PEN PARK HOLE INVERTEBRATE SURVEY, 2013

Top left: ***Niphargus fontanus*** **(Andy Lewington); top right: sampling the lake; bottom:** ***Niphargus kochianus***

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CONTENTS

1. INTRODUCTION

1.1 Description of the Cave System and its History

Pen Park Hole lies on the edge of Southmead, Bristol and has been formed in a submerged ridge of Carboniferous limestone (the Clifton Down Limestone). The system has developed along the line of a high angle reverse fault, which has formed parallel to the 50^{o} north-western dip of the limestone (Bristow, 1963). It is the largest cave known in the Bristol limestone; other caves exist further south, principally along the Avon Gorge [most notably St. Vincent's Cave (also known as Giant's or Ghystan's Cave) below the *camera obscura* on Clifton Down] and elsewhere but these are all very small in extent.

The system is 112m in length, with a vertical range of 61m (Mullan, 1993; Gray *et al.* 2013). The present entrance lies at 78m (AOD) [ST 5852 7921] and consists of a concrete tube that descends to a series of passages, passing through two chambers before reaching the Pitch Platform in the large Main Chamber; an enormous inclined rift 68m high, 30m across and 15m wide (Gray *et al.* 2013). A laddered descent of the pitch leads to a first ledge from which exposed traverses gain access to the West Platform [and hence Upper West Passage] and Upper East Passage [a much more tricky traverse due to its more exposed nature and loose mud and rock]. At the bottom of the pitch the main chamber is filled with a large body of water 'the lake,' which exhibits considerable fluctuations in depth. The highest height of the water level, 51.5m AOD was recorded on 29th January 1993 and the lowest, 24m AOD on 18th October 1957, representing a range of 27.5m, possibly up to 35m (Mullan, 1993). These fluctuations are responsible for the deep deposits of glutinous clay that cover much of the lower part of the system. The source of the water and the reasons for the fluctuations remain unknown, although it is thought to connect to the phreatic water table. Tratman (1963) hypothesised phreatic passages beneath the lake but these have not been discovered by diving and if they exist must lay beneath the extensive boulder field on the floor of the Main Chamber. Glennie (in Tratman, 1963) noted a small ephemeral spring along the north side of the Main Chamber in 1957 but this has not been seen during any subsequent visits. West Passage can be reached by an awkward climb up from the lake shore and East Passage by a rather muddy traverse climb. Both of these passages are frequently flooded by the lake. East Passage consists of a lower muddy section, at the end of which a climb leads into cleaner passage that ascends to a point just below the Entrance Series passages. These features are illustrated in the plan of the cave system in section 3 [Results] below.

The dendritic-like nature of the system and extensive, large dog-tooth spar calcite crystals found throughout the cave suggest that it was formed by hydrothermal processes, i.e by geothermal waters rising from below, rather than meteoric waters from above as is typical in the nearby Mendip Hills and elsewhere (Mullan, 1993). The cave is considered to be much older than the Mendip caves, possibly being active in the late Triassic / early Jurrasic (Mullan, 1993).

According to Bristow (1963) there were three phases of mineralisation during the development of the cave, the first of which was the deposition of galena, which is mostly found in the First Chamber and dies out to the west and lower down (Mullan, 1993). It is stated in Tratman (1963) that the cave was reportedly discovered and worked by lead miners, probably in the early 17th century, before its re-discovery in 1669. According to Mullan (1993) the evidence actually points to it being discovered by quarry workers looking for stone in 1669 and although miners investigated the cave for lead ore, it was only present in small quantities, mostly in the First Chamber and was never actually commercially worked. At the time of its discovery there were three known entrances: the current, eastern entrance; directly above the Main Chamber; and into the top of Upper West Passage (Tratman, 1963; Mullan, 1993).

In 1775 Reverend Newman fell to his death whilst investigating the main shaft and when William Smith took over possession of the surrounding land in the late 1870s he sealed the entrances to prevent further accidents (Mullan, 1993). During the mid 1950s, a proposal to erect buildings on a field adjacent to the cave's location required investigations to accurately ascertain the location of the cave and its proximity to the surface (Tratman, 1963). Consequently the eastern entrance was dug open by members of the University of Bristol Spelaeological Society (UBSS), the Wessex Cave Club (WCC) and the Bristol Exploration Club (BEC) during the winter of 1956 / 57. During the following three years the Cave Research Group of Great Britain (CRG) carried out various studies, documented in Tratman (1963). In August 1961, after completion of these investigations the cave was sealed once again (Mullan, 1963).

In 1992, as part of a landscape scheme for the area around the entrance to the cave, permission was granted by the City Council to re-open the cave on 7th February and the current concrete tube shaft and gate were installed (Mullan, 1993). Access to the cave is controlled by a leader system operated by BEC, UBSS and WCC (Gray *et al.* 2013).

Further to new proposals to develop the land close to the cave for housing, Natural England has decided to explore the scientific interest of Pen Park Cave with an intention to looking at designation as a SSSI (Site of Special Scientific Interest). Whilst the core interest is geological (as a hydrothermal cave system), on the basis of the CRG investigations the site appears to support an interesting cave fauna, which could form a feature of any proposed designation. The survey detailed in this report was conducted to update the existing but now rather dated information on the cave's invertebrate fauna.

1.2 Previous Biological Survey Work

The first biological investigation of the cave was conducted during the CRG investigations of the late 1950s and is detailed in Glennie & Hazelton (1963). The team was led by Brigadier E.A Glennie of the Wessex Cave Club and a prominent member of the biological group of the CRG and included: D.A. Coase (BEC), O.C. Lloyd (UBSS), T.R. Shaw (UBSS) and M. Hazelton (BRC Biological Recorder). They carried out seven visits to the cave from 20th January 1957 to 12th May 1958. The list of taxa recorded during this survey has been incorporated into the tables in section 3 [Results] below.

The team used various methods during their work including: manual searching; the examination of decaying timber found around the lake shore (believed to have been used to choke the Main Chamber entrance before it was filled with rubble and clay and which had fallen down the shaft in the intervening years); the use of four traps [Kilner jars arranged as 'lobster pots' by inserting a plastic funnel and baited with cheese] deployed at depths from two to four feet in the lake margins to the north of the rocky spur; and seven traps consisting of minced meat and cheese placed on small pieces of tin which were placed irregularly across the floor of the Main Chamber above the lake. Upper West Passage, West Passage and East Passage are not mentioned in the report and it was assumed that due to the limited caving techniques available at the time and the rather tricky climbs involved in accessing these areas that the biological survey was limited to the Entrance Series and the Main Chamber, including the lake. Upper East Passage was first entered in 1993 (Mullan, 1993) and thus was certainly not included in this biological investigation.

A total of four terrestrial taxa were recorded including: two species of Collembola, *Folsomia candida gp.*, frequent on damp mud in the Entrance Series, on the surfaces of pools in boot-prints in the mud around the lake shore and on the woody debris and *Oligaphorura schoetti* (Lie Pettersen, 1897) (recorded at the time as *Onychiurus schoetti*), frequent in the woody debris; *Bradysia sp.* fungus gnats (Mycetophilidae), several dead specimens found on threads hanging from the roof and on stalactites near the Pitch Platform; and a single larva and adult of the carabid beetle *Trechoblemus micros* (Herbst, 1784). The larva was first found just beneath the surface of a piece of the woody debris on the lake shore. This led to the bait traps being laid on the floor of the Main Chamber close to timbers, both to attract flies and capture the adult, which was subsequently captured near one of the traps.

The bait traps in the lake collected large numbers of the stygobitic amphipod *Niphargus kochianus* (Bate, 1859), which was recorded in equal numbers in all four traps and ten specimens of *Niphargus fontanus* (Bate, 1859) which were only collected in the trap closest to the rocky spur in the middle of the shore-line. Two species of cyclopoid copepods were also collected: *Diacyclops bicuspidatus* (Claus, 1857) (recorded at the time as *Cyclops bicuspidatus*), which was present in very large numbers and *Megacyclops viridis* (Jurine, 1820) (recorded at the time as *Acanthocyclops viridis*), which was present in very small numbers.

Enchytraeidae worms, in too poor a condition to be determined further were collected from the woody debris, along with an empty *Pisidium* shell, tentatively identified as *Pisidium nitidum* (Jenyns, 1832). The shell was half-embedded in a timber and was assumed to have fallen in with the timber from the surface.

Overall the terrestrial fauna of the cave was poor and Glennie & Hazalton (1963) hypothesised that the closure of the cave entrances in the 1870s had led to the extirpation of any threshold fauna that might have been present, leaving only an assemblage of troglophilic species. The most interesting fauna recorded were the species from the lake and the beetle *Trechoblemus micros*.

Trechoblemus micros is a small orangey-brown coloured species that has been recorded from caves in the Mendips, Derbyshire and from Otter Hole, beneath Chepstow race course on the shores of the lower Wye Estuary. In caves it appears to prefer damp, muddy situations such as in the entrance series to Otter Hole and Manor Farm Swallet on the Mendips, both of which support good populations (Chapman, 1993). Chapman (1993) mentions that the larvae are blind and have rarely been recorded outside of caves [the Pen Park Hole record was the second from Britain after its discovery in 1948 (Glennie & Hazelton, 1963)] although the adults have also been found in the mesocavernous spaces of the Subterranean Underground Compartment [SUC, also known as the milieu souterrain superficiel (MSS), the layer of fractured rock beneath the soil layer] and in scree slopes. Glennie & Hazelton (1963) considered it to be a troglobite [obligatory inhabitant of subterranean habitats] in Britain as at the time the species had been rarely found on the surface and then usually in flood debris, suggesting that it had been washed out from the subterranean habitat. *Trechoblemus micros* does not show any cavernicolous traits such as elongated legs and reduced eyes and Chapman (1993) considered it to be a troglophile [facultative subterranean inhabitant]. Until recent decades, the species has probably been under-recorded and Luff (1998) describes it as being generally distributed throughout Britain, except northern Scotland and usually found near water, possibly associated with the runs of small animals.

In March 2004 and October 2007, the recorder for the Hypogean Crustacea Recording Scheme visited Pen Park Hole to collect *Niphargus* specimens from the lake for study. On 7th March 2004, net trawls of the lake were carried out using a simple zooplankton trawl net. The contents of the net were periodically emptied into a black tray and specimens picked out and placed in a vial of Industrial Methylated Spirits (IMS, denatured ethanol) for later examination. During the first visit a single *Niphargus kochianus* specimen and a single juvenile *N. fontanus* were collected. On 28th October 2007, net trawls were combined with kick and sweep net sampling of the lake margins and eight female and five juvenile *Niphargus kochianus* were collected.

From 1948 to 1976, the recording of fauna within caves was carried out by a group within the CRG [which later changed its name to the British Cave Research Association (BCRA)] led by Aubrey Glennie and Mary Hazelton. These were published as a series of biological records in sixteen parts between 1955 and 1978. These records have since been digitised by Graham Proudlove, the current BCRA biological recorder as the 'Hazelton Database.' A search of this database and the literature revealed that the only records for Pen Park Hole were those collected during the 1957 / 58 CRG investigation (Hazelton, 1961). The Hypogean Crustacea Recording Scheme (HCRS) also maintains a database of records of the ten species of stygobitic Crustacea recorded from Britain and Ireland (available to download at: http://hcrs.freshwaterlife.org/hcrs-database) which only lists the CRG, 2004 and 2007 records described above.

2. MATERIALS AND METHODS

The invertebrate survey of Pen Park Hole was carried out on 18th December 2013 and consisted of two teams. Chris Proctor of Devon Spelaeological Society (DSS), assisted by Clive Owen and Tony Boycott (UBSS) primarily concentrated on the terrestrial element of the fauna in the Entrance Series and Upper West Passage. Since the work in the late 1950s a traverse line has now been installed to enable easier access to the West Platform and Upper West Passage. Lee Knight (HCRS recorder & DSS) and John Boulton (DSS) primarily concentrated on sampling the floor of the Main Chamber and the lake. At the time of the survey the level of the lake had dropped sufficiently such that access to East Passage was possible via a tricky traverse in chest deep water and a short swim, enabling this section of the system to also be included. Due to a mishap in communications West Passage was not investigated, as the second team erroneously thought that the first team had surveyed this section of the cave, which did not become apparent until the former had reached the top of the pitch and had begun to de-rig the ladder.

Terrestrial fauna was collected by means of manual searching, including the gentle turning of stones where clastic sediments were present. Specimens were collected using forceps and a paint brush; the latter was particularly useful in collecting Collembola from the surfaces of small pools. Several rotten timbers along the lake shore were carefully pulled apart in order to check for invertebrates living within the wood. Specimens were placed in vials of 70% IMS for later examination.

Aquatic habitats were investigated using three techniques. Manual searching was used in small pools and specimens were either picked out with forceps or if small enough collected using pipettes. A fine-mesh tea strainer was also employed to capture specimens in small pools, in particular the abundant, small boot-print pools at the beginning of East Passage. Larger pools were sampled by sweeps of the substrate using either a FBA pattern pond-net [250mm wide frame] or a smaller sized net [150mm wide frame], both of which were fitted with 250µm mesh collecting bags. Both nets had pole handle sections that could be either added for extra reach or removed to allow better manipulation in confined areas; the choice of net size was determined by the size of the pool and the ease of manipulation.

The lake was sampled using a combination of kick and sweep netting with the larger net along the western margin and net trawls into the deeper water using a weighted 300mm diameter zooplankton net, fitted with a removable screw-on filter attached to a length of rope. The time spent sampling the margins and the number of net trawls was not recorded as the purpose of the survey was to provide base-line data rather than to establish a repeatable method as the basis for future invertebrate monitoring. After sampling the combined contents of both nets were emptied into a plastic Nalgen container and preserved in IMS. The sample was later washed through a series of graduated sieves and small portions were individually placed in a large petri dish for sorting under a stereo-microscope and the picking out of specimens for identification. Further descriptions of the methods used above can be found at: http://hcrs.freshwaterlife.org/sampling.

The use of bait traps was considered but discounted as this would have involved a repeat visit for collection and there is always the risk that if not recovered within a maximum period of 48 hours they can cause pollution in a naturally resource-limited ecosystem. The CRG investigations showed that bait traps were successful in the lake but the terrestrial traps collected virtually no fauna at all, apart from the single *Trechoblemus micros* adult (Glennie & Hazelton, 1963). Glennie made widespread use of bait traps when sampling wells in the Chalk of south-east England during the 1950 and 60s, with marked success (HCRS database, 2014). However the author has had very limited success with bait traps during trials in various caves and from experience knew that much better results could be obtained by intensive net sampling conducted during a single visit.

3. RESULTS

The taxa lists below incorporate both the results of the current survey and also records from previous work in the cave to give comprehensive lists of the taxa so far recorded from Pen Park Hole. Records and taxa highlighted in bold are those from previous surveys. Section 3.3 describes each section of the cave and the fauna collected within it.

3.1 Terrestrial Fauna

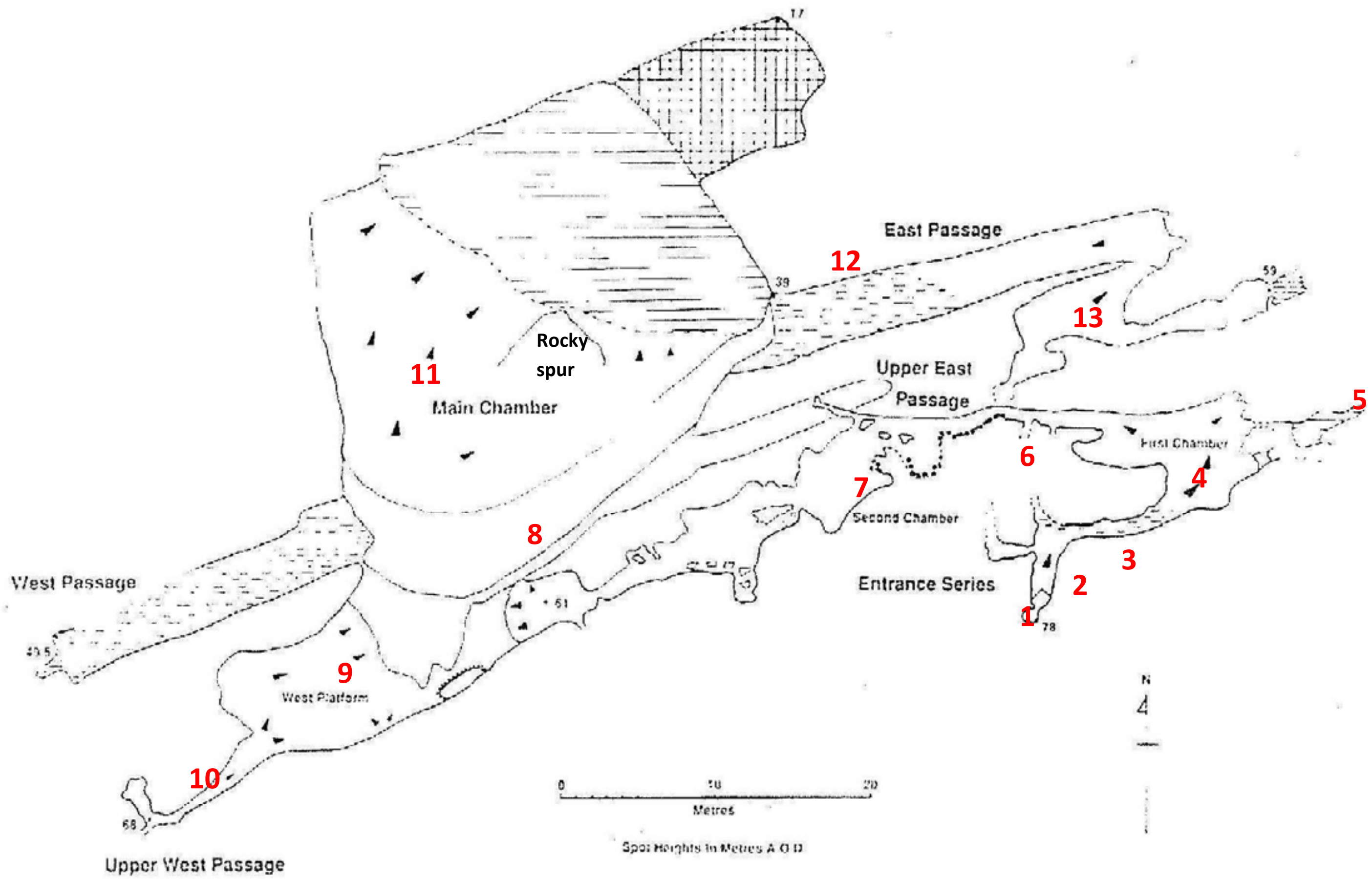
TAXA	LOCATION
DIPLOPODA	
Tachypodoiulus niger	1 Specimen near fixed ladder below entrance shaft
OILIONES	
Leiobunum blackwalli	1 Specimen at base of entrance shaft
COLLEMBOLA	
Cryptopygus garretti	1 Specimen on silk / fungal thread dangling from roof below entrance shaft
Folsomia candida	Several specimens on pool in Entrance Series; 2 specimens on pools on calcite slope in 2nd Chamber; several specimens on boot-print pools, beginning of East Passage.
	20/1/57: Several specimens seen on damp mud in Entrance Series.
	4/5/57: Many specimens on pools in muddy boot-prints and on woody debris around lake shore
	11/5/58: On woody debris around lake shore
Oligaphorura schoetti	3 Specimens on surface of pool in 1st Chamber
	11/5/58: Frequent in woody debris around lake shore
DIPTERA	
Culex pipiens	2 Specimens at base of entrance shaft, several more near fixed ladder
Heleomyza sp.	1 Specimen near fixed ladder
Bradysia sp.	**20/1/57: Several dead specimens on wall near the Pitch Platform**
COLEOPTERA	
Carabidae sp.	1 Specimen observed at base of entrance shaft (not captured)
Trechoblemus micros	**18/10/57: 1 larva collected from woody debris on lake shore**
	12/5/58: 1 adult collected near bait trap on lake shore

3.2 Aquatic Fauna

TAXA	LOCATION
OLIGOCHAETA	
Enchaetryidae sp. (indet.)	**4/5/13: A few specimens in woody debris along lake margins**
Enchytraeus sp.	**11/5/58: Collected from woody debris on lake shore**
BIVALVIA	
Pisidium sp.	Empty valve collected in net sweeps around lake margin
Pisidum nitidum?	**18/10/57: Dead shell embedded in woody debris on lake shore**
OSTRACODA	
Mixtacandona / Schellencandona sp. (indet.)	1 Specimen collected from pool in 1st Chamber.
COPEPODA	
Acanthocyclops vernalis	2 Specimens collected from lake; 9 Specimens collected from boot-print pools, East Passage
Acanthocyclops sp. (indet. damaged / early instars)	5 Specimens collected from lake; 2 Specimens collected from boot-print pools, East Passage
Diacyclops bicuspidatus	**5/5/57: Many specimens collected in 4 bait traps in lake margins**
	18/10/57: Many specimens collected in 4 bait traps in lake margins
Megacyclops viridis	**5/5/57: Few specimens collected in 4 bait traps in lake margins**
	18/10/57: Few specimens collected in 4 bait traps in lake margins
ISOPOPDA	
Asellus aquaticus	3 Specimens collected from lake
AMPHIPODA	
Niphargus fontanus	2 Specimens collected from lake; 7 specimens in boot-print pools in East Passage
	7/3/04: 1 juvenile collected in net trawls in lake
	5/5/57: Few specimens only in bait trap in lake margin close to spur
	18/10/57: Few specimens only in bait trap in lake margin close to spur
Niphargus kochianus	1 Specimen collected from pool in 1st Chamber; 149 Specimens collected from lake; 2 specimens collected from boot-print pools, East Passage; 4 specimens collected from pool at top of East Passage Series.
	28/10/07: 8 Females & 5 juvs. collected from lake using a combination of net trawls and sweeps along margins
	7/3/04: 1 Specimen collected in net trawls in lake
	5/5/57: large numbers collected in 4 bait traps in lake margins
	18/10/57: large numbers collected in 4 bait traps in lake margins
DIPTERA	
Chironomidae sp.	1 Larva collected from lake

3.3 Faunal Distribution

The sections of the cave described in this section are numbered on the cave plan on the following page.



PEN PARK HOLE

PLAN

UBSS 1993

Drawn CJM

(1) Entrance tube

This is a short concrete tube down from the entrance gate, with mud floor at the base. Scattered twigs and leaves were on the floor, fallen in from above. Species recorded: two *Culex pipiens* (Linnaeus, 1758), one carabid beetle in crevice of concrete tube, which evaded capture and one opilionid, *Leiobonum blackwalli* (Meade, 1861). A sheet spider's web was noted but there was no sign of its inhabitant, which was possibly in an adjacent crevice of the concrete tube.

(2) Fixed ladder

Just inside the entrance, the fixed ladder is down a very steep clayey mud slope with embedded baulks of rotting timber. The timber was not checked as warned by Tony Boycott that it could be unsafe. There were numerous small roots on the sediment: there was little sign of new growth with fresh root tips. Species recorded: Several *Culex pipiens* and one *Heleomyza sp*. fly on the walls, one *Tachypodoiulus niger* (Leach, 1814) millipede, and a single springtail, *Cryptopygus garretti* (Bagnall, 1939) on a silk strand or fungal thread dangling from roof.

(3) Passage

This has clean limestone walls and a floor of plastic, clayey mud. Milk crates have been placed to stand on. Small pools were present in depressions in the mud. On the surface of one of these pools were noted several *Folsomia candida* (Willem, 1902). A second tiny pool contained worm casts but when netted with a tea strainer no specimens were collected.

(4) First Chamber

This chamber has walls of limestone, with a lining of calcite crystals in many places. The basal layer of the calcite contains significant quantities of galena. The floor sediments comprise mud and loose stones of limestone and calcite/galena. No terrestrial fauna was noted in the chamber, although a silk or fungal thread, about 3cm long was noted dangling from roof.

(5) First Chamber pool

This is an ephemeral pool on the east side of the chamber, with a substrate of large rocks and full of water on the date of the survey. Net sweeps collected three springtails, *Oligaphorura schoetti* (Lie Pettersen, 1897), a single *Niphargus kochianus* and a single damaged candonid ostracod, identified as *Mixtacandona / Schellencandona sp*. It is likely from its small size to have been a groundwater species but due to the poor condition of the specimen further determination was not possible (D. Horne pers. comm.).

(6) Passage to Second Chamber

Between the first and second chamber is a short crawl through passages lined with calcite crystals, with a floor of mud and stones. No fauna were observed.

(7) Second Chamber

The Second Chamber has walls and roof lined with calcite crystals, and bare limestone exposed where they have collapsed. The floor consists of mud, calcite crystals (some *in situ*) and boulders. The southern wall of the chamber has a layer of calcite flowstone deposited on it and at the time of the survey a thin film of trickling water overlaid much of this damp wall. Several small, probably ephemeral pools were noted, with single specimens of *Folsomia candida* on the surfaces of two of them. A small pool was noted in a recess on the calcited slope, this was netted but no fauna were collected. In one of the pools on the mud floor burrows, approximately 1mm across were observed, possibly made by small annelids, although no specimens were observed. A silk / fungal thread, approximately 3-4cm long was noted dangling from roof near the top of the pitch.

(8) Ledge

This comprises boulders, stones and mud. No fauna observed.

(9) West Platform

The West Platform comprises boulders, limestone and calcite stones and mud. The walls are limestone with some areas of un-collapsed calcite crystal lining. No fauna was seen.

(10) Upper West Passage

This is a narrow, steeply ascending rift. The walls are calcite lined with limestone exposed where it has collapsed away. The floor comprises a loose scree of limestone and calcite/galena stones with mud. The top of the passage lies within 8-9m of the surface but no sign of surface-derived sediments were seen at its end. No fauna were found.

(11) Floor of Main Chamber

The lake was relatively low at the time of the survey, exposing a boulder slope, coated in deposits of glutinous clay and a rocky spur in the middle of the lake shore. The clay deposits were particularly deep along the north wall and had partly buried within them several rotting timbers. Other timbers were also noted submerged in the lake margins on the northern side of the spur. Examination of the slope and timbers yielded no fauna. Sampling in the lake collected: 149 *Niphargus kochianus*, two small *Niphargus fontanus*, two *Acanthocyclops vernalis* (Fischer, 1853), five *Acanthocyclops* too damaged to accurately identify further than genus, three *Asellus aquaticus* (Linnaeus, 1758), a single chironomid larva and a single *Pisidium* valve.

(12) East Passage

The first section of the East Passage Series is extremely muddy and is regularly flooded by fluctuations in the lake's level. A considerable amount of water was noted dripping from stalactites on the roof of the passage; this point is below the Second Chamber and it was assumed that this was the same water flowing down the calcite slope on the southern wall of the chamber above. Numerous flooded boot-prints were observed on the floor, on which were noted four *Folsomia candida*, with seven large specimens of *Niphargus fontanus* in the water. Netting of the pools collected eleven *Acanthocyclops vernalis*, five *Acanthocyclops* too young to accurately identify further than genus and two *Niphargus kochianus.*

(13) Upper East Passage Series

At the eastern end of East Passage a steep slope leads to several small crawls that terminate in a small chamber containing a pool. No fauna were noted on the way to this chamber. The pool had a substrate of rocks overlain with a thin layer of silt; netting of the pool collected four *Niphargus kochianus*.

4. DISCUSSION

4.1 Terrestrial Fauna

Overall, fauna in the upper part of the cave was very sparse. The limited threshold fauna at the entrance is typical of systems with closed artificial shaft entrances. The fauna in the concrete shaft was dominated by animals which had probably fallen or strayed in from the surface, with only *Culex pipiens* and the single *Heleomyza* fly representing genuine threshold species; both of these species are common over-wintering inhabitants in many British caves. Further in at the fixed ladder, a slightly more diverse fauna was present, but other typical elements of the parietal fauna were absent, such as cave-hibernating Lepidoptera [eg. tissue moth (*Triphosa dubita* Linnaeus, 1758) and herald moth (*Scoliopteryx libatrix* Linnaeus, 1758)] and the cave spider *Meta menardi* (Latreille, 1804). Their absence was probably attributable to the near-blockage of the entrance by the cave gate and tube. It was thought that the Upper West Passage, which approaches the surface and marks the site of a former entrance, might have a threshold fauna. However the loose scree in the passage was found to be derived from within the cave, implying no direct connection with the surface and no fauna was found.

Within the passages further into the cave, the only terrestrial fauna found were springtails (*Oligaphorura schoetti* and *Folsomia candida*), mostly on pool surfaces, although in comparison to many other caves the number of Collembola was relatively small. Significant amounts of galena were present in the calcite lining the cave in the First Chamber and Upper West Passage. Many fragments of this material were present in the floor sediments in these areas and may have made them toxic due to high lead concentrations. The scarcity of terrestrial fauna was similar to that recorded by Glennie and Hazelton (1963).

Oligaphorura schoetti is common in caves in England, Scotland, Wales and Ireland (Hopkin, 2007) and although Glennie and Hazelton (1963) regarded it as a troglobite in Britain it is known from other habitats elsewhere, including the shores of lakes and rivers (Hopkin, 2007) and is probably better regarded as troglophilic. *Folsomia candida* is another common inhabitant of caves, although it is also found in compost and flower pots (Hopkin, 2007). The third collembolan species recorded, *Cryptopygus garretti* is a common and widespread species with several records from caves and disturbed habitats such as slag heaps (Hopkin, 2007).

Dangling silk or fungal threads were seen in three places (at the fixed ladder, the First Chamber and the pitch head). These had no associated fauna apart from a single *Cryptopygus garretti* on one thread below the entrance shaft. The origin of these threads is unknown; they were too robust to have been the remnants of silk threads produced by fungus gnats such *Speolepta leptogaster* (Winnertz, 1863) or the *Bradysia* recorded by Glennie & Hazelton (1963).

Small fragments of plant matter were noted in the crawl between the first and second chambers, and at the head of the pitch. No fauna were observed within this material and it was suggested that it was probably brought in on cavers' kit.

4.2 Aquatic Fauna

The small pools in the upper part of the cave were mostly devoid of fauna, aside from some possible worm casts in two small boot-print pools, the single ostracod and *Niphargus kochianus* collected from the pool off the First Chamber and the four *N. kochianus* in the pool at the top of the East Passage series. The main interest for the aquatic fauna was thus centred on the lake and the numerous boot-print pools in East Passage.

As in previous surveys, large numbers of the stygobitic amphipod *Niphargus kochianus* and much smaller numbers of *N. fontanus* were collected from the lake; along with numbers of *Acanthocyclops vernalis*, three *Asellus aquaticus* and a single chironomid fly larva. The presence of these latter two taxa was somewhat surprising, as they are more commonly found in surface waters with which there is no [as yet known?] connection with the lake

Chrironomid larvae have occasionally been collected from deep down in boreholes and wells, although there is usually some connection to the surface (L. Knight pers. records). It is possible that adult flies might have found their way into the cave and deposited eggs in the lake margins or that alternatively eggs were washed into the lake from a surface water-body. Chironomid larvae have been recorded in a cave stream over 1km from the surface (Knight, 2011) and although no surface water-bodies lie immediately above the cave's location, chironomid larvae can be found in ephemeral pools.

On the surface the isopod *Asellus aquaticus* is a widespread and common inhabitant of the slower-flowing reaches of rivers and lentic habitats such as ponds and ditches (Gledhill *et al.* 1993). It is rarely recorded from caves, with the only records on the Hazelton database being those of *Asellus sp.* from Porth-Yr-Ogof in South Wales and Stoke Lane Slocker on the Mendips, both of which are caves that carry a large watercourse that sinks at the cave entrance. The species has been more widely recorded from allogenic cave streams in Ireland (Knight & Penk, 2008) and has also been occasionally collected from wells, usually those that are quite shallow and open at the surface (L. Knight pers. records). De-pigmented, eyeless specimens have been recorded in Crag Lower Cave, County Kerry (Knight & Penk, 2010) and in Eastern Europe there exists a subterranean sub-species *Asellus aqūticus* *cevrnicolous*, not currently known from the British Isles. In Britain this niche is filled by the closely related stygobitic *Proasellus cavaticus* (Leydig, 1971) which is common in many of the caves of the Mendips and South Wales, as well as being recorded from wells, boreholes and springs across the south. As with the chironomid larva, the *A. aquaticus* could have been washed into the cave from an ephemeral surface water-body.

A single, dead pea mussel (*Pisidum sp.*) valve was also collected from the lake margins. *Pisidium* species have been recorded from various caves (Knight & Wood, 2000; Knight 2011) but are generally rare in the habitat. As Glennie and Hazelton (1963) hypothesised with the specimen they found buried in a rotting timber, this single dead valve is likely to have originated on the surface.

Niphargus kochianus is widespread across southern England, from Norfolk and Kent in the east to Dorset, Somerset and Gloucestershire in the west; it is absent from Wales, Devon and Cornwall. Its distribution shows a close correlation with outcrops of Chalk (Cretaceous limestone), although it has been recorded from other strata, including Carboniferous and Jurassic limestones and the Upper Greensand (Proudlove *et al.* 2003; HCRS database, 2014) It has rarely been found in caves, there being only three known systems from which it has been recorded.

There is a record from 1966 for a single male and a single juvenile female from the Plantation Junction streamway in St. Cuthbert's Swallet, a cave system on the Mendips (Hazelton, 1967). There is some doubt over the validity of this record as *Niphargus fontanus* is by far the commonest niphargid recorded from caves in Britain and is widespread in the caves of the Mendips and South Wales. The Plantation Junction streamway is just upstream of Gour Hall, where there are several records [ranging from 1956 to 2010] of *Niphargus fontanus* and it is believed that the *N. kochianus* record is either an identification error or due to incorrect transcription. The determiner, M. H. Thurston was a renowned crustaceologist and although his main area of expertise was the marine fauna, he had examined and would have been familiar with *N. fontanus*; thus the accuracy of this record is still open to debate. There are two records of *N. kochianus*, dated February and March 1951 from Holwell Cave, located in a small pocket of Devonian Limestone on the Quantock Hills (Hazelton, 1960). The determiner in both cases was G.M. Spooner another renowned crustaceologist from the Plymouth Marine Laboratory who was familiar with niphargids, having first described *Niphargus glenniei* in 1952 (Spooner, 1952). In November 1951 *N. aquilex* was recorded from the same cave and modern visits [1998 and 2004] by the HCRS recorder have only recorded this latter species. On the basis of the rather old [and possibly dubious] records above, Pen Park Hole is the only known cave to currently hold a substantial population of *Niphargus kochianus*. It has been recorded from the lake on five occasions in 1957, 2004, 2007 and during the current survey. Prior to the current survey it was only known from the lake and this was believed to be due to its possible connection with the phreatic water table. However the presence of *N. kochianus*, albeit in small numbers in the two pools in the upper part of the cave indicate that is in fact widespread in the surrounding rock strata. Two specimens were also recorded from boot-print pools in East Passage close to the lake, although it is uncertain whether these specimens had been carried down in the dripping water from the roof or deposited there by fluctuations in the lake's level.

As mentioned above, *Niphargus fontanus* is the most cavernicolous [cave-dwelling] species of niphargid in Britain and is the dominant species in the caves of South Wales and the Mendips. It is widespread across the south of Britain from Kent in the east, as far north as Cambridgeshire and Oxfordshire to Carmarthenshire in the west. It is absent from the far south west [Devon and Cornwall], with the Mendips and Dorset currently marking the south-western edge of its distribution. In addition to caves it has also been recorded from wells, boreholes, springs and the hyporheic zone (Proudlove *et al*. 2003; HCRS database, 2014). It has been recorded from the lake in much smaller numbers compared to *N. kochianus* on four occasions in 1957, 2004 and 2013. Only two small specimens were recorded from the lake during the current survey, whilst seven large specimens were noted in the boot-print pools in the mud of East Passage. It is commonly found in such small pools, fed by percolating groundwater in caves and seems to prefer such habitat to cave streams.

During the CRG survey the copepod *Paracyclops bicuspidatus* was collected in the bait traps in the lake in large numbers, with *Megacyclops viridis* present in much smaller numbers. *Paracyclops bicuspidatus* is a rather cosmopolitan species that has been recorded from several caves including Swildon's Hole in the Mendips (Hazelton, 1975; Knight, 2011) and Poole and Peak caverns in the Peak District (Gunn *et al*. 2000; Wood *et al*. 2002; Wood *et al*. 2008). It has also been recorded from wells in the Chalk, often isolated from the surface and often in association with *N. fontanus* and *N. kochianus* (Glennie & Hazelton, 1963; Proudlove *et al.* 2003). *Megacyclops viridis* has also been recorded from Swildon's Hole (Hazlelton, 1975; Knight 2011) and from several other caves across Britain and Ireland in addition to wells. *Acanthocyclops vernalis* is known from several caves in South Wales (Chapman, 1993), Swildon's Hole (Knight, 2011) and from springs and wells. All three of the above species were recorded from cave streams in the Peak-Speedwell system (Gunn *et al*. 2000, Wood *et al.* 2002; Wood *et al*. 2008) but not from the surface sinks and resurgences and can probably be regarded as stygophilic. Copepoda have generally been under-recorded from subterranean habitats, probably due to their small size and difficulties in their identification and the groups as a whole is in need of further research (Proudlove *et al.* 2003). The reason for the shift in population structure from predominately *Paracyclops bicuspidatus* to *Acanthocyclops vernalis* within Pen Park Hole since 1957 is unknown. Several of the specimens collected during the current survey were either too young or too damaged to be accurately identified further than genus and it cannot be said for certain that the species recorded in 1957 are no longer present.

4.3 Comparsion of Pen Park Hole Fauna with that of Other Caves

Systematic studies of the invertebrate fauna of caves in Britain are few and have mostly been carried out using opportunistic manual searching. Otter Hole (Chapman, 1979) and Ogof Ffynon Ddu (Jefferson *et al.* 2004, which mostly details survey work carried out in 1979, with some additional modern records) have been the subject of fairly extensive studies and less detailed surveys have been conducted in Charterhouse Cave on the Mendips (Smart *et al.* 1984) and Dan Yr Ogof in South Wales (Edington, 1977). The only extant detailed modern surveys are those of Gunn *et al* (2000) and Wood *et al.* (2002 & 2008) in the Peak-Speedwell system of the Peak District and Knight (2011) in Swildon's Hole, which concentrated on sampling the aquatic biota. A similar study is also in progress sampling the numerous aquatic habitats in the large South Wales cave system of Ogof Draenen (Knight *et al*. in prep.). The Hazelton database does however provide lists of taxa collected from various caves across Britain and Ireland and thus data is available on which to base a comparison of the fauna of Pen Park Hole.

Within the environs of Bristol Pen Park Hole is the only large accessible cave system. As mentioned in section 1.1, other caves exist along the Avon Gorge but these are all generally small, with the exception of Giant's Cave, a large opening on the side of the gorge, which has been accessed by a lit, artificial tunnel and developed as a tourist attraction. These caves generally lie wholly within the threshold zone, no studies have been undertaken of their biota and they are thus not suitable for direct comparison with Pen Park Hole.

There are several artificial underground passages within Bristol including lead mines near to the Southmead area, which are mostly buried beneath housing developments and Redcliffe Caves, a network of underground quarries in the red sandstone south of the River Avon dug to mine sand for the local glass-making industry. These quarries are dry and access is by controlled tours only; no study has been made of their fauna. Nearby is Raven's Well, a series of medieval / Tudor conduits, also dug in the sandstone to conduct the water from a series of underground springs (Gray *et al.* 2013). Sampling was carried out at the underground source of these springs on 27th February 2014 and recorded a single specimen of the stygobitic amphipod *Microniphargyus leruthi* (Schellenberg, 1934), a recent addition to the British fauna (Knight & Gledhill, 2010). This was the first record of this species in the vice-county of West Gloucestershire, the same vice-county in which Pen Park Hole is located. However, due to the different geology direct comparison with the Pen Park Hole fauna is again not possible. There are hardly any records for fauna from wells in Bristol, the only known one being that from 1948 of *Daphnia sp*. and *Niphargus aquilex* (Schiődte, 1855) from Mangotsfield Well at Hanham. On the basis of the above limited information, it is probably best to assess the fauna of Pen Park Hole in relation to that of Otter Hole, beneath Chepstow racecourse and caves in the Mendip Hills to the south.

Chapman (1979) recorded a diverse range of fauna from Otter Hole, although it should be noted that the cave is considerably larger than Pen Park Hole. He recorded eleven species of Collembola [including *Folsomia candida, Cryptopygus garretti* and *Oligaphorura schoetti* (recorded as *Onychiurus schoetti*)] and numerous other taxa, including: Tricladida; Gordioidea; Gastropoda; Oligochaeta, including enchytraeid worms; four species of millipede; six species of terrestrial beetle, including *Trechoblemus micros*; Plecoptera; Trichoptera; Lepidoptera; seven species of Diptera, including *Culex pipiens* and *Bradysia sp*.; five species of Crustacea, including *Proasellus cavaticus* and *Niphargus fontanus*; four species of spider; and four species of mite. In comparison the fauna of Pen Park Hole rates quite poor.

Many of the caves on the Mendips are swallets, which contain streams that sink at the surface and run throughout the length of the cave before disappearing into inaccessible terminal sumps. Consequently in comparison to Pen Park Hole, their aquatic fauna can be quite diverse, including aquatic nymphs and larvae of many species [including representatives of the Plecoptera, Ephemeroptera and Trichoptera] washed in from the surface and which can survive quite some way underground, so long as a viable food source is present (Knight, 2011). Other aquatic taxa include: aquatic Coleoptera; *Pisidium*; Hirudinea; four species of Tricladida; occasional records of the water cricket (*Velia caprai* Tamanini, 1947) and water scorpion (*Nepa cinerea* Lennaeus, 1758); and various aquatic Diptera larvae (Hazelton, 1975). Away from the allogenic [surface-derived] streams are various autogenic streams [derived from percolating groundwater within the cave system] and pools of various sizes that frequently harbour the stygobitic Crustacea *Proasellus cavaticus* and *Niphargus fontanus*, as well as various stygophilic populations of Copepoda and the shrimp *Gammarus pulex* (Linnaeus, 1758), which is also ubiquitous in surface habitats (Proudlove *et al.* 2003).

Within the terrestrial biome records from Mendip caves include: numerous species of Gastropoda, Diptera, Oligochaeta, Symphyla, Chilopoda and Diplopoda, with *Nanogona polydesmoides* (Leach, 1814) being particularly common; over twenty species of Collembola, which can be particularly abundant in the drier sections of many caves; terrestrial Coleoptera; three species of woodlouse, of which *Androniscus dentiger* (Verhoeff, 1908) is a common inhabitant of many caves; three species of Opiliones; several species of spider; and many species of Acari (Hazelton, 1975). In comparison to many Mendip caves the fauna of Pen Park Hole is poor in diversity

5. CONCLUSIONS

The low diversity of terrestrial invertebrate fauna in Pen Park Hole was evident both in the earlier biological investigation (Glennie & Hazelton, 1963) and the current survey. Glennie and Hazleton (1963) mention that this might be due to the isolation of the cave from the surface for almost one hundred years prior to its re-opening in 1957. However by 2013 the fauna still appeared to be rather limited, with few species representative of the parietal and threshold communities characteristic of many other caves. It could be argued that the modern gate and shaft continue to isolate the cave from the surface but many Mendip caves also have similar gated shaft entrances and yet still maintain some semblance of a threshold community. Another explanation for the paucity of the fauna could be the presence of significant deposits of lead-bearing galena in the First Chamber and the Entrance Series possibly making the sediments of the cave toxic to many species found more abundantly in caves elsewhere.

The outstanding point of interest of the fauna of Pen Park Hole is that in light of current knowledge, it appears to be the only cave known to support a confirmed, substantial cavernicolous population of *Niphargus kochianus*, a species more usually found in the phreatic water of Chalk aquifers.

Watson *et al.* (1997) and Gunn *et al*. (2000) outline the many and varied threats to caves and their biota, including: quarrying and mining, landfill, diffuse agricultural pollution of groundwater and internal impacts from caving visits. While not causing direct destruction land clearance, construction and other developmental activities may disrupt caves and karst systems. Changes in soil cover, siltation of waterways (even from activities far outside of the actual karst landscape), diversion of or changes in water flow and changes in vegetation cover can all have major impacts (Watson *et al*. 1997). If the proposed development nearby does proceed then great care has to be taken to ensure that the hydrology of the surrounding area is not adversely impacted to the extent that it can cause major changes in the currently little known hydrology of the lake, with a concomitant impact on its valuable population of stygobitic amphipods.

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APPENDIX: Photos of Sampling and Habitat in Pen Park Hole.

Extensive photography was not carried out in the cave during the survey as underground this activity can entail considerable time, expertise and equipment, particularly sufficient illumination and lighting techniques to enable photography in the darkness of a cave system. Photographs of various parts of the Pen Park Hole system can be found at http://www.penparkhole.org.uk/gallery/index.html

Sampling in the lake margins. Note submerged timber in shallow water behind sampler

Wood timbers and clay deposits on shore of lake

Sampling lake with trawl net from rocky spur

Traversing across to entrance to East Passage

Small pool in recess on wall in Second Chamber

First Chamber

First Chamber pool

Large calcite crystals containing galena deposits, First Chamber

The Ledge, photographed from West Platform

West Platform