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Aquatic Invasions Records

Hemimysis anomala is established in the Shannon River Basin District in Ireland

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Abstract

The Ponto-Caspian mysid shrimp *Hemimysis anomala* was found in Ireland for the first time in April 2008. During 2009 it was found throughout most of the Shannon River Navigation (~250km) occurring in swarms at estimated densities of ~6 per litre in shallows and in lower densities at depths of ~20m where its distribution overlaps with the native *Mysis salemaai*. Broods were found from March to September. It occurs mainly in lakes but small numbers were found at one river site. In summer, shallow-water specimens were found only during the night but in winter could be captured in daytime. It is not known by what means the species arrived in Ireland, or when.

Key words: *Hemimysis*, mysid, Ireland, Shannon, lake, swarm

Introduction

In April 2008, the Ponto-Caspian mysid *Hemimysis anomala* G.O. Sars, 1907 was discovered for the first time in Ireland in a harbour on the western side of Lough Derg, the largest lake on the Shannon River system (Minchin and Holmes 2008). This species has spread throughout Europe by various means since the middle of the last century. There has been a progressive spread via the European inland waterways; there are records from near Budapest in 1946 (Dudich in Kelleher et al. 1999). The linking in 1992 of the shipping canal between the Danube and the Rhine (Audzijonyte et al. 2008) enabled its spread downstream to The Netherlands in, or before, 1997 (Faasse 1998). It has also spread westwards to eastern France and southwards towards the Mediterranean Sea (Wittman and Ariani 2009). In the 1950s and 1960s *H. anomala* was introduced from the Black Sea to Lithuanian lakes to serve as forage for freshwater fishes (Arbačiauskas 2002). Some of these stocking events included the mysids *Paramysis lacustris* (Czerniavsky, 1882) and *Limnomysis benedeni* Czerniavsky, 1882 also introduced from the same region of the Black Sea (Arbačiauskas 2002). The arrival of *H. anomala* in 1992 on the coast of Finland is thought to have been with ships' ballast water (Salemaa and Hietalahti 1993), as is also the case in the Great Lakes of North America (Audzijonyte et al. 2008). Since this mysid is able to tolerate salinities of up to 19 psu (Kelleher et al. 1999), it can readily survive in estuaries and brackish seas. This enabled it to spread along the Baltic coast as well as via interlinking canals in northern Europe. It was recorded by Holdich et al. (2006) in Britain in 2004 in an area where recreational craft may have been responsible for its introduction. We surmise there are two principle routes by which the species may have spread to Ireland from Britain or northern Europe, either via the southern corridor (Danube-Rhine link) or via the network of north European canals following stocking events.

Its expansion in Europe over the last number of decades has been attributed to increased inland boat traffic (Wittman and Ariani 2009), canal connections (Audzijonyte et al. 2008), improved water quality (Wittman and Arianai 2009) and perhaps alterations in climate (Daufresne et al. 2007). It is unclear how the species came to Ireland but most species arriving in Ireland have appeared in Britain beforehand (Minchin and Eno 2002).

Following the discovery of *H. anomala* in 2008, this study was undertaken to determine the overall distribution of adults within the Shannon Waterway.

Methods

The area investigated was the navigable region of the Shannon River Basin extending from Lough Key to Lough Derg (Figure 1). Lakes, canal sections and rivers between these two lakes were also examined.

Specimens of *H. anomala* were identified from the distinctive orange and transparent appearance of live specimens and by the posterior shape of the telson. In *H. anomala* the telson is un-notched and bears two prominent posterior-lateral spines whereas in the native *Mysis (relicta) salemaai* Audzijonytė and Väinölä, 2005 a larger mysid, this is notched. The shape of the telson also helps to distinguish the species from the other possible mysid invaders such as the Ponto-Caspian *Limnomysis benedeni* which is also expanding its range in Europe (Audzijonyte et al. 2009).

The following methods were used to capture *H. anomala*. The first three methods were used in the same way during the day, at twilight and at night.

Vertical plankton net hauls from the lake bottom to the surface over depths ranging from 2m to 36m using a 95cm diameter cone net of length 105cm and a bar-mesh size of ~1mm, hauled at a rate of ~0.5m sec^{-1}. This method has been successfully employed by Aaser et al. (1995), Ketelaars et al. (1999) and Viherluoto (2001).

Oblique tows using a weighted 30cm diameter plankton net with a bar-mesh of 5mm fished to a maximum depth of ~20m at speeds of 2 to 4 knots for periods of ~10 minutes to capture adults.

A handnet with a 30cm×30cm frame and 3mm black mesh that could be fished to depths of 3m, depending on local depth profiles, at various times during day and night. Handnets have also been used by Viherluoto (2001), Kringel et al. (2003) and Wittman and Arianai (2009). Estimates of relative abundance were based on the numbers captured per five minutes of sampling, recorded on a logarithmic scale. Estimates of density were calculated from the numbers captured over a known distance assuming 100% efficiency. This was the only method that revealed shallow water swarms, apart from one direct observation. Handnet sampling was employed alongside quays and over stones and boulders. Plastic bottles cut to form traps were arranged in arrays of three bottles suspended within one metre of the bottom and left overnight. These were baited with tablets containing Spirulina. This method has been used by (Oldenwald et al. 2005).

A net with a 30cm diameter and a 3mm mesh was anchored overnight on the bottom of different river sections in a direct current.

Observations of swarming, shallow water mysids during daytime were received from various sources (e.g. divers, fishermen).

Collections of *H. anomala* were made during daytime, at twilight and at night according to the opportunities available during the survey period. Samples of *H. anomala* were retained for study by other workers examining behaviour, growth and reproduction.

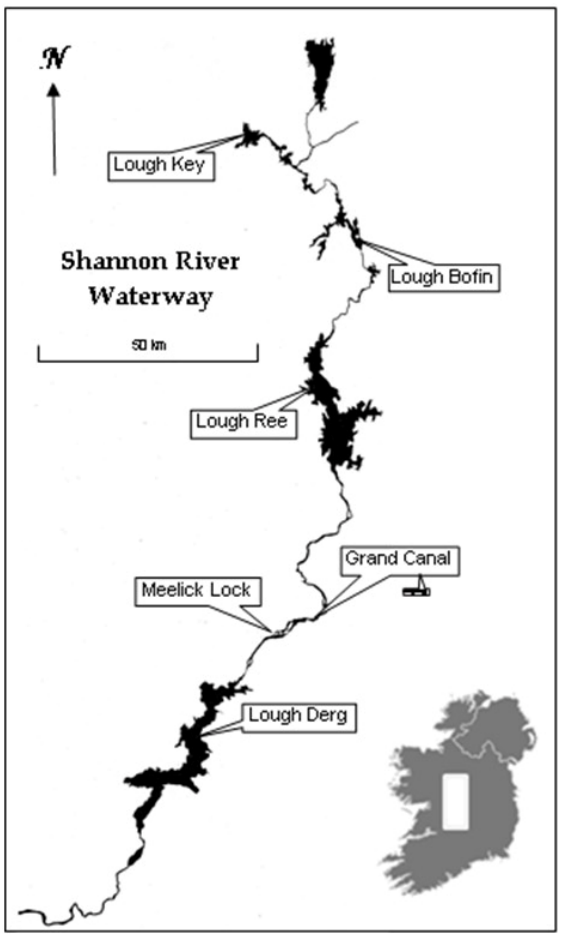

Figure 1. Map of study area.

Results

The specimen In Ireland, *H. anomala* is presently known only from the Shannon Waterway and was recorded from the shallows of four loughs (Key, Bofin, Ree and Derg) and from a single river site (Meelick Lock) situated between Loughs Ree and Derg in areas where there were boulders, stones or gravels (Figure 1, Annex 1). The first record outside of Lough Derg was from Lough Ree in February 2008 when swarms were seen in shallows adjacent to a quay wall (Figure 3). Only in Lough Derg was *H. anomala* found at depths of over 6m where it was captured along with *M. salemaai* and cladocerans (Figure 2). Low numbers of *H. anomala* were found to depths of 20+m, usually over silted rock. Brooding females were found from April to the end of September 2009. Mysids were not captured in canalised channels nor in Loughs Carnadoe and Grange which are part of the navigation and drain into the Shannon. Although vertical hauls of more than 6m in Loughs Ree and Key procured specimens of the native mysid, *H. anomala* was not found. While it is possible *H. anomala* entered the Shannon via the Grand Canal, two areas sampled along the canal in February 2009 did not provide specimens.

In the shallows, *H. anomala* showed a notable diurnal behaviour pattern, as shown by handnet captures at dusk and night-time from April to November. Numbers ranged from <10 to 1000s of individuals with five-minute sampling periods. Distributions were highly localised and patchy; samples taken some metres away from swarms often revealed only a few, or no, specimens. Repeated sampling at night showed that swarms can move or disperse within a few hours, thousands being captured early at night and none some hours later. Daytime captures were made only in February, March and early April. Swarms occurred on the shaded side of quays, many swimming within about 30cm of the surface.

In May 2008, a diver noted a swarm of mysids, almost certainly *H. anomala*, from 6m depth in the southern section of Lough Derg.

The handnet was the most efficient method for capturing *H. anomala* in shallow areas, producing <10 to >1000 individuals from some selected shallow water sites (Annex 1). Swarms were found over boulders, stones and gravels. Sampling over small distances showed clear differences in abundance. Individuals were captured in depths ranging from <1m to ~3mover

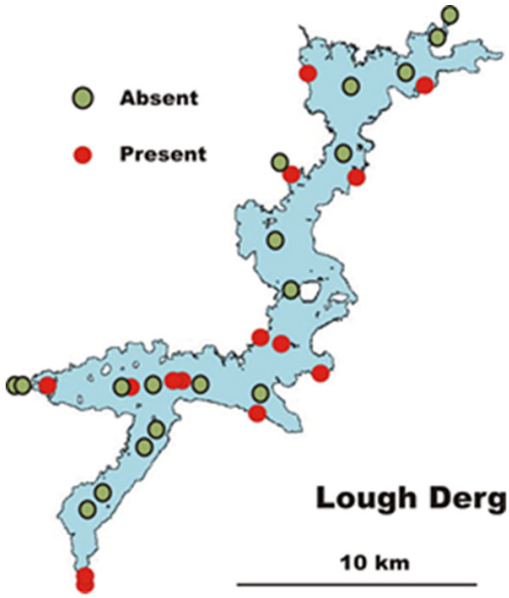

Figure 2. Presence and absence of *Hemimysis anomala* in LoughDerg.

Figure 3. *Hemimysis anomala* captured from a February swarm in Lough Ree (Photographs D. Minchin).

substrates containing stones and cobbles, and where overhanging spaces occurred nearby. Swarms were most apparent in these areas. Small numbers were found over soft sediments and in deeper water, however in shallows their distribution is mainly confined to coarse substrates. Traps deployed in shallows did not always result in captures of *H. anomala* but their absence in traps did not mean that mysids were absent in that region since many specimens could sometimes be captured using a handnet at the same localities.

Baited traps collected small numbers of mysids. The numbers of individuals captured for sets of three traps ranged from one to twenty-three. Both sexes were captured in traps, including females with brood. Amphipods were often captured along with *H. anomala*.

Discussion

The until recently, *M. salemaai* (Audzijonyte et al. 2008) was the only species of mysid known from Irish lakes (Reynolds 1998). *Hemimysis anomala* is now established and widely distributed in the large lakes on the Shannon Navigation producing broods from March to September. Environmental conditions in Ireland fall well within the range of this species and extensions in distribution may be expected. The species has a preference for temperatures within the range of 9-20°C (the typical range in Irish lakes from April to November). It is ovigerous from 8-9°C and may produce up to four broods in the year, with sexual maturity developing after about 45 days (Borcherding et al. 2006). These authors also record that *H. anomala* can tolerate salinities to 19 psu.

The mode of arrival by *H. anomala* to Ireland remains unknown but will certainly have required transport in water because the species lacks a resting stage. All indications suggest anthropo-genic movement but it is unclear where the seminal inoculation took place. Possible transmissions include leisure craft (bait wells, bilge water or toilet water), water involved in the stocking of imported fishes, living aquarium foods or imports of aquatic plants. Its subsequent dispersal in Ireland may involve more than one pathway but transmission along navigable canals and other waterways, as well as with downstream movements, are expected to result in further spread as happened in continental Europe. In Europe, the spread of several Ponto-Caspian species has been attributed to the linking of different navigations and river basins by canals, their widening to take larger vessels and increases in traffic (Leuven et al. 2009). Changes in water quality have also enabled such expansion according to Bij de Vaate et al. 2002). Since *H. anomala* is a poor swimmer its appearance in L. Derg could be by downstream dispersal from L. Ree. However, it is also possible that leisure craft transferred specimens upstream from L. Derg. Propagule size for this species is unknown but transport of the relatively inconspicuous young (after release from the adult) could easily go unnoticed. Some possible modes of transmission are given in Table 1.

Expansions in the distribution of *H. anomala* are likely to arise inadvertently through transfer of water (e.g. bilge water, farm vehicles, drainage systems etc.) between catchments, with subsequent transport occurring mainly in a downstream direction as the species is a weak swimmer (Wittmann and Ariani 2009). The canal system in Ireland links several different water catchments across the Irish central plain to the east, south-east and north-west coasts (Figure 1). This study shows that *H. anomala* occurs in dense swarms depending on the time of day and has a distinct behaviour pattern, similar to the findings of other workers (Borcherding et al. 2006; Holdich et al. 2006). The species has a greater tolerance to light than the native *M. salemaai* and so occurs in shallows. Handnet samples show clear differences in the numbers captured between day and night and according to season and is the preferred method of sampling. However, Wittman and Arianai (2009) found bottle traps procured more specimens during daytime compared to handnets. Holdich et al. (2006) found that *H. anomala* swarmed extensively in the evening hours of June in a canal in the midlands of Britain. Its behaviour in a large flooded gravel pit was studied by Borcherding et al. (2006) in the Netherlands. Swarms appeared near to the surface at twilight and during the night in summer but could also be found near the surface in daytime in November and December - a pattern generally observed in this study. Noctural behaviour is also recorded by Dekker and Brun (1993) for the related *Hemimysis lamornae*. Faasse (1998) and Scheuter et al. (1998) found *H. anomala* was associated with substrata that had crevices, consistent with our observations which showed greatest numbers around gravels, stones and boulders that provide shade for the mysids

Table 1. Possible modes of arrival of *Hemimysis anomala* in Ireland.

Mode of arrival (pathway)	Description
Boat toilet water	The amphipod *Gammarus tigrinus* has been found alive within the toilet water of boats imported to Ireland. The hiding of *H. anomala* in small spaces such as intake areas in the hull could also result in their entrainment into toilet water before boat transport. *H. anomala* are known to have survived in boat toilet water. Boat toilet systems, depending on design, can hold >4 litres
Boat bilge water	Bilge water seeped or splashed into the hull by boat movement may carry mysids. This would most likely occur in winter when animals are higher in the water column. Small boats used in winter for wildfowl shooting might be involved in this method of dispersal, including perhaps boats brought by ferry to Ireland
Bait boxes in craft	Bait boxes in craft moved upstream, overland or by ferry, containing up to about 40+ litres of water could provide an efficient means of dispersal. Water collected close to a swarm of mysids, decanted into such a container, could transmit large numbers
Fish stocking by fisheries agencies and unapproved releases	This pathway could result in local transfers but illegal stocking events have also taken place, for example the unapproved stocking of chub to the River Inny draining to Lough Ree (Caffrey et al. 2008), and releases of carp directly to Lough Derg. The capacity of water containers used for such purposes would, of course, be highly variable
Deliberate or accidental release into the wild	The acquisition via the internet of mysids, available as an aquarium fish food (Prepiorka and Walter 2006), and subsequent release to ponds to provide a continuous replicating food source, is another possible means of dispersal. Should the ponds become flooded, or drained to streams and rivers, they may continue to survive there and ultimately enter lakes (Rey et al. 2005)
Imports of aquatic plants to garden centres and supermarkets	The trade in aquatic plants held in imported water, and sourced from northern Europe, could result in transport to Ireland. Mysids are known to hide among aquatic plants in daytime (Salemaa and Hietalahti 1993). Aquatic plants have been suggested as dispersal mechanisms by van der Velde (2000) and Dumont (2006). It is known that large numbers of aquatic plants have been distributed in the spring through retail outlets (supermarkets and garden centres) in Ireland. These could have contributed to the introduction and/or spread of imported organisms, including *H. anomala*

during daytime in summer. Salemaa and Hietalahti (1993) indicated that individuals may disperse to the algal zone during daytime. In the absence of an algal zone, we attempted to recover *H. anomala* from macrophyte stands but this proved unsuccessful.

The occurrence of females with brood from March to September would indicate that this species has a high reproductive capacity. The species is omnivorous, has a wide-ranging diet and has even been found to prey upon damaged or weak specimens of its own species. *H. anomala* is highly competitive and is likely to be found in more Irish lakes in the future. According to Borcherding et al. (2006), adults feed mainly on crustaceans, preferring copepods, whilst Verslycke et al. (2000) considered cladocera to be the main prey organisms but the species also feed on detritus (Marty et al. 2009). Young specimens are known to feed on phytoplankton (Borcherding et al. 2006). All of these taxa were common or abundant in vertical tows taken in summer within the Shannon lakes.

Traps provide an indication of the presence of *H. anomala* but do not provide a quantitative measure of abundance. Likewise, the absence of specimens in traps does not indicate that the species is absent in the adjacent area i.e. traps can indicate presence but not absence. Trap efficiency probably varies according to orientation, proximity of weed, habitat type and depth.

Mysids have an ability to swim short distances rapidly (7+ cm/sec) when alarmed (Gruner 1993) and so many may avoid the handnet. Handnet sampling was most effective at night in summer, and at some shaded localities during daytime in winter. Swarming makes reliable estimates of density difficult to obtain as abundance is highly variable over short distances. Ketelaars et al. (1999) measured densities of ~6 per litre; our estimations are consistent with this.

In this study *H. anomala* was found to depths of ~3m at all seasons and occasionally to depths of 20m+. It has been found to depths of 50m in Europe (Borcherding et al. 2006). In vertical tows the species was found together with *M. salemaai*, indicating a possible vertical overlap in the distribution of the two species. Samples from deep water were not taken during night-time and overlap might thus be more extensive than found in this study.

The preference of *H. anomala* for warmer water conditions than those favoured by *M. salemaai* provides it with a competitive advantage over the native species which has only one brood per year and is dependent on temperatures below 7ºC for reproductive success. Four broods a year have been reported for *H. anomala* in Europe (Borcheding et al. 2006), brood size depending on female size and season. According to Borcherding et al. (2006), mean brood size in April was 29 individuals and in September 20 individuals according to length-weight ratios, the heaviest individuals occurring in the spring.

There is a clear difference in behaviour between summer and winter. During daytime in winter large swarms occur in shallow water close to the surface while a few individuals have been found over deeper water. In summer, daytime captures are rare and the mainly nocturnal behaviour of *H. anomala* could explain why the species was not recorded until recently.

The great abundance of the species in two large lakes suggests that *H. anomala* has almost certainly been present for some years and the observation by divers in May 2008, at a site 10 km from the initial observation, of what is likely to be this species could mean that the mysid was already widely distributed in Lough Derg at that time. The occurrence of brooding females in April 2008 indicates that they were present since at least 2007, and probably earlier.

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Annex 1. Records of *Hemimysis anomala* in the Shannon Lakes.

Location name	Coordinates		Sampling time/date	Number collected	Depth	Substrate (biotope)	Sampling method
	Latitude, N	Longitude, W					
Parker Deep, L. Derg	52º54'46"	08º23'26"	07:10/17.10.2008	1	15m	water column	oblique tow-net
Parker Deep, L. Derg	52º54'57"	08º22'53"	13:10/23.12.2008	1	15m	water column	oblique tow-net
Droman Hbr L Derg	52º56'37"	08º19'50"	14:00/31.01.2009	4	<1m	tyre	in tyre fender
Hodson Quay, L Ree	53º27'39"	07º58'53"	14:15/26.02.2009	1000s	<3m	stones/gravel	handnet
Hodson Quay, L. Ree	53º27'39"	07º58'53"	14:00/14.03.2009	1000s	<3m	stones/ gravel	handnet
Hodson Quay, L. Ree	53º27'39"	07º58'53"	12.06.2009	15	<2m	stones/gravel	9 traps
Hodson Quay, L. Ree	53º27'39"	07º58'53"	22:30/12.06.2009	100s	<2m	stones/gravel	handnet
Hodson Quay, L. Ree	53º 27'39"	07º58'53"	01:00/13.06.2009	1	0- 3m	sand and silt	vertical tow-net
Portrunny, L. Ree	53º35'30"	08º03'38"	00:30/14.06.2009	100s	<1	stones	handnet
Portrunny, L. Ree	53º35'31"	08º03'36"	14.03.2009	15	<2m	stones/mud	3 traps
Portrunny, L. Ree	53º35'30"	08º03'37"	24:00/14.03.2009	1	0- 2m	stones/mud	vertical tow-net
Quigleys Pt., L. Ree	53º27'53"	07º55'21"	01:00/16.06.2009	4	0-6.6m	mud	vertical tow net
Quigleys Pt., L. Ree	53º27'53"	07º55'21"	01:30/16.06.2009	100s	<2m	stones	handnet
Terryglass, L. Derg	53º03'37"	08º12'21"	23:00/23.06.2009	1000s	<2m	large stones	handnet
Terryglass, L. Derg	53º03'37"	08º12'21"	23.06.2009	9	<2m	stones/ mud	3 traps
Cluandavaun, L. Derg	53º03'22"	08º17'49"	23.06.2009	16	<2m	boulders/stones	3 traps
Dromineer, L. Derg	52º55'32"	08º16'40"	24.06.2009	12	<2m	stones/gravels	9 traps
Dromineer, L. Derg	52º55'32"	08º16'40"	21:00/24.06.2009	1000s	<1m	stones/mud	handnet
Kilgarvan, L. Derg	53º01'07"	08º15'31"	24.06.2009	23	<1m	boulders/stones	3 traps
Rossmore, L. Derg	53º01'11"	08º18'43"	24.06.2009	4	<2m	stones/mud	3 traps
Garrykennedy, L. Derg	52º54'18"	08º20'29"	25.06.2009	24	<2m	boulders/stones	9 traps
Garrykennedy, L. Derg	52º54'18"	08º20'29"	22:00/25.06.2009	100s	<2m	boulders/stones	handnet
Droman Hbr., L. Derg	52º56'35"	08º19'50"	04.08.2009	4	<2m	mud by pier	15 traps
Garrykennedy, L. Derg	52º54'18"	08º20'29"	23:30/05.08.2009	100s	<2m	boulders/stones	handnet
Garrykennedy, L. Derg	52º54'18"	08º20'29"	05.08.2009	8	<2m	boulders/stones	15 traps
Lily Bay, L. Derg	52º54'09"	08º29'18"	09.08.2009	1	<1m	stones	15 traps
Ballina, L. Derg	52º48'45"	08º26'48"	22:00/26.08.2009	100s	<1m	stones & wreck	handnet
Dromad Hbr. L. Bofin	53º51'18"	07º55'29"	17.09.2009	52	<1m	boulders	3 traps
Dromad Hbr. L. Bofin	53º51'18"	07º55'29"	23:00/17.09.2009	100s	<2m	boulders/mud	handnet
Rockingham Quay	53º59'12"	08º14'17"	23:30/18.09.2009	1000s	<1m	boulders/ stones	handnet
Knockvickar Lough	54º00'02"	08º12'09"	18.09.2009	3	<1m	under quayside	3 traps
Hodson Bay, L Ree	53º27'39"	07º58'53"	20:00/19.09.2009	100s	<3m	stones	handnet
Parker Deep, L Derg	52º54'30"	08º22'45"	13:30/08.10.2009	5	0-20.7m	silted bedrock	vertical townet
Parker Deep, L Derg	52º54'40"	08º22'45"	14:00/08.10.2009	3	0-17.6m	silted bedrock	vertical townet
Lushings Deep, L Derg	52º54'08"	08º25'45"	17:00/08.10.2009	2	0-18m	silted bedrock	vertical townet
Meelick Lock, on river	52º10'05"	08º04'46"	15.10.2009	4	<1m, 3m	stones and mud	6 traps
Garrykennedy, L Derg	52º54'18"	08º20'29"	23:00/16.10.2009	100s	1-3m	mud	handnet
Dromineer	5255'32"	08º16'40"	23:00/04.10.2009	100s	<1-3m	stones and mud	handnet
Dromineer inner Hbr	52º55'31"	08º16'37"	13:00/18.10.2009	1000s	<1.5m	stones and mud	handnet
Parker Deep	52º 54'46"	08º23'26"	11:00/10.12.2009	4	0-25m	silted bedrck	vertical townet
Lushings Deep	52º54'08"	08º25'45"	12:30/10.12.2009	1	0-20m	silted bedrock	vertical townet