support over recent years. Ian BOOMER was supported by funding from Newcastle University and the Royal Society, and also wishes to thank Simon HILDON and Andy BAKER for assistance in the field. David HORNE thanks Rebecca WEBBER and Luke EVERITT (students) and Ian SLIPPER (supervisor) (University of Greenwich) for their field collections, made in the course of undergraduate project work. Robin SMITH gratefully acknowledges tenure of a Royal Society Post-Doctoral Research Fellowship during which fieldwork for this study was undertaken.

References

BENZIE, J.A.H., 1989. The distribution and habitat preference of ostracods (Crustacea: Ostracoda) in a coastal sand-dune lake, Loch of Strathbeg, north-east Scotland. *Freshwater Biology*, 22: 309-321.

BRADY, G.S., 1868. A Monograph of the Recent British Ostracoda. *Transactions of the Linnean Society of London*, 26: 353-495.

BRADY, G.S. & NORMAN, A.M., 1889. A Monograph of the marine and freshwater Ostracoda of the North Atlantic and of Northwestern Europe, Section 1, Podocopa. *Scientific Transactions of the Royal Society of Dublin*, series 2, 4: 63-270.

FRYER, G., 1980. Acidity and species freshwater in freshwater crustacean faunas. *Freshwater Biology*. 10. 41-45.

FRYER, G., 1993. *The Freshwater Crustacea of Yorkshire*. Yorkshire Naturalists' Union and Leeds Philosophical and Literary Society. 312pp.

FRYER, G. & FORSHAW, O., 1979. The freshwater Crustacea of Rhum Inner Hebrides – a faunistic and ecological survey. *Biological Journal of the Linnean Society,* 11: 333-367.

GEOLOGICAL SURVEY OF GREAT BRITAIN (SCOTLAND), 1965. *Assynt District*. Solid Geology Sheet (1:50,000), Ordnance Survey.

GOODENOUGH, K. PICKETT, E. KRABBENDAM M. & BRADWELL, T., 2004. *Exploring the Landscape of Assynt: A Walkers' Guide and Map Showing the Rocks and Landscape of Assynt and Inverpolly*. British Geological Survey. Keyworth, England 55 pp. and 1:50,000 geological map.

GRIFFITHS, H. I. & EVANS, J. G., 1992. *Potamocypris arcuata* (Sars, 1903) (Ostracoda) new to Britain. *Crustaceana*, 62: 110-112.

GRIFFITHS, H.I. & MARTIN, D.S., 1993. The Spatial Distribution of Benthic Ostracods in the Profundal Zone of Loch Ness. *Scottish Naturalist,* 105: 137-147.

GRIFFITHS, H.I., MARTIN, D.S., SHINE, A.J. & EVANS, J.G., 1993. The ostracod fauna (Crustacea, Ostracoda) of the profundal benthos of Loch Ness. *Hydrobiologia*, 254: 111-117.

HORNE, D.J., 1988. *Recent freshwater Ostracoda of the Lake District*. British Micropalaeontological Society Field Guide No. 7, 28 pp. University College of Wales, Aberystwyth.

HORNE, D.J., BALTANAS, A. & PARIS, G., 1998. Geographical distribution of reproductive modes in living non-marine ostracods, *In*: Martens, K. (ed.), *Sex and parthenogenesis: evolutionary ecology of reproductive modes in non-marine ostracods*, 77-99, Backhuys, Leiden, the Netherlands.

HORNE, D.J., HORNE, D.M. & HORNE, J.E.M., 1990. New records of ostracods from the Lake District. *Transactions of the Natural History Society of Northumbria*, 55 (2): 147-148.

HORNE, D. J. & SMITH, R. J., 2004. First British record of *Potamocypris humilis* (Sars, 1924), a freshwater ostracod with a disjunct distribution in Europe and southern Africa. *Bolletino della Societa Paleontologica Italiana,* 43: 297-306.

LAWSON, T.J. (Editor), 1995. *The Quaternary of Assynt and Coigach*: Field Guide. Quaternary Research Association, 162 pp.

MEISCH, C., 2000. *Freshwater Ostracoda of Western and Central Europe*. In: J. SCHWOERBEL & P. ZWICK (Editors), Suesswasserfauna von Mitteleuropa 8/3. Spektrum Akademischer Verlag, Heidelberg, pp. 522.

PROCTOR, C.J., BAKER, A. & BARNES, W.L., 2002. A three thousand year record of North Atlantic climate. *Climate Dynamics*, 19: 449-454.

PROUDLOVE, G.S., WOOD, P.J., HARDING, P.T., HORNE, D.J., GLEDHILL, T & KNIGHT, L.R.F.D., 2003. A review of the status and distribution of the subterranean aquatic Crustacea of Britain and Ireland. *Cave and Karst Science*, 30(2): 53-74.

SMITH, A.J. & HORNE, D.J., 2002. Ecology of marine, marginal marina and nonmarine ostracodes, *in*: HOLMES, J.A. & CHIVAS, A.R. (eds), *The Ostracoda: Applications in Quaternay Research*, AGU Geophysical Monograph Series, Vol. 131: 37-64.

SMITH, R.J. & HORNE, D. J., 2004. First record of *Paralimnocythere psammophila* (Crustacea, Ostracoda) from the British Isles. *Journal of Micropalaeontology,* 23: 133-134.

WOOD, R.N., 1992. *Ecology of Lake District Ostracoda.* Unpublished Ph.D. Thesis, University of Greenwich, London, 273 pp.

Ian BOOMER
School of Geography, Earth and Environmental Sciences,
University of Birmingham,
Birmingham B15 2TT, UK.
Email: i.boomer@bham.ac.uk

David J. HORNE
Department of Geography,
Queen Mary, University of London,
Mile End Road, London E1 4NS
and
Department of Zoology,
The Natural History Museum,
Cromwell Road, London SW7 5BD

Robin J. SMITH
Lake Biwa Museum,
1091 Oroshimo-cho,
Kusatsu-shi, Shiga 525-0001, Japan

Appendix 1. Faunal lists of freshwater ostracods records for NW Scotland (from the Great Glen northwards), based on the NODE database and other literature discussed in the text.

Loch Alsh 5° 36' W, 57° 15' N (BRADY & NORMAN, 1889)
Pseudocandona rostrata (BRADY & NORMAN, 1889)

River, Portree, Isle of Skye (type locality) 6°12' W, 57°24' N (BRADY & NORMAN 1889)
Psychrodromus robertsoni (BRADY & NORMAN, 1889)

Isle of Skye (unspecified locality/localities) (BRADY & NORMAN, 1889)
Bradleycypris obliqua (BRADY, 1868)
Candonopsis kingsleii (BRADY & ROBERTSON, 1870)
Potamocypris variegata (BRADY & NORMAN, 1889)
Potamocypris villosa (JURINE, 1820)
Sarscypridopsis aculeata (COSTA, 1847)

Isle of Lewis (Rowan Bridge) (BRADY & NORMAN, 1889)
Bradleycypris obliqua (BRADY, 1868)
Candonopsis kingsleii (BRADY & ROBERTSON, 1870)
Cyclocypris globosa (SARS, 1863)
Cypria exsculpta (FISCHER, 1855)
Heterocypris salina (BRADY, 1868)
(recorded as *Cypris prasina* FISCHER)
Potamocypris villosa (JURINE, 1820)

Isle of Rhum (FRYER & FORSHAW, 1979)
Bradleystrandesia reticulata (ZADDACH, 1844)
Candona candida (O. F. MÜLLER, 1776)
Cryptocandona vavrai KAUFMANN, 1900
Cyclocypris globosa (SARS, 1863)
Cyclocypris ovum (JURINE, 1820)
Cypria ophtalmica (JURINE, 1820)
Cypridopsis vidua (O. F. MÜLLER, 1776)
Eucypris virens (JURINE, 1820)
Herpetocypris chevreuxi (SARS, 1896)
Potamocypris villosa (JURINE, 1820)

Harris (Horne & Smith, 2004)
Cypria ophtalmica (JURINE, 1820)
Ilyocypris bradyi SARS, 1890
Potamocypris humilis (SARS, 1924)

Isle of Barra (SMITH & HORNE, 2004)
Eucypris virens (JURINE, 1820)
Paralimnocythere psammophila FLOSSNER, 1965

Loch Ness (GRIFFITHS *et al.* (1993)
Candona candida (O. F. MÜLLER, 1776)
Candona neglecta+ SARS, 1887
Cryptocandona reducta (ALM, 1914)
Cyclocypris ovum (JURINE, 1820)
Cypria ophtalmica (JURINE, 1820)
Potamocypris smaragdina (VAVRA, 1891)
Psychrodromus robertsoni (BRADY & NORMAN 1889)
(fish gut contents)

+ Note that in this publication, the species is given as *C. angulata*. GRIFFITHS (pers. comm.) later revised his opinion and corrected the species to *C. neglecta*.

Appendix 2. Faunal checklist (alphabetical) of freshwater ostracod species for the whole of Scotland, based on the NODE database and other literature discussed in the text. New Scottish records identified in the present study are marked with an asterisk.

Bradleycypris obliqua (BRADY, 1868)
Bradleystrandesia reticulata (ZADDACH, 1844)
Candona candida (O.F. MÜLLER, 1776)
Candonopsis kingsleii (BRADY & ROBERTSON, 1870)
Cavernocypris subterranea (WOLF, 1920)*
Cryptocandona reducta (ALM, 1914)
Cryptocandona vavrai KAUFMANN, 1900
Cyclocypris globosa (SARS, 1863)
Cyclocypris laevis (O.F. MÜLLER, 1776)
Cyclocypris ovum (JURINE, 1820)
Cyclocypris serena (KOCH, 1838)
Cypria exsculpta (FISCHER, 1855)
Cypria ophtalmica (JURINE, 1820)
Cypridopsis vidua (O.F. MÜLLER, 1776)
Cypris pubera O.F. MÜLLER, 1776
Cyprois flava (ZADDACH, 1844)
Cytherissa lacustris (SARS, 1863)*
Darwinula stevensoni (BRADY & ROBERTSON, 1870)
Eucypris pigra (FISCHER, 1851)
Eucypris virens (JURINE, 1820)
Fabaeformiscandona breuili (PARIS, 1920)
Fabaeformiscandona fabaeformis (FISCHER, 1851)
Fabaeformiscandona protzi (HARTWIG, 1898)
Herpetocypris chevreuxi (SARS, 1896)
Herpetocypris reptans (BAIRD, 1835)
Heterocypris incongruens (RAMDOHR, 1808)
Heterocypris salina (BRADY, 1868)
Ilyocypris bradyi SARS, 1890
Limnocythere inopinata (BAIRD, 1843)
Limnocytherina sanctipatricii (BRADY & ROBERTSON, 1869)
Nannocandona faba EKMAN, 1914
Notodromas monacha (O.F. MÜLLER, 1776)
Paracandona euplectella (ROBERTSON, 1889)
Paralimnocythere compressa (BRADY & NORMAN, 1889)
Paralimnocythere psammophila FLOSSNER, 1965
Penthesilenula brasiliensis PINTO & KOTZIAN, 1961
Plesiocypridopsis newtoni (BRADY & ROBERTSON, 1870)
Potamocypris arcuata (SARS, 1903)*
Potamocypris fulva (BŘADY, 1868)
Potamocypris humilis (SARS, 1924)
Potamocypris pallida ALM, 1914
Potamocypris smaragdina (VAVRA, 1891)
Potamocypris variegata (BRADY & NORMAN, 1889)
Potamocypris villosa (JURINE, 1820)
Potamocypris zschokkei (KAUFMANN, 1900)
Pseudocandona albicans (BRADY, 1864)
Pseudocandona compressa (KOCH, 1838)
Pseudocandona rostrata (BRADY & NORMAN, 1889)
Psychrodromus olivaceus (BRADY & NORMAN, 1889)
Psychrodromus robertsoni (BRADY & NORMAN, 1889)
Sarscypridopsis aculeata (COSTA, 1847)
Scottia pseudobrowniana KEMPF, 1971
Tonnacypris lutaria (KOCH, 1838)