THE FIRST OCCURRENCE OF THE PONTO-CASPIAN INVADER, HEMIMYSIS ANOMALA G.O. SARS, 1907 (MYSIDACEA) IN THE U.K.

BY

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ABSTRACT

An invasive Ponto-Caspian mysid, Hemimysis anomala G.O. Sars, 1907, was recorded in England for the first time in 2004. Usually a deep water species, in England H. anomala has been observed in shallow waters, in which it shelters under or within anthropogenic structures during daylight. This behaviour renders traditional, net-based survey methods ineffective. Therefore, a distribution survey of the English

East Midlands was conducted by searching for individuals by torchlight after dark. H. anomala was found to be widespread within the study area, occurring at 24 out of 51 sites surveyed. However, the geographical limits of its distribution were not determined. The species occurred at low densities in canals and in backwaters of the River Trent, whilst dense swarms were observed in September 2005 in a regatta lake connected to the River Trent. H. anomala has the potential to spread through England's canal network and could colonize the lower reaches and estuaries of rivers including the River Thames and River Severn. Habitat preference analysis indicated

that flowing water and absence of shelter prevented population establishment, although the species' U.K. distribution suggests that it can migrate through such areas of unsuitable habitat.

INTRODUCTION

Biological invasions, the introduction of species to ecosystems outside of their natural range, have become an increasingly serious ecological and economic issue over the last century (Perrings, 2005). Freshwater ecosystems are particularly vulnerable to invasions due to both deliberate inoculations and accidental introductions (Sala et al., 2000), the latter facilitated in particular by ballast water deposition during the international shipping of goods. The Ponto-Caspian region (comprising the Black, Caspian, and Azov Seas) is a notable donor of invasive aquatic species to Western European and North American waters (Bij de Vaate et al., 2002). One such Ponto-Caspian species to have undergone considerable anthropochorous range extension in recent years is <u>Hemimysis anomala</u> G.O. Sars, 1907 (Mysidacea) (fig. 1), which has spread west across Europe since its inoculation into impounded waters in Eastern Europe in the 1950s and 60s (Ketelaars et al., 1999).

Fig. 1. Dorsal view of a <u>Hemimysis anomala</u> G. O. Sars, 1907 specimen caught in the U. K. (Total length ~10 mm)

<u>H. anomala</u> is a euryhaline species, native to both brackish and fresh waters (Mauchline, 1980), and as such the salinity of an invaded ecosystem offers no barrier

to its colonization (Pienimäki & Leppäkoski, 2004). H. anomala is thought to produce two or three generations annually (Borcherding et al., 2006). Consideration of this regeneration period alongside the species' mean brood size, determined as 20-29 eggs or larvae per female (Borcherding et al., 2006), indicates that an introduced H. anomala population could reach high densities within 3 years. As an adaptable omnivore with a high feeding rate (Ketelaars et al., 1999), populations that attain high densities may have profound effects on the receiving ecosystem (Ketelaars et al., 1999; Borcherding et al., 2006).

H. anomala was originally recorded as a deep-water to sublittoral species (Mauchline, 1980), with early reports suggesting a depth range of 6-10 m (Salemaa & Hietalahti, 1993). In deep water, H. anomala performs diurnal vertical migrations (DVM). Ketelaars et al. (1999), for example, compared H. anomala's positioning in the water column at 10.00 hrs and 22.00 hrs, finding it exclusively at depths >7.5 m during daylight, whilst at night some individuals dispersed into waters of <2.5 m deep. DVM can be accompanied by horizontal dispersal of swarms into open water after dark (Borcherding et al., 2006). Mysids including H. anomala are sensitive to elevated light levels (Lindström, 2000), indicating that diurnal migrations are a negatively phototaxic response that has evolved to reduce predation by fish (e.g., Næsje et al., 2003).

H. anomala was first recorded in the U.K. in November 2004 when two specimens were found in a kick-and-sweep macroinvertebrate sample from the Erewash Canal, close to its confluence with the River Trent in Derbyshire, England. It was subsequently observed in dense swarms in a regatta lake connected to the River Trent at Holme Pierrepont, Nottingham in spring 2005. In these shallow water habitats, DVM was not observed. Instead, individuals remained close to the surface, sheltering under anthropogenic structures such as jetties and slipways during daylight before dispersing into open water at night. These findings, including initial records from the current distribution survey, were recently reported by Holdich et al. (2006).

Whilst invasive populations of H. anomala are widely distributed across Europe, current observations are scattered, reflecting H. anomala's concealed daytime behaviour and thus its preclusion from standard sampling methods (Ketelaars et al., 1999). Workers documenting H. anomala's recent range extension have employed various techniques involving diving (Salemaa & Hietalahti, 1993; Dumont, 2006), hand nets (Verslycke et al., 2000), vertical plankton hauls (Ketelaars et al., 1999) and trapping (Borcherding et al., 2006). However, none of these methods are appropriate for conducting a large-scale distribution study of H. anomala in shallow water habitats.

The principal aim of the current research was to determine the distribution of H. anomala in the English East Midlands. To this end, a method for surveying the species' occurrence in shallow waters (<1 m deep) was developed. To ensure the validity of observations made during distribution surveys, monthly surveys of species abundance were conducted at Holme Pierrepont regatta lake, where H. anomala was known to be abundant. The survey season for H. anomala in English waters could thus be determined. In addition, habitat features were recorded during the distribution survey and used to identify those habitats in which H. anomala is likely to thrive and thus potentially impact upon native communities.

STUDY SITES

The species was known to occur in abundance in the regatta lake at Holme Pierrepont National Water Sports Centre (hereafter, Holme Pierrepont) (52°56.47′N 1°05.66′W). The regatta lake was visited on a monthly basis to ensure that H. anomala abundance was still above the detection threshold, thus validating the results of any distribution surveys undertaken. Holme Pierrepont is connected to the River Trent south-east of the city of Nottingham in the East Midlands, England (fig. 2). The lake is a man-made water body measuring 2000 m in length and is used for recreation and regattas. Distribution surveys were conducted in the English East Midlands, largely within the River Trent catchment area.

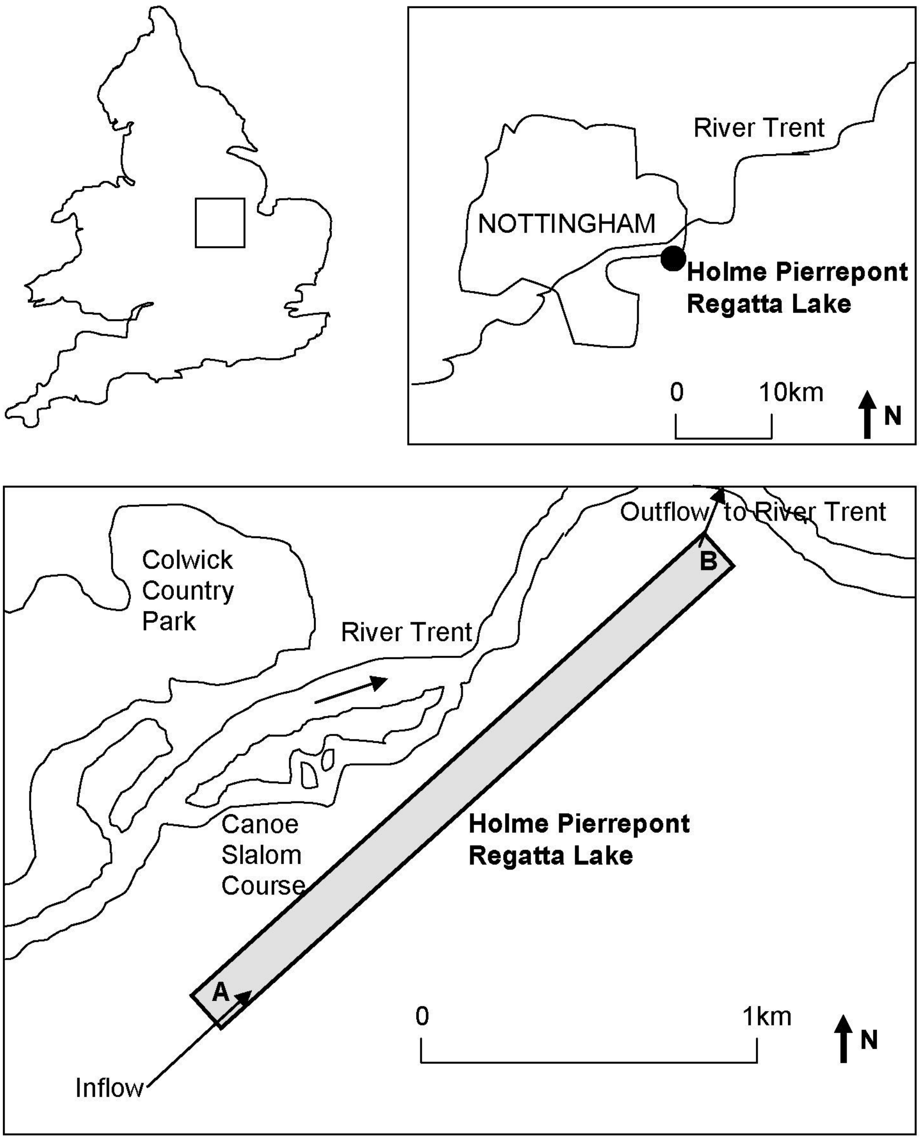

Fig. 2. Location of Holme Pierrepont Regatta Lake, at which the occurrence of Hemimysis anomala G. O. Sars, 1907 was surveyed at monthly intervals. A and B indicate the areas where survey sites were concentrated due to the presence of anthropogenic structures.

METHODS

Development of the survey technique

Preliminary investigations were conducted at Holme Pierrepont to develop an effective survey technique. Vertical plankton hauls (mesh 1 mm, frame size 25 cm x 40 cm), used successfully by Ketelaars et al. (1999) in deep water, proved ineffective due to the mysids' concealed daytime lifestyle and net avoidance behaviour. Equally, few mysids were caught using a sweep net (mesh 1 mm, bag length 30 cm, frame diameter 25 cm), despite the previous success of the technique in a deep, steep sided pond (Verslyke et al., 2000). SCUBA diving, as used by both Salemaa & Hietalahti (1993) and Dumont (2006), was inappropriate for the current investigation due to the specialist equipment and personnel required.

Therefore, considering Hemimysis anomala's dispersal into open water after dark, searching for individuals by torchlight was utilized. A torch beam was adjusted to maximize light penetration into the water column and then used to examine the site thoroughly. Unnecessary illumination of the water column was avoided as this could cause mysids to seek shelter. H. anomala individuals were easily identified by their red coloration, size and reflective eyes. Since no other mysids are known to occur in the study area, this method of identification was adequate in the field. In addition, numerous specimens were collected using a hand net (mesh 1 mm, bag length 30 cm, frame diameter 25 cm) and identification confirmed in the laboratory.

The torch-searching method proved extremely effective compared to the other techniques examined for determining presence or absence of H. anomala. It was therefore used for both the distribution survey and to confirm the occurrence of H. anomala at Holme Pierrepont each month. However, surveys could not be undertaken if visibility into the water column had been reduced by precipitation or strong winds.

Previous reports of invasive H. anomala populations have indicated a preference for lentic waters (Ketelaars et al., 1999; Verslyke et al., 2000; Dumont, 2006). In addition, research has suggested that in shallow waters the species is confined to areas where boulders or anthropogenic structures (such as jetties, ledges, and rip-rap) provide shelter (Janas & Wysocki, 2005; Dumont, 2006). Initial investigations indicated that these habitat preferences also applied to English H. anomala populations, and therefore subsequent surveys were concentrated on such areas.

Determination of seasonal occurrence

Nine sites were selected around the perimeter of Holme Pierrepont Regatta Lake, concentrated in regions A and B (fig. 2) where anthropogenic structures provided extensive shelter and H. anomala occurred in abundance. Each site was visited after dark between 19.30 and 21.00 hours at monthly intervals from September 2005 to - April 2006, and in July and August 2006. At each site, presence or absence of H. anomala was determined using the torch-searching technique.

Distribution survey

Surveys commenced in October 2005 and continued until January 2006, when a severe decline in mysid abundance at Holme Pierrepont indicated that further surveys would be likely to record false negative results. On arrival at a site, the watercourse was assessed for suitable habitat and searching targeted around these areas. The site was surveyed using the torch searching technique. Habitat features were recorded, including the nature of the watercourse and the type of shelter available. The amount of shelter was estimated as a percentage of the area searched. Any factors reducing visibility into the water column were also noted. If mysids presumed to be H. anomala were observed in a watercourse where they had not been previously been recorded, multiple individuals were collected for identification to species level.

RESULTS

Seasonal abundance of Hemimysis anomala

The monthly surveys conducted at Holme Pierrepont regatta lake found Hemimysis anomala to occur in high density swarms in September 2005. Densities then gradually declined but the species remained easily detectable until December. Abundance was low in January 2006, with adults mysids being observed at only two sites. No H. anomala were observed during February or March, however, juveniles reappeared at low densities in April. Surveys were not undertaken in May or June. By July, abundance had increased considerably and swarms of adult mysids were observed. Observations indicated that mysid abundance had unexpectedly declined by August, although the species was still easily observed. Rainfall in the Midlands was 123% of the long term average in August 2006 (Met Office, 2006), and included several high intensity rainfall events (NERC, 2006). Such events have the potential to displace zooplankters (Campbell, 2002) such as mysids and/or their prey, which may have resulted in the observed decline in population density.

Distribution survey

The distribution survey revealed H. anomala to be widely distributed in the East Midlands, occurring at 24 of the 51 sites surveyed (47%), all of which were within the River Trent catchment (fig. 3). The species was recorded exclusively in lentic waters, occurring in canals, river backwaters, and one lake.

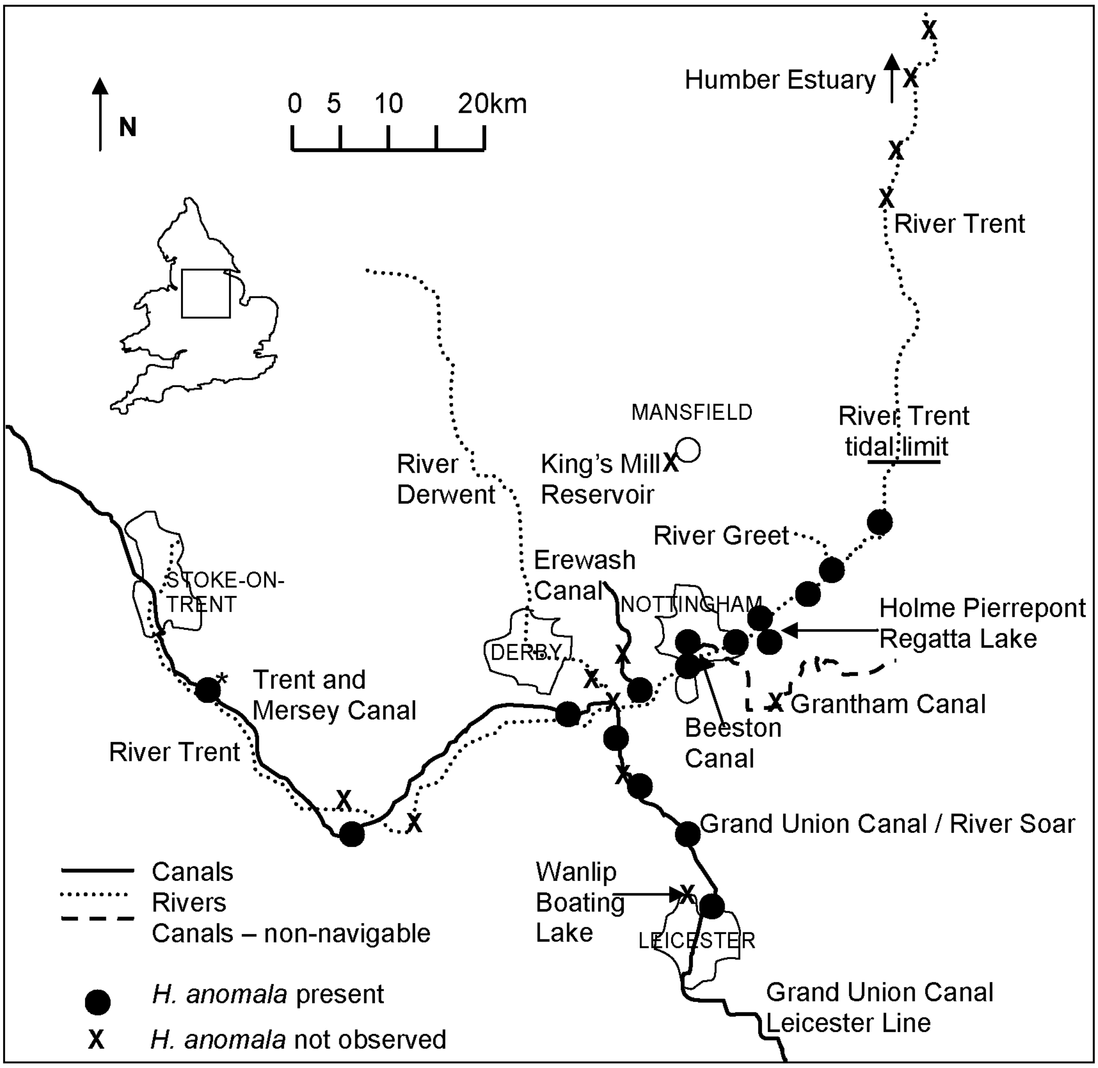

Fig. 3. Map of the East Midlands and surrounding area, showing the location of survey sites at which presence or absence of Hemimysis anomala G. O. Sars, 1907 was determined.

The species was observed most frequently in canals, occurring in all four surveyed watercourses (Trent and Mersey Canal, Grand Union Canal, Erewash Canal, and Beeston Canal), and at a total of 14 out of 22 sites. On the Trent and Mersey Canal, the species was observed close to the confluence with the River Trent south-east of Derby and was also found in a routine Environment Agency kick-and-sweep macroinvertebrate sample taken approximately 50 km from this confluence (indicated by * in fig. 3) (D. Ottewell, pers. comm.). Similarly, the species was recorded at several locations on a 25 km stretch of the interlinking River Soar/Grand Union Canal, between the Leicester and the River Trent confluence. H. anomala was also common in backwaters of the non-tidal River Trent, occurring at 9 out of 21 sites. Four surveys were conducted on the tidal section of the River Trent but no mysids were observed (fig. 3), possibly due to severe turbidity. Of the four standing water bodies investigated, H. anomala was only observed at Holme Pierrepont. Here, dense swarms were recorded, whilst at all other sites only a few individuals were observed.

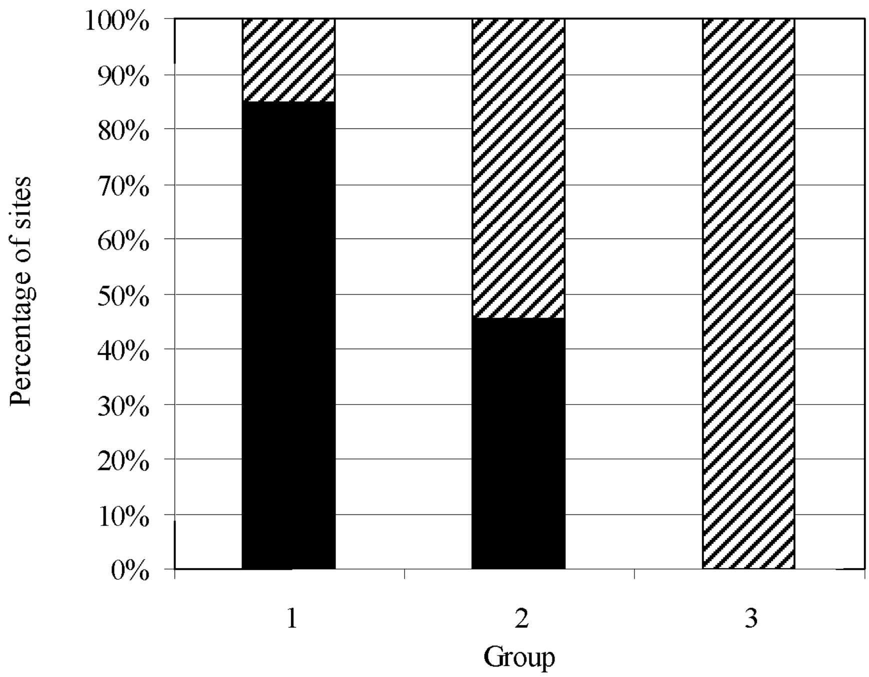

Fig. 4. Frequency of occurrence of Hemimysis anomala G. O. Sars, 1907 at survey sites in group 1 (>50% of the site covered by anthropogenic structures), group 2 (<50% of the site covered by anthropogenic structures), and group 3 (natural sites). Sites at which H. anomala was found are black, sites at which the species was not observed are hatched.

Observations made during the distribution survey indicated that the occurrence of H. anomala was affected by the availability of shelter in the form of anthropogenic structures, such as crevices in canal walls and reinforced river banks, rip-rap, jetties and slipways. To investigate this association, sites were divided into those that lacked shelter from anthropogenic structures, those at which <50% of the area searched was sheltered, and those at which >50% was sheltered. H. anomala was found at 45% of sites at which <50% of the area searched was sheltered, increasing to 85% of sites at which >50% was sheltered (fig. 4). The species was not found at any site at which no shelter was provided by anthropogenic structures (fig. 4). The observed increase in the occurrence of H. anomala with increasing shelter was found to be significant (Kruskal-Wallis test, $n = 51$, $H = 12.80$, $p = 0.002$).

DISCUSSION

A deep-water to sublittoral species in its native Ponto-Caspian region (Mauchline, 1980), Hemimysis anomala has been observed close to the surface in several English water bodies (fig. 3). The species has thus proved itself adaptable, using anthropogenic structures to obtain the protection from predation usually afforded by deep water. The diurnal vertical migrations reported in deep water (Mauchline, 1980; Ketelaars et al., 1999) are replaced in shallow waters by horizontal dispersal into open water after dark. This adaptability has allowed the species to exploit a range of lentic habitats (canals, river backwaters, lakes) and to become widespread in the English Midlands. However, whilst H. anomala has been observed at high population densities in lentic waters with abundant shelter, lotic waters and an absence of shelter appear to act as barriers to population establishment.

Survey season and methodology

The population density estimates made at Holme Pierrepont detected the year's first H. anomala juveniles in April. However, at only ~1 mm long (Ketelaars et al., 1999) these juveniles are not easily observed. Larger individuals (≤10 mm) were apparent from July and remained easily detectable until December, and thus these months are suggested as the appropriate survey season for this species in England.

Torch searching proved to be a simple and effective technique for determining the presence or absence of H. anomala in most shallow water habitats. In contrast to the scattered records from continental Europe (Bij de Vaate et al., 2002), this investigation established a relatively complete picture of H. anomala's distribution within the limited study area (fig. 3). Torch searching could therefore be used to help clarify H. anomala's European occurrence in shallow waters. However, the method is not quantitative and as such requires further development. Also, the method is not effective in turbid waters, for example the tidal section of the River Trent. This investigation failed to establish the limits of H. anomala's geographic distribution in England, due to the species being more widespread than originally envisaged. Further surveys are therefore required to establish a baseline against which future changes in the species' distribution can be monitored.

Invasion and future range extension

The current distribution survey revealed neither the mechanism nor the route by which H. anomala reached England. However, considering the invasion history of H. anomala (see Ketelaars et al., 1999) and other Ponto-Caspian species (e.g., Ricciardi & MacIsaac, 2000) its arrival was almost certainly anthropochorous. The species may have been first introduced into Holme Pierrepont via contaminated boats or equipment by rowing teams that train both here and at potential donor sites in Belgium and the Netherlands. Individuals could have then entered the River Trent through the Regatta Lake's outfall (fig. 2). More likely, the species was released into the River Trent Port Area during ballast water exchange, from here entering Holme Pierrepont during flood conditions or via an inflow operated by regatta lake staff. The limited space available in the River Trent's backwaters combined with predation from adult H. anomala (cf. Ketelaars et al., 1999) may have promoted upstream migration of juveniles (Turner & Williams, 2000), leading to the species' current known distribution.

It is highly likely that H. anomala will spread through the Midlands via the extensive, interconnected canal network (fig. 5), particularly considering its recent large-scale canal-facilitated range extension across Europe (Bij de Vaate et al., 2002). From the canal network, the species has access to several large rivers including both the River Thames and the River Severn (fig. 5). Movement upstream in such lotic environments will be dictated by the species' as yet uncharacterized current velocity tolerance. However, the known distribution of H. anomala in England (fig. 3) indicates that individuals have some capacity for upstream migration through flowing waters unsuitable for permanent habitation. For example, the species occurs in several lentic sections of a 25 km stretch of the Grand Union Canal/River Soar watercourse, between which are several kilometres of slow flowing riverine habitat.

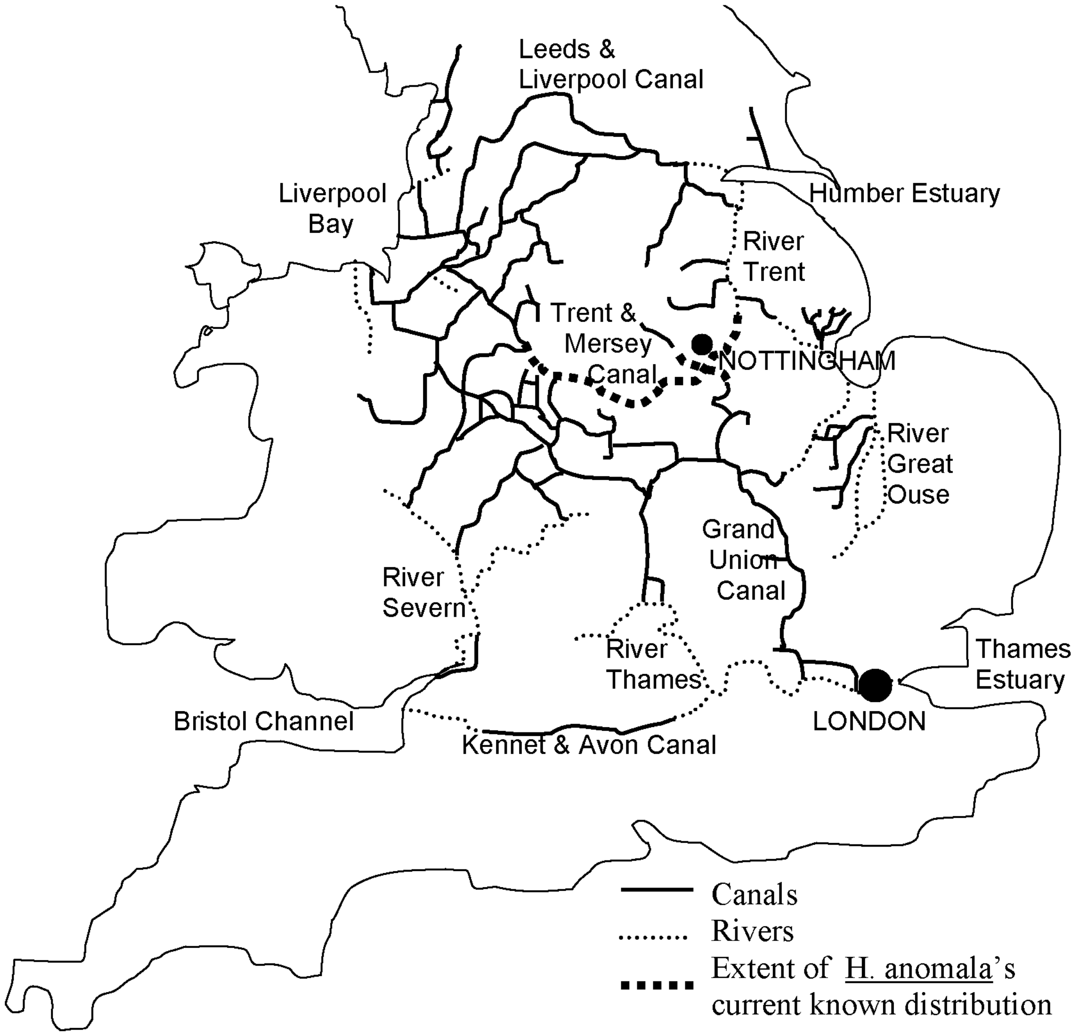

Fig. 5. Map of England and Wales, illustrating the interconnectivity of the canal and navigable river network.

Weirs may act as barriers to upstream migration on non-navigable rivers as they can only be negotiated during conditions of very high flow. King's Mills weir on the River Trent, for example, has a minimum flow rate of ~1 m s^{-1} (N. Martin, pers.

comm.) and as such is unlikely to be overcome. H. anomala has not been observed at sites above this structure, despite the availability of suitable habitat.

Habitat preferences and effects on the receiving ecosystem

H. anomala's association with sheltered habitat has previously been noted by Verslyke et al. (2000), who suggest that the species only inhabits areas where holes and crevices are present. Similarly, in the Gulf of Gdańsk H. anomala occurs between stones and boulders and under peat overhangs (Janas & Wysocki, 2005). Dumont (2006) observed the species under a pier and under rocks during daylight, noting their dispersal into open water after dark. Analysis of the 51 sites surveyed during the current investigation found a positive association between the amount of cover provided by anthropogenic structures and the occurrence of H. anomala (cf. Kruskal-Wallis test, $p = 0.002$). Indeed, the species was observed exclusively at sites where anthropogenic structures provided some shelter, and in addition occurred only in lentic habitats. The results of the present study thus indicate that the sites at which H. anomala is able to reach densities with the potential to cause ecological damage may be scarce and of low ecological value due to existing anthropogenic pressures.

Ketelaars et al. (1999) linked the arrival of H. anomala in a Dutch reservoir to decreases in the abundance of various zooplankters, whilst Irvine et al. (1993) attributed an increase in the growth of submerged macrophytes to consumption of periphyton by the native mysid, Neomysis integer Leach, 1814. Staff at Holme Pierrepont reported an atypical absence of cyanobacteria and a profusion of macrophytic weed growth in summer 2005, however whilst these events coincide with high densities of H. anomala, any link has yet to be proven.

CONCLUSION

Torch-searching proved a simple and effective technique for determining the presence of Hemimysis anomala in shallow waters, and revealed the species to be widespread within the River Trent catchment. However, the geographical limits of the species distribution in England were not reached. Further research is thus required to establish a baseline against which future changes in distribution and abundance can be monitored. Whilst such monitoring of invasive species is intrinsically valuable, no methods currently exist for the control of zooplankters such as H. anomala.

This investigation indicated that in shallow water habitats, Hemimysis anomala is confined to lentic waters sheltered by anthropogenic structures. It is hoped that these requirements will limit the habitats in which invasive populations are able to reach high densities to those already subject to considerable anthropogenic pressures.

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