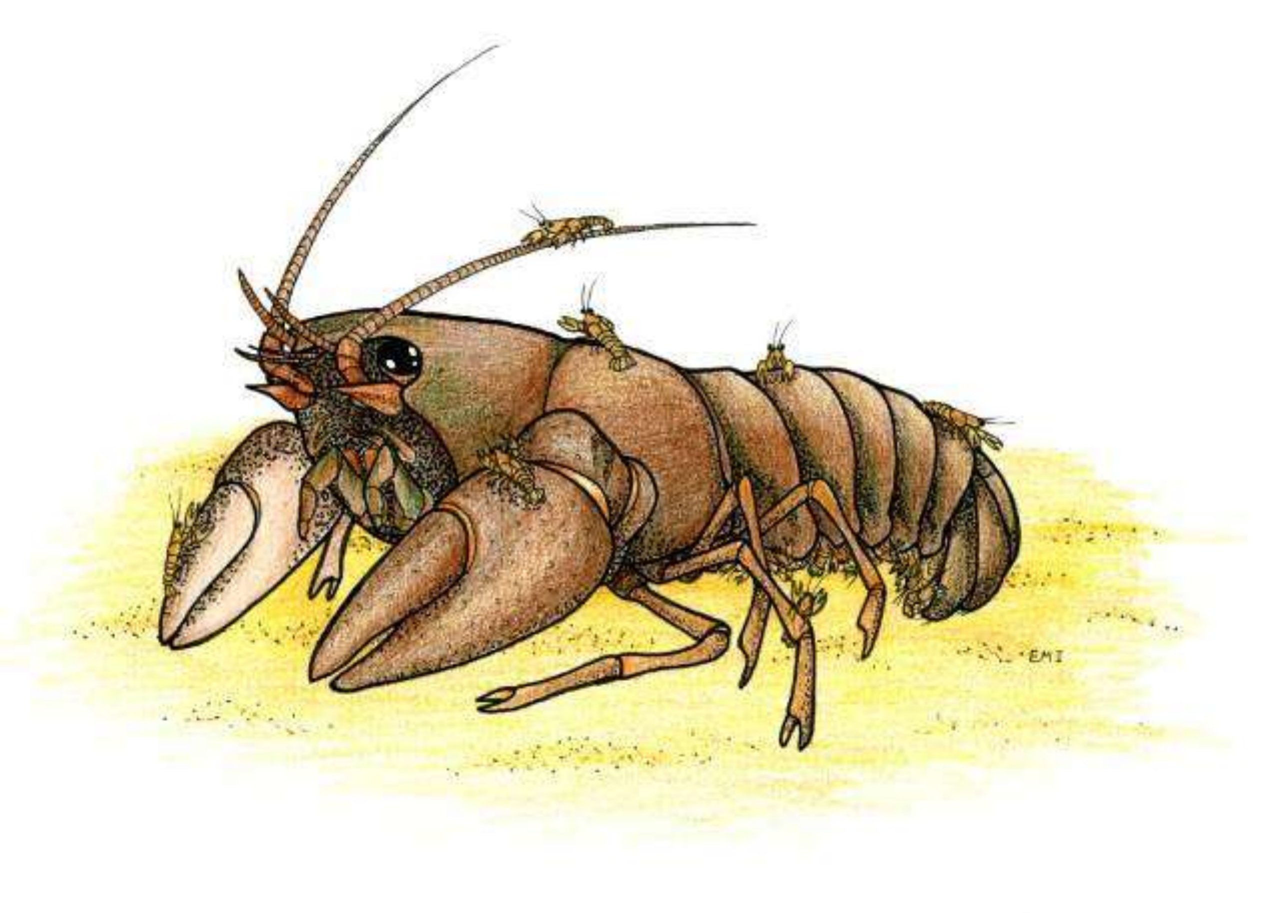
Crayfish Conservation in the British Isles

Proceedings of a conference held on 25th March 2009 at the British Waterways Offices, Leeds, UK



Edited by

Jonathan Brickland (Peak Ecology Ltd)

David M Holdich (Crayfish Survey & Research)

Emily M Imhoff (University of Leeds)

December 2009

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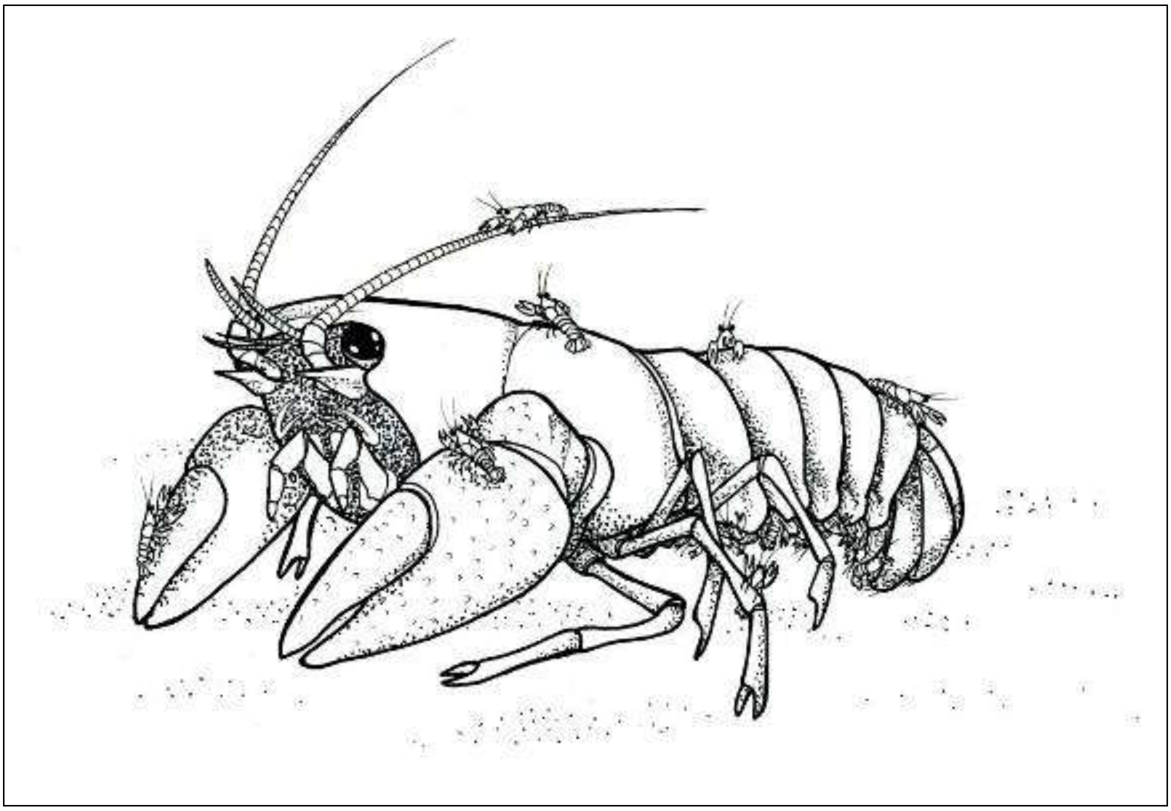

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Editorial

This conference follows on from previous ones held in Leeds in 2000 (Rogers and Brickland 2000) and Nottingham in 2002 (Holdich and Sibley 2003) by having a conservation and management theme.

Since the 2003 conference there has been a continuing interest in crayfish conservation in the British Isles due to the threat to the survival of our indigenous white-clawed crayfish (*Austropotamobius pallipes*) from non-indigenous crayfish species (NICS), particularly the signal crayfish (*Pacifastacus leniusculus*), and crayfish plague. Quite a lot of papers at the 2009 conference focussed on "ark sites" as the way forward to conserve the remaining stocks of white-clawed crayfish.

Some 59 delegates attended the 2009 conference but due to restrictions on space, unfortunately, many people who wanted to attend could not.

On the day of the conference Jonathan Brickland opened proceedings with an amusing review of organizations that use the word crayfish in their titles, including a rock band and a crayfish liberation group! Fourteen papers were presented covering a wide range of topics. Jonathan Brickland, Mark Robinson and Julian Reynolds chaired the three sessions.

The edited proceedings include the majority of papers presented at the conference plus additional ones by Jonathan Brickland, David Holdich and Ben Rushbrook, which we thought might be of interest to readers.

In 2001, the European network CRAYNET "European crayfish as keystone species linking science, management and economics with sustainable environmental quality" was set up (Souty-Grosset et al. 2006a). This involved workshops being held in France, Ireland, Norway, Austria and Italy, the proceedings of which were published in the *Bulletin Français de la Pêche et de la Pisciculture* (this journal and its successor - *Knowledge and Management of Aquatic Ecosystems*, contain many articles on crayfish in English, and can be accessed via: http://www.kmae-journal.org). Another end product of CRAYNET was the atlas of crayfish in Europe (Souty-Grosset et al. 2006b), which not only updated the distribution of the indigenous crayfish species (ICS) and NICS in Europe, but gave details of their origins, biology, diseases and conservation. This was accompanied by a new identification guide to European ICS and NICS (Pöckl et al. 2006). A major review of the crayfish situation in all European countries has recently been undertaken (Holdich et al. 2009) and it is clear that the British Isles is not alone in having to face up to a continued decline in the range of its indigenous species in the face of the continuing spread of NICS and outbreaks of crayfish plague. The 2002 book "*Biology of Freshwater Crayfish*" edited by David Holdich has been out of print for a few years but is now available again via bookshops (ISBN no. 9780632054312) or online at www.wiley.com/go/fish.

The next crayfish conference in the British Isles is likely to be that in Autumn 2010 organized at Bristol Zoo (see Nightingale this volume), but before that the 18th International Association of Astacology conference will be held in Columbia, Missouri, USA in July 2010 (http://muconf.missouri.edu/IAA18/index.html).

Holdich, D.M. (ed) (2002). Biology of Freshwater Crayfish. Blackwell Science, Oxford. 702 pp. ISBN 0-632-05431-X

Holdich DM, Reynolds JD, Souty-Grosset C and Sibley PJ (2009). A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems.* (In press).

Holdich DM and Sibley PJ (2003). Management & Conservation of Crayfish. Proceedings of a conference held on 7th November, 2002. Environment Agency, Bristol, 217 pp. These proceedings are available as a PDF file from David Holdich (david.holdich@ntlworld.com).

Pöckl M, Holdich DM and Pennerstorfer J (2006). Identifying native and alien crayfish species in Europe. European Project CRAYNET, Guglar Cross Media, Melk, Austria, 47 pp. Copies can be obtained from Dr Manfred Pöckl (manfred.poeckl@noel.gv.at)

Rogers D and Brickland J (2000). Crayfish Conference Leeds. Proceedings of a conference held on 26th/27th April, 2000. Environment Agency, Leeds, 139 pp. These proceedings are available as a PDF file from Jonathan Brickland (jonathan.brickland@peakecology.co.uk)

Souty-Grosset C, Reynolds J, Gherardi F, Schulz R, Edsman L, Füreder L, Taugbøl T, Noël P, Holdich D, Śmietana P, Mannonen A and Carral J (2006a). European crayfish as keystone species-linking science, management and economics with sustainable environmental quality. *Freshwater Crayfish* 15: 240-250.

Souty-Grosset C, Holdich DM, Noël P., Reynolds JD and Haffner P, (eds) (2006b). Atlas of Crayfish in Europe. Muséum national d'Histoire naturelle, Paris, Patrimoines naturels, 64, 187 pp. ISBN: 2-85653-579-8.

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Darran Sharp
Paul Moody

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List of reviewers

The editors would like to thank the following for refereeing the papers:

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Emily Imhoff
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Julian Reynolds
John Foster
David Rogers
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British Waterways

British Waterways is a public corporation that cares for the 2,200-mile network of canals and navigable rivers in England, Scotland and Wales. Our aim is to ensure that the waterways can be enjoyed by all members of society now and into the future. Our purpose is to protect the historic waterways in our care, to secure and earn the necessary funding to do this, to increase the numbers of people who value and invest in them and to optimise the public benefit they can deliver.

In the last decade Britain's inland waterway network has undergone a widely acclaimed revival, with more than 200 miles of canals built or restored and record number of boats and towpath visitors using the system. British Waterways is influencing and enabling an estimated £10 billion of waterside regeneration, which has helped towns and communities across the country to rediscover their local waterway. This revival has been made possible thanks to the support of Defra and the Scottish Government, the lottery, local authorities and countless volunteers and enthusiasts.

The extraordinary and beautiful natural environment of our waterways is without doubt a key element in making them very special places to visit and enjoy. British Waterways cares for 73 Sites of Special Scientific Interest (SSSIs) and 1,000 wildlife conservation sites. It is the third largest owner of listed structures in the UK, including five World Heritage sites, 99 Scheduled Monuments and the locks, bridges, aqueducts, reservoirs and tunnels that make up the architecture of our industrial past.

Above all else, we must maintain our inland waterways so that they are safe and accessible for the 11 million people who visit and enjoy them every year. We work with public sector bodies, private sector partners and the voluntary sector and reinvest all the income we earn back into maintaining our canals and rivers.

British Waterways was in the news in 2009 with the Government looking to sell off substantial amounts of British Waterways property; an asset that is vital to British Waterways as it contributes to the funding of the waterways. Alternative structures to secure the future of the nation's 200-year-old canals and rivers have been reviewed and British Waterways is looking to create a 'national trust' for the waterways. The move to the third sector from direct state control has been met with wide-ranging support in England and Wales since its initial proposal in May 2009. For more information, visit www.britishwaterways.co.uk/twentytwenty

www.waterscape.com is British Waterways' official online guide to Britain's canals, rivers and lakes. From boat trips, pubs, fisheries, cycling and walking routes, to the latest news and events, waterscape.com helps you discover things to do and places to go by your local waterside.

www.britishwaterways.co.uk

Peak Ecology Ltd

Peak Ecology Limited is a specialist ecological consultancy co-founded by its two directors, Jonathan Brickland and Dr. Mark Webb, who together have the benefit of over thirty years of ecological experience.

Based in Bakewell, Derbyshire, Peak Ecology offer a comprehensive range of ecological consultancy services to a varied client base, including developers, planning consultants, landscape architects, multi-disciplinary consultants, government agencies and public bodies. We have worked on housing, mixed-use and leisure developments and on transport and energy schemes including road, pipeline, power station, waterway navigation and airport projects. We also provide training and technical support on specific ecological issues and projects.

Jonathan has had a keen interest in crayfish for many years, it began when he worked for the Environment Agency and he set up the UK BAP white clawed crayfish Steering Group; chairing the group for several years. He maintained this interest whilst working as National Ecologist for British Waterways and continues to work on crayfish both professionally and personally.

Peak Ecology Ltd support conservation initiatives in general and are an active supporter of the Derbyshire Wildlife Trust. They have been happy to contribute time and resources to making the Crayfish Conservation in Britain conference a great success.

Crayfish Survey and Research

Crayfish Research and Survey is a consortium of experts, primarily comprising Jonathan Brickland, David Holdich and Julian Reynolds but with additional skills and resources available as and when required.

Jonathan Brickland began working on crayfish during his time with the Environment Agency when he set up the Steering Group for the UK Biodiversity Action Plan; he still plays an active role on the Steering Group. His work with the Environment Agency and British Waterways has given him a good grounding in crayfish ecology, surveys and rescues and the issues affecting our native species.

For many people David Holdich needs no introduction, he is renowned around the world for his work on crayfish and other crustaceans. In recent years he has played a lead role in Europe-wide crayfish issues, notably as a member of the European Task Group known as Craynet. David is the editor of the definitive crayfish textbook, the Biology of Freshwater Crayfish and has published many papers on crayfish and other Crustacea.

Julian Reynolds is a freshwater ecology specialist trained in Ireland, Ghana and Canada and is a Fellow Emeritus at Trinity College, Dublin. He has been involved in the research of the ecology, aquaculture and diseases of freshwater crayfish for 30 years and is a Craynet member. His work extends beyond crayfish to other aquatic invertebrates, ephemeral habitats and has included the biology of eels and the ecology of woodlice!

For more information on the above go to www.peakecology.co.uk or call Jonathan on 01629 812511.

INTERNATIONAL ASSOCIATION OF ASTACOLOGY

The International Association of Astacology (IAA), founded in Hinterthal, Austria in 1972, is dedicated to the study, conservation, and wise utilisation of freshwater crayfish. Any individual, organisation or firm interested in furthering the study of crayfish is eligible for membership. Discounted membership is available for students. Benefits of membership include a quarterly newsletter, discounted registration at the society's biennial International symposia, access to an online archive of IAA publications, searchable online membership directory, and publication in the journal *Freshwater Crayfish*. Members who are organising regional crayfish-focused meetings are eligible to apply for limited IAA funding support.

There are over 500 members in the society including scientists, university students, government departments, hobbyists, biologists, aquaculturists, research institutes, and libraries representing over 50 countries. The main goals of the IAA are to: (1) encourage the scientific study of crayfish for the benefit of mankind, (2) provide for the dissemination of research findings relating to crayfish, and (3) develop an international forum for the free discussion of problems relevant to crayfish. Since its formation in 1972, the IAA has gradually grown in size and complexity, and is now an extensive international network. The day-to-day operations of the society are conducted through the secretariat, which is located in Alabama (USA), but the society also has elected officers and an appointed board who run the organization on a two-year cycle. Those interested in joining the IAA should visit the IAA web page, contact the IAA Secretariat or any of the IAA officers directly.

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The indigenous status of *Austropotamobius pallipes* (Lereboullet) in Britain

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ABSTRACT

In order to qualify for indigenous status in Britain, with concomitant implications for its conservation, the white-clawed crayfish, *Austropotamobius pallipes*, needs to have been in residence before 1500 AD. Available evidence from palaeontology, distributional, and genetic studies is examined, as well as records of crayfish in historical documents. The conclusion is that there is sufficient evidence from historical literature to indicate that *A. pallipes* was in residence in Britain before 1500. This has been accepted by the IUCN.

Keywords: *Austropotamobius pallipes*, Britain, indigenous, evidence

INTRODUCTION

The following statement of the International Union for the Conservation of Nature and Natural Resources (IUCN) caused the authors to try to clarify the indigenous status of the white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet) in Britain.

"*To decide whether an introduced species is now considered naturalized to a region for the purposes of a Red Data Book, IUCN recommends that a preset year or event may be used (IUCN 2003). For assessments of species in Europe, IUCN uses a cut-off date of 1500 and if a species existed in a country since that date it is considered indigenous for the purposes of the Red List assessment*."

Live freshwater crayfish have been transported around Europe as a food commodity for centuries (Hirsch 2008) so there is a possibility that *A. pallipes* was introduced to Britain relatively recently. However, there is currently considerable investment in the conservation of *A. pallipes* because it has been regarded as a threatened species indigenous to Britain. In order to justify this effort, it is important to establish the status of *A. pallipes* and this has triggered a search for evidence to demonstrate that it was part of the British freshwater fauna prior to 1500 AD.

DISTRIBUTION BEFORE THE INTRODUCTION OF SIGNAL CRAYFISH

Austropotamobius pallipes was widely distributed in England and Wales from Victorian times until the early 1980s (Thomas and Ingle 1971, Holdich and Reeve 1991). This in itself might suggest that it has been resident in Britain for a long time and that it has spread both naturally and by human-mediated means as it was perceived as a useful food. At the time it entered Britain *A. pallipes* would have been the largest mobile, polytrophic invertebrate and in some instances may have had a significant impact on other freshwater biota although arguably less so than other more aggressive introduced species (Holdich 1999a). As seen from the introduction of the signal crayfish *Pacifastacus leniusculus* (Dana) into Britain in the late 1970s (Holdich 1999b), colonization can be rapid, i.e. it took less than 25 years for this non-indigenous species to occupy more 10 km squares than *A. pallipes* (Sibley 2003, Holdich et al. 2004). Its spread has been both natural and by human-mediated means for commercial purposes. One wonders if *A. pallipes* could have spread that quickly when it re-colonized (or was re-introduced to) Britain.

The only two populations of *A. pallipes* in Scotland (Loch Croispol in Durness and White Moss Reservoir in the catchment of the lower Clyde) are thought to have been introduced in recent times (Holdich and Reeve 1991, Thomas 1992, Maitland et al. 2001) and therefore cannot be considered as indigenous. The origin of the introduced crayfish is not known but Maitland et al. (2001) suggest they may have originated from stock (1100 individuals) brought in by Lord Breadalbane over 150 years ago for possible introduction to the River Tay, or from stock introduced into a number of Scottish counties about the same time. Thomas (1992) states that the population in Loch Croispol was derived from an introduction into a feeder stream in 1945 by H Campbell, Keeper of the Keadal Estate, Durness, but its origin is unknown.

Although Ireland is not dealt with in this paper, there are similar issues regarding the indigenous status of *A. pallipes* (Gouin et al. 2003, Demers et al. 2005, Reynolds this volume).

Machino et al. (2004) provide a useful summary of *A. pallipes* introductions throughout Europe.

FOSSIL EVIDENCE AND POSSIBLE POST-GLACIAL MIGRATION

The Ice Age, or Pleistocene, came to an end about 10 000 years ago. Bell (1921) refers to "*A. pallipes*" in Pleistocene deposits: "*Potamobius pallipes* Lereboullet. (*Astacus fluviatilis*) Fabr. Pleist. Clacton, Essex, and Stapenhall in the Lower Trent Valley". Albrecht (1983) comments on this as follows, although he gives Bell's paper as 1920: "In Bell (1920) we find two statements about Pleistocene findings of *A. pallipes* in Mid-England. Unfortunately these two statements are problematic. Bell only gives a list of different findings without any description. It is impossible to know how many parts of the animals existed nor which criteria were applied to classify them. There is also no statement where these pieces were stored. Even if they were really *A. pallipes* these findings must come from anteglacial migration, which were deposited in the Pleistocene. The English populations of today are only to be understood as postglacial new immigrations." He goes on to say that "If *A. pallipes* reached Great Britain in a natural way, it could have reached Southern England, as there was a post-glacial stream connection in existence between France and England. The British Isles were linked since the Tertiary until approx. 6000 years ago with the mainland through a bridge of land. The rivers of southern England met with the original Rhine, the Seine, Somme, Authie and Cauche. The first immigrants (whether *A. pallipes* or not) stood no chance to survive the Ice Age in England, as the British Isles were partly ice-over or belonged partly to the area of permafrost."

Spitzy (1979) has speculated that prehistoric man would have recognised crayfish as a valuable food source and, due to the ease by which they can be transported in damp baskets, may well have seeded lakes in new areas with them. However, he, as the current authors have found, could find no reference to crayfish in

European literature in or before the Middle Ages (1066-1485 AD), or references to their remains being found in middens. Their absence from middens, unlike the shells of bivalve molluscs such as those of swan mussels, he speculated could be put down to the fact that their remains may have been carried away by birds and rodents, thrown in a fire, or just not survived in the soil conditions round encampments.

Much more is known about the recolonization of Britain by freshwater bivalve molluscs after the last Ice Age. Killeen et al. (2004) state that most species now regarded as native are a result of recolonization from the latter part of the Lateglacial (c. 14 000 years ago) and that by the early to middle Holocene (7500-5000 years ago) the "native" freshwater bivalve fauna was complete. One has to wonder whether crayfish would have been equally capable of such recolonization, especially as they are much more mobile as adults than bivalve molluscs, although they do lack larvae, i.e. what hatches out from the egg is an almost fully formed crayfish (Holdich 1992). The production of free-swimming larvae is probably the means by which the larger bivalve molluscs recolonized British waters.

GENETIC EVIDENCE

There is, therefore, speculation as to how some of the current marginal populations subsequently came about in Europe. For example are the populations of *A. pallipes* in Britain natural or introduced by man in relatively recent times? Grandjean et al. (1997a) found a lack of genetic diversity in *A. pallipes* from Britain suggesting a recent origin. Grandjean et al. (1997b) found a strong genetic similarity to some populations in northern France, suggesting that British *A. pallipes* may have originated from there. Whether this was by tribes moving north with the melting ice when the British Isles were connected to mainland Europe some 6000 years ago, or much more recently, i.e. in the last 1000 years, is not known. One also has to consider the fact (as mentioned above) that as the ice melted some of the rivers between mainland Europe and the British Isles were joined, so colonisation of the British Isles by *A. pallipes* may also have been natural, as has occurred with some fish species (George 1962, Maitland and Campbell 1992).

Grandjean and Souty-Grosset (2000) found no genetic differences amongst the most northern French and the British populations, whereas there was marked interpopulation genetic diversity in southern French populations. They thought that the former observation may be due to the fact that new areas free from the retreating ice were generally colonized by a limited number of individuals and consequently only represent a small part of the genetic pool present in refugial zones. The latter observation is probably due to habitat fragmentation and subsequent recolonizations from refugial areas during the Pleistocene. Souty-Grosset et al. (1997) have suggested that at least three refugia were formed during the last ice age: the first in the Iberian Peninsula, the second the Balkans, and the third in the south of France; north-western Europe being colonized from this latter refuge after the last ice period. Grandjean et al. (2001a, b) have elaborated further on this matter and, based on RFLP analysis from mDNA, have suggested at least four main refugia for *A. pallipes* during the Pleistocene, which could have been located in the Balkans, Carpathians, Italy and France. Three clusters with specific haplotypes have been found in north-western France and Britain, southern France and northern Italy. Each had low genetic differentiation, thus indicating recent divergence during the last periods of glaciation with three refugia located in the Atlantic French region, Mediterranean French region and Italy. England and northern France could have been colonised by individuals from Atlantic refugia. Gouin et al. (2001) using *RAPD* analysis suggests a historical separation into three refugial areas, probably in the Rhine, Mediterranean and Atlantic basins during recent glaciations. They thought that the close genetic relationships between English and western French populations were in accordance with a natural postglacial origin of English populations from individuals that survived in an Atlantic refugium.

ORIGIN OF THE NAME "CRAYFISH"

Huxley (1881 and other editions) discusses (pp. 12-13) the origins of the name "crayfish". He suggests that it could be a modification of the French name "écrevisse" or of the Low Dutch name "crevik". Swahn (2004) states that "The French word "(é)crevisse" was altered, and with the typical English way of murdering French the new word "cray-fish" was born."

The 1933 edition of *The Oxford English Dictionary* states that the word "crayfish" is derived from the Old French "crevice". It gives numerous variations on the word, including "creuesse", "crefysshe", "crefish", "craveys", "crevis", "creavis", "krevys" and "crawfish". These words might refer to freshwater crayfish or marine Crustacea other than crabs.

HISTORICAL ACCOUNTS OF CRAYFISH POPULATIONS

There are plenty of records of wild crayfish populations in Britain for the late 19th and early 20th C, also several for the 17th C, e.g. Hungerford in 1668, Oxfordshire in 1677 and Staffordshire in 1677 (Thomas and Ingle 1971).

Earlier records are few and far between, but two 16th C journals provide evidence of the presence of *A. pallipes* in England. Holinshed (1587, p. 224) says "As for the little crafishes they are not taken in the sea, but plentifullie in our fresh rivers in banks, and under stones, where they keep themselves in most secret maner, and oft by likeness of colour with stones among which they live, deceive even skilfull takers of them, except they use great diligence." There is even a suggestion that they were protected, as earlier Holinshed says "Besides the salmons therefore …. which are very plentifull in our greatest rivers …. we have the trout, barbelle, graile …. shrimps, crevises, lampreys, and such like, whose preservation is provided by very sharpe lawes, not only in our rivers, but also in plashes as lakes and ponds."

Fryer (1993) cites Camden (1586) as evidence that crayfish were introduced into the River Ure (Yorkshire) in the 16th C. Camden states (under Yorkshire, Section 58): "From hence runneth Ure downe amiane, full of Crefishes ever since Sir Christopher Metcalfe in our remembrance brought that kind of fish hither out of the South part of England." (*Hine citus defertur Urus cammaris fluvitialibus abundans ex quo C. Medcalfe nostra memoria id genus piscium ex Australi Angliae parte huc detulerit*.). Barker (1854) remarks that "one of Mr. Camden's editors states that crayfish were introduced into the Yore from the south by Sir Christopher Metcalfe, of assize display, but tradition avers that they were put there by the renowned Sir Walter Raleigh, whilst on a visit to Nappa, probably some years later." But Camden (1551-1623) was Sir Christopher's contemporary and may be supposed to have known the facts. Christopher Metcalfe's dates are 1513-1574. (http://www.thedales.org.uk/NappaHallAndThe MetcalfesOfWensleydale).

CRAYFISH AS FOOD IN MONASTERIES AND MEDIEVAL BRITAIN

During the Middle Ages (11th to 15th C) humans started to have a major impact on animal distribution, transporting and introducing many species to other geographical areas (Laurent 1988). Hartley (1954) states that monks were very fond of crayfish and that they are said to have introduced them to many of our streams. Reynolds (1997) has suggested that *A. pallipes* might have been introduced to Britain by monastic orders from France as early as the 12th C.

Swahn (2004) recounts how in the 10th C the two most important countries in Europe utilising crayfish were France and England, with a definite link to monastic centres. "It was in the monasteries that the crayfish started its culinary progress through North- and Northwest European countries. Monks and nuns had, as you all know, a lot of worries concerning the menus during the many and long periods of fasting, and they hunted high and low for substitutes for the meat they were denied by theology. All kinds of fish were allowed, so they were anxious to create a fish concept that was as large as possible. Consequently the church liberally and without zoological hesitation declared that, among other, beavers, seals and whales and also decapods were fishes, because they thrived in water. Especially during the long Easter lent they gorged on crayfish in the monasteries. From a Bavarian monastery comes a report that they devoured thirty thousand crayfish yearly." He goes on to say, "From the monasteries the eating of crayfish rapidly spread to wider circles in medieval Germany. In the fifteenth century crayfish dishes were a very common element in an upper class dinner, and the oldest German cookery books have a lot of crayfish recipes. And so the foundations were laid also for the Scandinavian interest in crayfish as food." He also states that there is a notice about crayfish eating as early as the 10th C, but it has not proved possible to substantiate this as the author has not responded to our requests for information.

No information is available for crayfish in Welsh waters prior to 1500, but on the English-Welsh border there may be historic links between monastic establishments and the somewhat fragmented distribution of *A. pallipes* (infilled later by the actions of 19th C aristocrats) (Howells and Slater 2004, Slater 2009, pers. comm.). The historic distribution on the River Ithon (a tributary of the R. Wye) links with the Cistercian Abbey at Abbeycwmhir (estab. 1143); populations around Brecon centre radiate from Christ College, which was a Dominican Friary from the 1200s; the Monnow tributaries with some of the best extant populations are in the valleys of Llanthony Priory (estab. 1118) and Crasswall Priory established in the 1200s (Slater 2009, pers. comm.). Crayfish were apparently so abundant in the R. Usk that until the mid-20th C, Christ College held annual crayfish parties (Slater 2009, pers. comm.). There have been several recorded introductions into Welsh rivers, the earliest was in 1800 into the River Irfon (Slater 2002).

Pitre (1993) states that, "In England, crawfish are mentioned in literary works, religious texts, and even household account books recording their purchase as early as the 1400s." Serjeantson and Woolgar (2006) state that "crevice" and "creye" are referred to in the household accounts of the Countess of Pembroke and Duchess of Brittany in the 13th and 14th Cs. Woolgar, in a chapter on seafood and late medieval diet in Starkey *et al*. (2000), states that "Joan Holand, Duchess of Britanny, at Castle Rising, Norfolk, had crayfish on two days in February and two in October 1378". Hartley (1954) quotes a recipe from 1400, unfortunately without giving the reference: "A crews – dyght him thus – dearte hym a sonder, and slyt the belly and take out y fysshe, pare away the reed skynne and mynnce it thynne – put vynegre in the dysshe and set it on ye table without hete." Austin (c.1430) gives an English fish recipe including "fenne haddok, creuej, perchys, tenchej".

There are several references to crayfish being consumed by various blue-bloods at the British-history website (http://www.british-history.ac.uk/report.aspx?compid=91235), e.g. Henry VIII, which specifically mentions "creves" among a vast list of items being feasted upon in 1514.

A panel in the Corinium Museum, Cirencester lists items from the wedding feast menu of Jean du Chesne in 1394 and includes under "Entremets" crayfish in jelly and loach fish, describing these as fairly typical of an upper middle class meal:
(http://www.cotswold.gov.uk/nqcontent.cfm?a id=2679 &tt=cotswold#FOOD_AND_DRINK).

Some of these sources may be referring to marine, rather than freshwater crayfish. However, under the section on freshwater crayfish (*Astacus fluviatilis*) the Oxford English Dictionary (1933) gives John Russell's *The Boke of Nurture*, *folowyng Engondis gise* c. 1460 as the earliest reference to "crevis dewe deuz", a transliteration of the French "crevisse d'eau douce". This distinguishes the freshwater crayfish from possible marine Crustacea used in other recipes and provides good evidence of the presence of *A. pallipes* in England prior to 1500 AD.

ARCHAEOLOGICAL EVIDENCE

A supposed 16^{th} C or 17^{th} C ceramic crayfish trap recovered from sediments in the R. Waveney is housed in Norwich Castle Museum (Jennings 1992)

DISCUSSION AND CONCLUSIONS

Europe has an impoverished indigenous crayfish fauna with only five out of nearly 600 species world-wide (Holdich 2002a, Souty-Grosset et al. 2006). In Europe, the three indigenous species *Astacus astacus*, *Austropotamobius pallipes* and *Austropotamobius torrentium* are listed as Vulnerable in 1996 by the IUCN in their global Red List of Threatened Species (Baillie and Groombridge 1996). *Austropotamobius pallipes* was listed as such because of continuing decline and extreme fluctuations in its area of occupancy and in the number of mature individuals. These assessments still stand at present (IUCN 2009), although with the caveat "needs updating" as they were produced using now out-dated guidance (IUCN 1994). A new assessment of the red list status of crayfish species is being undertaken by the IUCN, using its most recently published global threat criteria (IUCN 2001) (Holdich et al. 2009)..

National Red Lists are authorized by relevant authorities in individual countries; in Britain this is the responsibility of the Joint Nature Conservation Committee. The IUCN has recently produced *Guidelines for Application of IUCN Red List Criteria at Regional Levels* (IUCN 2003) for use in this process. The guidelines state that "the categorisation process should only be applied to wild populations inside their natural range, and to populations resulting from benign introductions." (A benign introduction is defined as "An attempt to establish a taxon, for the purpose of conservation, outside its recorded distribution but within an appropriate habitat and ecogeographical area.")

Austropotamobius pallipes is not currently red listed in Britain because the British red list of invertebrates other than insects (Bratton 1991) was drawn up before the IUCN produced its recent series of guidelines (IUCN 1994, 2001, 2003), which introduced a stringently quantitative approach to assessing risk of extinction and laid strong emphasis on rate of decline. Before that, red listing in Britain relied heavily on counts of 10 x 10 km square records. However, Bratton (1991) comments "*A. pallipes* is not considered to fall within the bounds of any Red Data Book category at present, but the contraction of its range currently occurring is obviously of great concern." British red lists have recently been updated for plants (e.g. Cheffings and Farrell 2005) using the latest IUCN guidance and red lists for some insect groups have been published or are in the pipeline. Only indigenous species are considered when British red lists are drawn up, but this term has come to include archaeophytes – non-indigenous plant taxa that became established in Britain before AD 1500 (Preston et al. 2004). The same cut-off date for regarding a species as indigenous has been adopted by the IUCN for pan-European threat assessments.

Austropotamobius pallipes is protected throughout Britain against taking from the wild and sale, through listing on Schedule 5 of the Wildlife and Countryside Act 1981. It is also a priority species under the UK Biodiversity Action Plan, drawn up in response to the 1992 UN Convention on Biological Diversity. *Austropotamobius pallipes* is listed on Appendix III of the Bern Convention and on Annexes II and V of the Habitats Directive (Directive

92//43/EEC). Appendix III of the Bern Convention and Annex V of the Directive require management of exploitation and taking from the wild, where this is considered necessary. Annex II species are species of “Community interest” whose conservation requires the designation of protected areas (Special Areas of Conservation) (Article 3). The Directive (Article 4) stipulates that “each Member State shall propose a list of sites indicating which species in Annex II that are native to its territory the sites host.” A suite of SACs has been designated in the UK for *A. pallipes* (www.jncc.gov.uk).

The Natural Environment and Rural Communities (NERC) Act, which came into force in 2006, requires the Government to publish lists of habitats and species of principal importance for the conservation of biodiversity in England and Wales. These lists (based on the UK Biodiversity Action Plan priority list) are to be used to guide decision makers and public bodies in implementing their duty "to have regard to the conservation of biodiversity" when carrying out their functions. *Austropotamobius pallipes* is included on the “NERC lists” for both England and Wales.

Effort and resources for species conservation in Britain have invariably been directed towards indigenous species. Non-indigenous species have a bad reputation, especially those such as *Pacifastacus leniusculus* that are invasive and damaging to our indigenous wildlife, so they often attract resources for their control or extermination. The introduction of an Order (“The prohibition of Keeping of Live Fish (Crayfish) Order 1996”), under the Import of Live Fish Act, of “no-go” areas for keeping live non-indigenous crayfish (Scott 2000) was largely a response to the need to conserve our “native” crayfish species. The indigenous status of *A. pallipes* has not generally been questioned by British conservationists and its current high profile has resulted in considerable efforts being made to conserve it. However, results of the last Biodiversity Action reporting round suggest that populations are continuing to decline. The 2002 BAP report gave a figure of 260 occupied 10 km squares, but the figure for 2008 was 239 – an 8% decline (www.ukbap-reporting.org.uk) (see also Holdich and Sibley this volume). If *A. pallipes* should come to be regarded as non-indigenous, the momentum for its conservation might be in danger of stalling. This is despite the argument that Britain has a responsibility for conserving a species that is threatened in Europe, even if it is a relatively recent immigrant to this country. The authors therefore felt it necessary to search for evidence of the presence of *A. pallipes* in Britain prior to 1500 AD.

Evidence from the palaeontology record and from genetic studies for the presence of *A. pallipes* in Britain before 1500 is inconclusive. However, there is strong evidence from historical documents and medieval recipes that *A. pallipes* has for centuries been regarded as a valued food resource in Britain. There are compelling accounts of the presence of thriving wild populations of *A. pallipes* in England in the mid 16th C by Holinshed (1587) and Camden (1586), also a reference in The Oxford English Dictionary (1933) to a 15th C recipe for freshwater crayfish. The authors conclude that there is sufficient evidence to indicate that *A. pallipes* was established in the wild in Britain prior to 1500 and that for the purposes of red listing and conservation this species should be regarded as indigenous. This view has now been formally recognised by the IUCN (Dewhurst 2009, pers. comm.).

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ICS and NICS in Britain in the 2000s

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ABSTRACT

From having one crayfish species living in the wild in the 1960s Britain now has seven, only one of which is indigenous, and its future is in doubt. In addition, one Australian species is legally available through the aquarium trade. Four of the introduced crayfish originate from North America, and three are proven carriers of crayfish plague. Comparative details are given of the eight species along with photographs of living specimens. In addition, potential introductions such as the marbled crayfish are discussed. The current distribution of the species is discussed with particular emphasis on those present in South-west England, which along with some other regions of Britain, has suffered a dramatic decline in the number of indigenous crayfish populations in the last few decades.

Keywords: crayfish, indigenous, non-indigenous, comparisons, distribution, Britain, future

INTRODUCTION

The five indigenous crayfish species (ICS) in Europe (Souty-Grosset et al. 2006) are threatened by a variety of factors including overfishing, poaching, predation, habitat change, pollution, North American crayfish and crayfish plague. Three of the European ICS, *Astacus astacus* (Linnaeus), *Austropotamobius pallipes* (Lereboullet) and *Austropotamobius torrentium* (Shrank), are listed as Vulnerable by the IUCN in 1996 (Baillie and Groombridge1996) and are still listed as such in 2009 (IUCN 2009); however, the listings may change in the near future (Holdich et al. this volume, Holdich et al. 2009). The main threats to the single ICS (*A. pallipes*) in Britain are from non-indigenous crayfish species (NICS) and crayfish plague (Holdich et al. 2004).

Since the 1960s seven NICS have been deliberately introduced into Britain for various purposes, i.e. fish markets, restaurant trade, aquaculture, aquarium trade, and probably by anglers either for bait or as supplemental food for fish stocks (Peay et al. 2010). In recent years the number of 10 km squares occupied by six of these NICS has overtaken that occupied by *A. pallipes* (Sibley 2003a) and continues to increase (www.ukbap-reporting.org.uk). Crayfish plague outbreaks continue to decimate populations and thus add to the decline of *A. pallipes*. This is despite some of the most stringent crayfish legislation in Europe (Holdich and Pöckl 2005). Predictions are that *A. pallipes* may become extinct by 2034 unless something is done to protect it (Sibley 2003a, Holdich et al. 2004). However, whilst the emphasis has been on the impact of the signal crayfish *Pacifastacus leniusculus* (Dana) on *A. pallipes* it must be borne in mind that there are five other NICS in Britain that could also be a threat to its survival. Risk assessments have recently been carried out for *A. astacus* and *Astacus leptodactylus* Eschscholtz, which despite being ICS in mainland Europe are considered NICS in Britain; and the North American species *P. leniusculus*, *Procambarus clarkii* (Girard) and *Orconectes limosus* (Rafinesque), but not yet for

Orconectes virilis (Hagen), as part of the UK strategy for non-indigenous species (Defra 2008, Peay et al. 2010). A seventh NICS, *Cherax quadricarinatus* (von Martens), can legally be kept in aquaria, except in Scotland, but no risk assessment has been carried out for it. A risk assessment has recently been commissioned for *Procambarus* sp., the marbled crayfish, which, due to it parthenogenetic nature (Scholtz et al. 2003), could pose a major threat if it became established in British waters. This unique species of crayfish is popular amongst aquarists and is widely available via the internet (Marmorkrebs 2009).

Since the publication by Sibley (2003a), and collation of distributional data for the CRAYNET atlas (Souty-Grosset et al. 2006), nothing detailed has been published on the national distribution of ICS and NICS in Britain, although the NBN database (www.searchnbn.net) is available for scrutiny. The latter is a useful tool for charting the spread of NICS but, without frequent revision it can give a false impression of the distribution of the ICS in a rapidly changing landscape.

The aim of this paper is to provide comparative details of the biology and characteristics of the eight species of crayfish in Britain, to highlight potential introductions, and to discuss the distribution of ICS and NICS, particularly the on-going situation in SW England where a strategic effort to conserve *A. pallipes* in the region is currently underway.

CRAYFISH IN BRITAIN

Details of the legislation covering crayfish in Britain can be found in Holdich and Rogers (1992), Rogers and Holdich (1997), Scott (2000), Stewart (2000), Sibley (2003b), Holdich et al. (2004), Holdich and Pöckl (2005) and Bean et al. (2006), but a brief summary of that relating to NICS is given below.

Under Schedule 14 (1) of the Wildlife and Countryside Act (WCA) it is an offence (except under licence) to release, into the wild animals, that are either "not ordinarily resident" or have been listed as pest species on Schedule 9 of the Act (HMSO 1981). Section 14 covers all of the NICS in Britain, three of which were added to Schedule 9 of the WCA in 1992 (HMSO 1992) and another two in 2009 (Department of Environment, Fisheries and Rural Affairs - Defra 2009) (see below). In 1996 a "Crayfish Order" and "no-go" areas were introduced by the Ministry of Agriculture, Fisheries and Food (MAFF 1996). The "Crayfish Order" made it an offence to keep NICS anywhere in England and Wales without a licence ("no-go" areas), with the exception that *P. leniusculus* could be kept without a licence in designated areas, mainly in the south of England where it was already widespread, and on crayfish farms that were already established. NICS can also be kept for human consumption in England and Wales, and *C. quadricarinatus* can be kept in heated, indoor aquaria. However, no live NICS can be kept in Scotland even for the purposes of human consumption. The MAFF "Crayfish Order" and "no-go" areas are currently under review by Defra. It is perhaps worthy of note that the use of traps for catching all crayfish species in England and Wales is regulated and consent is required from the Environment Agency, although in many EA Areas requests are only granted in special circumstances.

Various aspects of the biology, characteristics and legislation of crayfish in Britain are summarized under 10 headings below for easy comparison: 1. Origins; 2. European distribution; 3 Generalized distribution in Britain; 4. Characteristics; 5. Biology; 6. Disease; 7. Legislation; 8. Risk to *A. pallipes*; 9. Impacts; and 10. Control. Details of crayfish morphology and a guide to identifying crayfish in British waters are given in Holdich (this volume).

Occurrences in European countries are based on a recent survey (Holdich et al. 2009) and are an update on figures given in the crayfish atlas (Souty-Grosset et al. 2006). Detailed keys for distinguishing between ICS and NICS in Europe can be found in Pöckl et al. (2006) and Souty-Grosset et al. (2006) – some characters that may cause confusion or help in identification are highlighted below.

***Austropotamobius pallipes* (white-clawed crayfish). (Astacidae).** (Fig. 1).

1. The indigenous crayfish species in England and Wales, although it was probably introduced from France prior to 1500 AD (see Holdich et al. this volume); also introduced into Scotland but more recently (see Gladman et al. this volume).
2. Widespread distribution in Europe - currently recorded from 17 territories, including the island of Corsica where it has been introduced. It is thought to now be extinct in Portugal.
3. Widespread but scattered distribution in England, sparse in Wales; range decreasing due to habitat changes, and the impact of NICS and crayfish plague. Two introduced populations in Scotland.
4. Characterized by whitish (occasionally pinkish) underside to claws, rough dorsal surface to claws, no prominent spur on inner medial margin of chelar carpus **(a small spur may occur on inner distal margin, particularly in juveniles)**, broad-based rostrum with mat of fine hairs on surface, single pair of post-orbital ridges on carapace, row of small sharp spines on shoulder of carapace behind cervical groove (**can be felt by rubbing finger over surface; useful for distinguishing from *P. leniusculus*, which has a smooth carapace**). Body colour is variable, but usually brown to olive green, occasionally blue specimens have been recorded.
5. Slow individual and population growth, low fecundity, small to medium adult body size (usually less than 12 cm total body length). Inhabits lakes, rivers, streams and canals. Occasional burrower.
6. Highly susceptible to crayfish plague caused by the fungus-like organism *Aphanomyces astaci* Schikora. Mortalities have been a regular occurrence since the early 1980s. Porcelain disease caused by *Thelohania contejeani* Henneguy affects many populations.
7. Added to Schedule 5 of the WCA 1981 in 1986, but only protected from “taking” and “sale”. Natural England licence needed for specific sampling and photographing. Environment Agency consent needed for trapping. Also protected under EU legislation (see references above). See below for the establishment of “ark” sites.
8. N/A
9. As a large polytrophic component of the freshwater environment *A. pallipes* can be considered as a key species where it occurs. Its addition or removal may upset the ecological balance in the short term although it would appear by nature far less aggressive than its non-indigenous counterparts. In suitable substrates it will burrow into the banks of rivers, streams and even lakes. Some complaints from anglers about interference with bait and keep-nets.
10. None practised in Britain.

Comments: despite the dramatic decline of *A. pallipes* in England and Wales some very large populations still exist, e.g. Lewis and Morris (2008) reported that over 20 000 individuals became stranded in a field after a river flooded in the north of England. The incidence of porcelain disease in populations can be high (Imhoff et al. this volume) but rarely leads to their extinction, unlike crayfish plague. The range of habitats occupied by *A. pallipes* is varied (Holdich 1993), but until recently it was not thought that they occupied muddy habitats. However, Holdich and Rogers (2000), Holdich et al. (2006) and Peay et al. (2006b) have shown that they can be abundant in such habitats. Significant efforts are currently underway to set up new isolated populations in protected sites termed “arks” as a means of conserving *A. pallipes* (see below, and Kindemba and Whitehouse, Nightingale, and Peay this volume). See below for further comments on its distribution.

***Astacus astacus* (noble crayfish). (Astacidae).** (Fig. 2).

1. Introduced from Germany into SW England in the early 1980s for aquaculture purposes.
2. Widespread in Europe – currently recorded from 39 territories.
3. Distribution currently confined to a reservoir and local streams in South-west England.
4. Characterized by **dull red underside to claws** and **serrated profile to end of rostrum**, no prominent spur on inner medial margin of chelar carpus, two pairs of post-orbital ridges on carapace, spines on shoulder of carapace behind cervical groove. May be confused with specimens of *P. leniusculus*, but has spines on shoulder of carapace and lacks the white-turquoise patch on the upper side of the chela. Body colour various shades of brown, beige, brilliant red, occasionally blue.
5. Slow individual and population growth, medium fecundity, reaches large body size (≥15 cm body length). Occasional burrower. Inhabits a reservoir and streams in Britain.
6. Susceptible to crayfish plague. Mortalities in mainland Europe occurring on a regular basis, often mediated by the transfer of spores other than by *P. leniusculus*, e.g. human activities.
7. Added to Schedule 9 of the WCA in 1992.
8. Risk Assessment carried out; potential impact on *A. pallipes* considered low.
9. None recorded in Britain.
10. None practised in Britain.

Comments: surprisingly for such a commercially valuable species (Skurdal and Taugbøl 2002), *A. astacus* has not been intentionally spread in Britain; neither has it spread naturally very far from its original site in the Mendip Hills (Holdich et al. 1995a). The risk to *A. pallipes* from *A. astacus* in Britain is considered low, although if mixed populations were to develop *A. astacus* might dominate. However, in Germany it does co-exist with *A. torrentium*, which is of a similar size to *A. pallipes* (Holdich 1998, pers. obs). In Finland it has been recorded as co-existing in a lake with *P. leniusculus* over many years (Westman et al. 2002). In culture ponds at least it can do substantial damage to the banks due to its burrowing (Keller 1999).

***Astacus leptodactylus* (narrow-clawed crayfish). (Astacidae).** (Fig. 3).

1. Originating from the Ponto-Caspian region and has spread naturally and via human-mediated means into much of Europe. Introduced into Britain for culinary purposes since the 1960s.
2. Widespread in Europe and the Near East - currently recorded from 32 territories.
3. Widespread in England in lakes, ponds, quarries, and some rivers, streams and canals.
4. Characterized by **long, narrow claws** in adults; no prominent spur on inner medial margin of carpus of chela, **but prominent spur may occur inner distal margin** (this can cause confusion when trying to separate specimens from members of the Cambaridae, which have a prominent spur on the inner medial margin); carapace rough and spiny with two pairs of post-orbital ridges. Body colour variable from sandy yellow to dark green, usually with **mottled background** in paler specimens, occasionally blue; leg joints often orange.
5. Rapid individual and population growth, high fecundity, large adult body size (≥16 cm), invasive. Inhabits lakes, ponds, rivers, streams and canals.
6. Susceptible to crayfish plague.
7. Added to Schedule 9 of the WCA in 1992.
8. Risk Assessment carried out; risk to *A. pallipes* in Britain considered low.
9. None recorded in Britain.
10. None practised in Britain.

Comments: *Astacus leptodactylus* is a commercially valuable species throughout Europe (Skurdal and Taugbøl 2002). According to Wickins (1982) some 50 tonnes per annum of this species were being imported through London's Billingsgate Fish Market in the 1970s from where they were distributed to other fish markets. Opportunities for escape into the wild from such markets would have been (and still are) quite possible and may have given rise to populations such as that in the Serpentine Lake in Hyde Park via underground waterways (Holdich et al. 1995a). There are also records of stock been dumped into waterbodies when transporters broke down, e.g. Aldenham Reservoir (R Colne in R Thames catchment), whence large populations have developed there and in connected waters (Holdich et al. 1995a). Wild populations are being harvested (Rogers and Holdich 1995), some of which is exported, but there is no record of the current amount. Live *A. leptodactylus* have recently been seen on sale in fish markets as far apart as Cornwall and Scotland (Collen 2008, pers. comm.). In both cases the specimens allegedly came from France. *Astacus leptodactylus* is a very adaptable and tolerant species (Skurdal and Taugbøl 2002), and can build up large populations very quickly in suitable waters. It can tolerate a range of environmental conditions even those which are saline (Holdich et al. 1997), although it has yet to penetrate estuaries in Britain. If *P. leniusculus* can occupy waters unsuitable for *A. pallipes* as in SW England and Scotland (see below), then *A. leptodactylus* should also be able to do so. A new riverine population was discovered in Leicestershire in 2008, its source probably being a fish pond containing a large stock of *A. leptodactylus*, which according to the owner had appeared in the pond at least 15 years previously (Holdich 2008, pers. obs.).

There have been a number of recent mortalities in Eastern England (R. Colne and R. Waveney), which have been proven to have been caused by crayfish plague (Environment Agency 2007). Populations are declining in some East European countries due to impact of NICS and crayfish plague (Holdich et al. 2009). However, there are indications from continental Europe and Turkey that not all individuals may be killed and that natural recovery of a population may occur suggesting there may be some resistance to the disease (Souty-Grosset et al. 2006, Harlioğlu 2008). The threat to *A. pallipes* from *A. leptodactylus* is considered low, although if mixed populations were to develop then *A. leptodactylus* would be likely to dominate (Holdich et al. 1995b).

***Pacifastacus leniusculus* (signal crayfish). (Astacidae).** (Fig. 4).

1. Originating from western North America. Introduced into Britain from Sweden in 1970s for aquaculture purposes.
2. Widespread in Europe - currently recorded from 27 territories.
3. Widely distributed in England and Wales, as well as most of the main river catchments in Scotland.
4. Characterized by smooth body surface with **absence of spines behind cervical groove**, two post-orbital ridges, **smooth robust claws with bright red underside and white-turquoise patch** at junction of fixed and moveable finger. Body colour reddish-brown or light to dark brown.
5. Rapid individual and population growth, early sexual maturity and high fecundity, large adult body size (≥15 cm), invasive. Extensive burrower. Inhabits lakes, ponds, rivers, streams and canals.
6. Known vector of crayfish plague. Also affected by porcelain disease.
7. Added to Schedule 9 of the WCA in 1992. Can be kept outside of no-go areas (for a list of areas where *P. leniusculus* may be kept without a licence (see www.defra.gov.uk/fish/freshwater/pdf/licreq.pdf).
8. Risk Assessment carried out; risk to *A. pallipes* in Britain considered very high.
9. Substantial impact on freshwater environment due to its high numbers, feeding and burrowing activity. Considerable nuisance to anglers.
10. Control by trapping and manual collection has had limited success. Trials in progress using natural biocides.

Comments: in its home range in western North America *P. leniusculus* appears to cause few environmental problems, and has not even been recorded as a burrower (Shimizu and Goldman 1983, Lewis 2002). Its introduction into other parts of the world has caused problems for the indigenous biota (Holdich 1999). In some cases it has been introduced with the specific intention of suppressing resident species, for example macrophyte control in irrigation ponds and lakes, as has been successfully attempted in France by Laurent and Vey (1986). In Britain it has built up large populations very quickly and has had a negative impact on local flora and fauna, including benthic fish, e.g. the Great Ouse in Buckinghamshire (Guan and Wiles 1996, 1997) invertebrates (Crawford et al. 2006). Established populations have been found to be capable of spreading 2.4 km yr^{-1} downstream (Bubb et al. 2005). The size of some populations can be very large, e.g. commercial trappers caught over 100 000 *P. leniusculus* from the River Lark in Suffolk in two months in 2005 (Stancliffe-Vaughan 2009). There is considerable concern that the activities of *P. leniusculus* may affect the recruitment of salmonid fish in some rivers (Griffiths et al. 2004, Peay 2009, pers. comm.). The number of commercial operations cultivating *P. leniusculus* in Britain was as high as 99 in the 1990s (Rogers and Holdich 1995), but has plummeted due to a lack of demand and the ease with they can be harvested from the wild, and in 2003 was less than five (Scott 2003, pers. comm.). Wild populations are being harvested by commercial trappers, some of which is exported, but there is no record of the current amount. It is still sold live in fish markets for human consumption across England and Wales and continued opportunities for escape into the wild therefore exist within and outside of no-go areas. Fresh frozen and cooked *P. leniusculus* can also be obtained over the internet; the cooked product being of a similar price to that of lobsters (www.TheFishSociety.co.uk). In England some populations of *A. pallipes* have existed downstream of *P. leniusculus* populations for many years, suggesting that the latter do not harbour crayfish plague. However, in many other instances *P. leniusculus* has been proven to be its vector since, including in Britain (Alderman et al. 1990). A recent study in the Czech Republic, however, found that a very low percentage of *P. leniusculus* carried crayfish plague (Kozubíková et al. 2009). Dunn et al. (2009) and Imhoff et al. (this volume) have shown that *P. leniusculus* may be affected by porcelain disease in Britain, but they could find no evidence of crayfish plague in 15 specimens tested.

The risk to *A. pallipes* from *P. leniusculus* in Britain is considered very high (Peay et al. 2010), and it is known that in mixed populations the former is likely to be eliminated by crayfish plague or competition (Holdich and Domaniewsky 1995, Holdich et al.1995b, Bubb et al. 2006, Dunn et al. 2009). In SW England *P. leniusculus* is gradually pushing out *A. pallipes* as well as occupying habitats not suitable for the latter (see below). In Scotland, *P. leniusculus* is now known from more than 20 sites in 15 river catchments and is spreading into most of the main river catchments – waters that will not have experienced such an aggressive predator before (Freeman et al. 2009, Gladman et al. this volume). Peay and Hiley (2004) have shown that the presence of *P. leniusculus* in waters used by coarse fish anglers can lead to complaints and, in some cases, abandonment of angling altogether. As mentioned above the potential impact the species could have on salmonid spawning gravels is also a worry to stakeholders in key salmon and trout fisheries. Peay et al. (2006a) have been carrying out trials using natural pyrethrins to try and eliminate nuisance populations in England and Scotland. Whilst they have met with some success, it is likely that costs for the chemical and employing manpower, as well as legislative problems, will prohibit its widespread use. Guan (1994) and Sibley (2000) have shown that the burrowing activity of *P. leniusculus* can have a considerable impact on river banks, and Holdich et al. (1995) showed this also to be the case for ponds. It has been estimated that in some stretches the banks of the River Lark in Suffolk are being eroded by 1 m yr^{-1} due the burrowing activity of *P. leniusculus* (Stancliffe-Vaughan 2009). This species is very tolerant of different environmental conditions, even those which are saline (Holdich et al. 1997), although it has yet to penetrate estuaries in Britain. See below for further comments on its distribution.

***Procambarus clarkii* (red swamp crayfish) (Cambaridae).** (Fig. 5).

1. Originating from the southern USA.
2. Widespread in Europe – currently recorded from 15 territories, including five large islands, i.e. São Miguel (Azores), Majorca, Sardinia, Sicily and Tenerife.
3. Introduced into Britain for the culinary trade in the 1980s. Limited wild distribution in Britain.
4. Characterized by **red, sinuous claws**, which are covered dorsally in **tubercles**. **Areola between branchiocardiac grooves absent**. Body colour dark red, orange or reddish-brown, but olive-green to brown when young.
5. Rapid individual and population growth, early sexual maturity and high fecundity, medium adult body size (≥10 cm), invasive, extensive burrower.
6. Known vector of crayfish plague.
7. Recently added to Schedule 9 of the WCA (Defra 2009).
8. Risk Assessment carried out; risk to *A. pallipes* in Britain considered high if the species were to spread.
9. None yet reported for Britain but could have a substantial impact on freshwater environment due to its high numbers, feeding and burrowing activity.
10. None practised in Britain.

Comments: *Procambarus clarkii* is a commercially valuable species throughout Europe, USA and parts of Asia (Huner 2002). Its spread into northerly latitudes is restricted by low temperatures but any increases due to global warming may enable it to increase its range. In Britain *P. clarkii* has been present in Hampstead Heath ponds since 1991. It is thought that the populations developed from individuals released by a local restaurant owner (Holdich et al. 1995). Ellis and England (2008) found them in four lakes on the heath and also in Regents Canal adjacent to London Zoo. This species is popular in the aquarium trade as well as being used for aquaculture purposes in mainland Europe (Huner 2002). Its spread from its introduction point in southern Spain in 1973 has been rapid, mainly due to translocations by humans. It has had a negative impact on the environment particularly in Mediterranean countries where it has had an effect at all trophic levels due to its large numbers and feeding and burrowing habits (Rodriguez et al. 2003, 2005). It currently has a restricted distribution in Britain, but should it spread into wetlands it could have a dramatic impact on the ecology (Peay et al. 2010).

***Orconectes limosus* (spiny-cheek crayfish) (Cambaridae).** (Fig. 6).

1. Originating from the eastern USA.
2. Widespread in Europe - occurring in 21 territories.
3. Known from three lacustrine sites and one riverine site in England.
4. Characterized by **spiny sides to anterior carapace** and **horizontal reddish brown stripes across tail segments**. Body colour pale or dark brown to olive-green; may appear black from some lacustrine sites with dark sediments.
5. Rapid individual and population growth, early sexual maturity and high fecundity, medium adult body size (≥12 cm), invasive, burrower.
6. Known vector of crayfish plague.
7. Recently added to Schedule 9 of the WCA (Defra 2009).
8. Risk Assessment carried out; risk to *A. pallipes* in Britain considered high if species were to spread.
9. None yet reported for Britain but could have a substantial impact on freshwater environment due to its high numbers, feeding and burrowing activity.
10. None practiced in Britain, but biocides have been used in France to try and eliminate it.

Comments: *Orconectes limosus* was the first NICS to be introduced into Europe in 1890 (Souty-Grosset et al. 2006). Its range in Europe is still being extended, both naturally and via introductions. It is not such a commercially valuable species as other North American crayfish introduced into Europe (Hamr 2002). It has recently been recorded as spreading down the River Danube in Romania towards the Black Sea (Pârvulescu et al. 2009).

Holdich and Black (2007) studied a population in a gravel pit in Nottinghamshire, which had been introduced by an angler. A large population had developed in the pit within a relatively short time. Another population exists in fish ponds in Lincolnshire, and another in a catfish pond and adjacent river in Worcestershire, where they may possibly have been used as bait. Kozubíková et al. (2009) found that a high percentage, but not all individuals, of *O. limosus* carried crayfish plague in the Czech Republic, and were responsible for recent mortalities of indigenous species. However, in Lake Constance (Germany) *O. limosus* co-exists with *A. leptodactylus* (Hirsch 2009a), as it does in many other lakes southern Germany (Hirsch 2009b, pers. comm.).

Orconectes virilis **(virile crayfish) (Cambaridae).** (Fig. 7).

1. Originating from North America.
2. Known only from England and The Netherlands in Europe.
3. Currently only known from the River Lee catchment in North London.
4. Characterized by **broad, flattened claws**, which are bordered by **pale-coloured prominent tubercles**. Body colour usually brown.
5. Rapid individual and population growth, early sexual maturity and high fecundity, medium adult body size (≥12 cm total length), invasive.
6. Probable vector of crayfish plague.
7. Not yet considered for inclusion on Schedule 9 of the WCA by Defra.
8. Risk Assessment not carried out; but risk to *A. pallipes* in Britain considered high if species were to spread.
9. None yet recorded for Britain, although in The Netherlands it is having a negative impact on the freshwater environment.
10. None practiced in Britain.

Comments: *Orconectes virilis* is mainly harvested from wild populations in North America (Hamr 2002). Unsuccessful attempts were made to introduce it into France (1897) and Sweden (1960). However, the origin of the current populations in Europe is unknown. Filipová et al. (2009) studied the molecular genetics of specimens from England (R. Lee) and The Netherlands, finding them to be of the same lineage, but different from American specimens analysed.

Orconectes virilis was originally identified as *O. limosus* from a pond in Enfield and the River Lee in North London in 2004 (see Holdich and Black 2007). This error was only recently discovered by Ahern et al. (2008) who re-identified it as *O. virilis*, and recorded it in watercourses adjacent to the pond within a 7 km radius, a dispersal rate of more than 2 km a year. It is thought that the original population was derived from the dumping of the contents of an aquarium. Apparently, although densities are fairly low, this species is still spreading downstream in the Lee Navigation and connecting streams and ditches (Ellis 2009a, pers. comm.). The only other record for *O. virilis* in Europe is from The Netherlands (Souty-Grosset et al. 2006). The first record there was for 2004, but it is thought to have been present before that as it was already widespread. It is now known from numerous sites and had colonized several hundred kilometres of waterway by 2006 (Koese and Blokland 2008, Soes 2008a, pers. comm.). In some sites it has displaced *O. limosus*, although the opposite has occurred in some parts of North America (Hamr 2002). It is thought to be having a negative impact on the freshwater environment in The Netherlands (Soes 2008a, pers. comm.).

Cherax quadricarinatus **(redclaw). (Parastacidae).** (Fig. 8).

1. Indigenous to northern and north-eastern Australia, but has been introduced into Asia, the Americas, Africa and some tropical islands for commercial purposes.
2. Common in the aquarium trade in Europe, including Britain. Cultivated in Italy.
3. Common in the aquarium trade as "Blue lobsters".

4. **Characterized by red patch on outer margin of claw in males. Inner margin of claw longer than moveable finger, whereas in members of the Astacidae and Cambaridae, it is shorter.** Body smooth**.** Antennae and claws very long in adult males. Body colour usually blue, mottled with beige, and red.
5. Rapid individual growth, early sexual maturity and high fecundity, large adult body size (≥35 cm total length).
6. Susceptible to crayfish plague.
7. Can legally be imported and kept for aquarium purposes (but is still subject to Section 14 of the Wildlife & Countryside Act), but not in Scotland.
8. Risk Assessment not carried out; but risk to *A. pallipes* in Britain considered low if species were to become established in the wild.
9. None recorded.
10. None practiced in Britain.

Comments: *Cherax quadricarinatus* was not recorded from the wild in any European country in the crayfish atlas. This tropical Australian species is cultured extensively in Australia and elsewhere (Lawrence and Jones 2002), and is popular in the aquarium trade in Europe. It is the only crayfish legally allowed into Britain from outside Europe (Scott 2000, Holdich et al. 2004). There have been reports from England (Peay 2009, pers. comm.).) and The Netherlands (Soes 2008b) of individual specimens being found in the wild, presumably having been dumped by hobbyists, although in both cases they were dead. However, anglers also reported seeing live specimens at one site in England (Peay 2009, pers. comm.). There has been a report of a breeding population in a pond in northern Germany (Lukhaup 2007, pers. comm.), but no further details have been forthcoming.

POTENTIAL INTRODUCTIONS

In addition to the NICS outlined above there are a number of other species present in the wild in Europe that could be brought illegally into Britain. Also, many American and Australian species are available through the aquarium trade and via the internet and could be purchased by hobbyists in mainland Europe and brought back illegally to Britain.

North American crayfish listed in the atlas for the wild in mainland Europe, but not yet present in Britain, include: *Procambarus* sp. (the parthenogenetic marbled crayfish or marmorkrebs – see below), also common in the aquarium trade; and *Orconectes immunis* (Hagen) (the calico crayfish), also common in the aquarium trade; and from Australia, *Cherax destructor* Clarke (yabby) (Souty-Grosset et al. 2006). *Orconectes rusticus* (Girard) was listed in the atlas as being present in mainland Europe, but this has since proved to be the closely-related *O. juvenilis* (Hagen) (no common name) (Chucholl and Daudey 2008). In addition, since the atlas was produced it has come to light that another North America crayfish *Procambarus acutus* (Girard) (the white river crayfish) is present in the wild in The Netherlands (Koese and Blokland 2008).

Procambarus sp. (Fig. 9) is currently only known from a small number of sites in three European countries (Italy, Germany and The Netherlands), but it is widely available through the aquarium trade and on the internet and is a popular pet in many countries in mainland Europe as well as in other parts of the world. An attempt (Brickland 2009, pers. comm.) to purchase some from Germany over the internet proved only too easy, although it was not followed through. Outside of Europe it has been imported into Madagascar where it is sold in fish markets and has been found extensively in the wild. It is thought that it poses a serious threat to other freshwater biota, including indigenous crayfish species, and may also impact on fishing and rice culture (Jones et al. 2009). Although specimens tested from Madagascar proved negative for crayfish plague, it has recently been shown that it is capable of harbouring this disease in Europe (Environment News Service 2008). In addition, due to its parthenogenetic properties it is being highlighted as a useful laboratory animal (Vogt 2008). *Procambarus* sp. has been recorded from England, e.g. when a hobbyist tried to offload some at a pet shop because they were multiplying too fast; however, it is not known where they were obtained from (Scott 2007, pers. comm.). Warnings have been given in at least one trade magazine, e.g. Practical Fishkeeping (2007) about the illegality of keeping this species in Britain. It is characterized by small chelipeds and a marbled appearance (Fig. 9) on a brownish, dark-brown, green or blue background (Pöckl et al. 2006, Souty-Grosset et al. 2006).

Many species of crayfish from the Americas and Australia are advertised for sale in certain aquarist catalogues in Europe, e.g. *Procambarus alleni*, *P. clarkii*, *P.* sp., *P. spiculifer*, *P. toltecae*, *Orconectes durelli*, *O. luteus*, *Cambarus coosae*, *C. manningi*, *C. rusticiformis*, *C. speciosus*, *Cambarellus chapalanus C.* montezumae, *C. patzcuarensis*, *C. puer*, *C. shufeldtii*, *Cherax destructor*, *C. holthuisi*, *C. lorentzi*, *C. quadricarinatus*, and *Cherax* spp. of various colour varieties. Crayfish species are regularly intercepted by UK Customs service at port of entry. Some 31 consignments of non-indigenous crayfish illegally imported as tropical ornamentals were intercepted between 1996 and 2005 and destroyed (Scott 2005). Twelve species have been found as illegal imports since 1996, when all imports of crayfish for aquaria (except *Cherax quadricarinatus*) were banned (Peay et al. 2010).

CURRENT DISTRIBUTION OF ICS AND NICS IN BRITAIN

The distribution of *A. pallipes* in Scotland is restricted to two introduced populations; populations in Wales are widespread but sparse; there are widely distributed abundant populations in northern England, including a few catchments with no NICS, and scattered populations in southern and central England (Peay et al. 2010). However, the situation is dynamic and there is an ongoing loss in most catchments, except upstream of major barriers, mainly due to the impact of *P. leniusculus* and crayfish plague. In a few decades *A. pallipes* is likely to become absent in southern England, except in a few isolated sites; and have a reduced range in northern England; it will also be lost from most watercourses in Wales (Peay et al. 2010). However, many new isolated populations may be set up through various conservation initiatives designed to protect the species (see below).

All the NICS introduced into Britain have become established with the exception of *C. quadricarinatus*. However, only *P. leniusculus* and *A. leptodactylus* have a widespread distribution, the others are currently restricted to small areas. Currently, *P. leniusculus* is having most impact on *A. pallipes*, but *O. limosus* and *O. virilis* possess similar characteristics, and have the potential to spread. They could cause major problems for the remaining *A. pallipes* populations in the future, although currently only *O. virilis* is spreading rapidly (Ellis 2009a, pers. comm.). There appears to be no easy way to control NICS without employing a great deal of manpower and spending a great deal of money. Any attempt will probably have to involve a combination of mechanical, chemical, physical and biological methods (Holdich et al. 1999, Stebbing et al. 2003, Ribbens and Graham 2004, Aquiloni et al. 2009).

The situation concerning *A. pallipes* is particularly critical in SW England (Sibley et al. 2009). Figure 10 shows the approximate distribution in 1975 before the introduction of NICS. Its range is wide, although somewhat restricted by unsuitable water quality and geology. Figure 11 shows the situation in 2009 following more than three decades of deliberate introductions, escapes and continued colonization. Three NICS are now present, i.e. *A. astacus*, *A. leptodactylus* and *P. leniusculus*.

Of these only *P. leniusculus* has become widespread and this has been at the expense of *A. pallipes*, mainly through outbreaks of crayfish plague since the 1980s. Since 1990-96 there has been a 28% decline in *A. pallipes* distribution by 10 km squares in SW England and an increase of 71% in NICS. However, if one looks at this from a sub-catchment point of view the decline is more dramatic. Pre-1975, 87 sub-catchments in South-west England were occupied by *A. pallipes*, but at the end of 1999, this had declined to 48, and by the end of 2008 to 26. This represents a decline by sub-catchment of 45.8% from the end of 1999 to the end of 2008, and a decline of 70.1% from 1975 to the end of 2008.

In other areas the situation is even more serious with a 95% reduction in *A. pallipes* populations at the 2 km square level in Hampshire since the 1970s (Hutchings this volume), a likely loss of >95% in the Thames EA Region since the 1970s (Ellis 2009a, pers. comm.). Four NICS occur in the sub-catchments of the Thames Basin and whereas *A. pallipes* once occurred in all the major tributaries it has only been recorded in eight of the 55 sub-catchments since 2004 (Ellis 2009b). In East and West Sussex a 100% loss of *A. pallipes* is likely since the 1970s, although a few small populations exist in Kent (Foster 2009, pers. comm.). Pugh (2008) and Pugh et al. (2008) have documented the severe decline of *A. pallipes* in Essex and Suffolk, thought mainly to be due to NICS and crayfish plague. Pugh (Dewhurst 2009, pers. comm.) has estimated a 77% decline in Eastern England over the last 30-40 years. The prediction that *A. pallipes* would disappear from all 10 km squares nationally by 2034 (Sibley 2003a) looks like becoming a reality in SW England, with a regional estimate of 2038 if *P. leniusculus* continues to spread. As in other parts of Britain the loss of *A. pallipes* populations has often been rapid and includes those of significant historic importance, including formerly re-introduced stock such as on the Bristol Avon in Wiltshire (Spink and Frayling 2000). Faced with this decline the need for a strategic approach to crayfish conservation through translocations to isolated "ark" sites has become more urgent (Peay this volume). In SW England Bristol Zoo Gardens are leading a partnership adopting such an approach at a landscape scale across the region (Nightingale et al. 2009). This builds on work undertaken by Avon Wildlife Trust and the Environment Agency and has thus far resulted in the translocation of crayfish from two threatened populations to five new ark sites (one stillwater and four streams). The first of these was set up in 2006 (Sibley *et al*., 2007) and further locations across the region are now under consideration, with pre-translocation monitoring underway at further sites in Devon, Dorset and Somerset. These newly translocated stocks have assumed real significance, representing approximately one fifth of the surviving discrete populations of *A. pallipes* in the SW region at the time of writing. Under the guidance of the invertebrate conservation trust Buglife (www.buglife.org.uk) these include a network of aggregate sites (see Kindemba and Whitehouse this volume) that will be examined using the criteria of Peay (this volume) as to their suitability for crayfish introductions. Many sites in other regions of Britain are also being considered as ark sites (Gladman et al. this volume, Peay this volume).

Figure 1. The white-clawed crayfish, *Austropotamobius pallipes*.
Figure 2. The noble crayfish, *Astacus astacus*.

Figure 3. The narrow-clawed crayfish, *Astacus leptodactylus*.
Figure 4. The signal crayfish, *Pacifastacus leniusculus*.
Figure 5. The red swamp crayfish, *Procambarus clarkii*.
Figure 6. The spiny-cheek crayfish, *Orconectes limosus*.
Figure 7. The virile crayfish, *Orconectes virilis*.
Figure 8. A male Australian redclaw, *Cherax quadricarinatus*.

Photos courtesy of Chris Lukhaup.

Figure 9. The marbled crayfish, *Procambarus* sp. (photo: C Lukhaup).

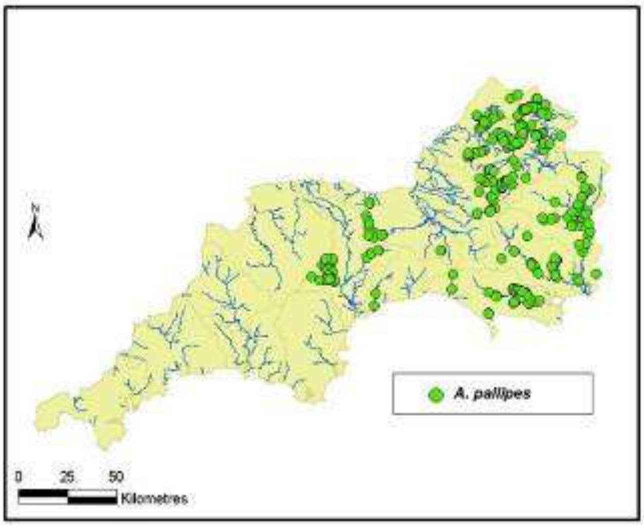

Figure 10. Approximate distribution of crayfish in South-west England in 1975.

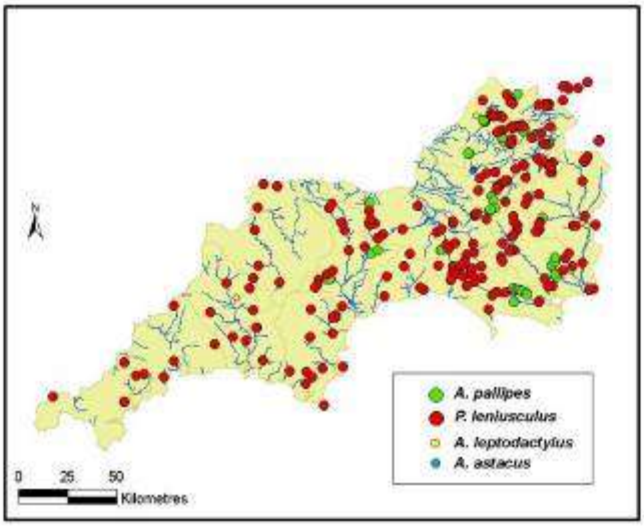

Figure 11. Approximate distribution of crayfish in South-west England in 2009.

DISCUSSION

Lindqvist and Huner (1999) highlighted fast individual and population growth and early sexual maturity and high fecundity as attributes when choosing a crayfish species for aquaculture purposes. All the NICS in Britain, even *C. quadricarinatus*, have such attributes, so it is perhaps not surprising, when coupled with their invasive tendencies, that they, with the exception of *C. quadricarinatus*, quickly became established in British waters.

Austropotamobius pallipes is the only indigenous crayfish in Britain, and it would appear that it has been here for hundreds of years (see Holdich et al. this volume). However, its demise is probable if nothing is done (Sibley 2003a). Nearly two decades ago Holdich and Reeve (1991) suggested that it might be necessary to set up "Noah's Ark" populations to try and ensure the survival of *A. pallipes* in Britain. Work such as that being undertaken in SW England and other parts of England and Wales is putting this suggestion into practice (see Peay this volume). In addition, in some areas the reintroduction of *A. pallipes* into waters previously affected by crayfish plague is being undertaken using crayfish that have been captive bred on site (Rogers and Watson 2007).

The possible demise of ICS is not an entirely British problem. In their discussion on the future of ICS in Europe, Taugbøl and Skurdal (1999) predicted that if plans were not put in place, then in 100 years time it might be that all watersheds suitable for crayfish in Europe are occupied by NICS, and all ICS are critically endangered and survive in a few protected localities. To avoid this scenario and to ensure that some countries remain free from NICS and retain extensive populations of ICS they suggested the following actions: restoration of aquatic habitats; protection of ICS as a national aim: obtaining a good knowledge of the status and distribution of crayfish; identifying and establishing "native crayfish areas", preventing the further spread of NICS, implementing effective legislation, fostering cooperation and coordination, re-establishing ICS where they have been eradicated, informing the public, and exploiting ICS. Whilst most of the actions are commendable the last one is contentious. Taugbøl and Skurdal (1999) and Taugbøl (2004) maintain that exploitation and protection are closely linked, as those who exploit are usually concerned about the resources and will protect them. However, this only applies to countries where there is a strong tradition of harvesting and consuming crayfish. In light of what is happening in Europe, Taugbøl and Skurdal (1999) considered the setting up of "native crayfish areas" (NCAs) to be of prime importance in ensuring the future of ICS. These could be as large as a country, a region, a watershed, or even a single watercourse or waterbody. They highlighted Ireland and Norway as being suitable NCAs for *A. pallipes* and *Astacus astacus*, respectively as both countries were at the time free of NICS. Unfortunately, Norway has since had a number of incursions of *P. leniusculus* into its waters, although in one case they have may have been eradicated (Johnsen et al. 2007, Johnsen and Vrålstad 2009). Ireland retains its status as the only country solely occupied by *A. pallipes* with no NICS present (Gallagher et al. 2005, see Reynolds this volume).

In order to try and prevent the extinction of *A. pallipes* the process of identifying and setting up "ark" sites in Britain, is gaining momentum, particularly in SW England, where the number of *A. pallipes* populations is declining rapidly (Sibley et al. 2009, Kindemba and Whitehouse this volume, Nightingale this volume). Key to this process is a strategic approach, which offers benefits of scale and experience, hopefully maximising the chances of successful translocations at a region-wide scale.

CONCLUSIONS

The ICS in many European countries are under threat and their distributional ranges are being eroded by NICS and other factors as in Britain (Holdich et al. 2009). The situation is dynamic as illustrated by the sudden rapid expansion of *O. limosus* down the R. Danube into Romania, and *P. leniusculus* into Norway and Scotland. In the west, due to its island status, Ireland stands alone in having extensive populations of *A. pallipes* and no NICS, although other threats to their future such as pollution occur (see Reynolds this volume). In the east Albania, Azerbaijan, Bosnia-Herzegovina, Bulgaria, Estonia, European Turkey, Georgia, Kazakhstan, Moldova, Montenegro, Ukraine, and possibly Russia have no NICS (Holdich et al. 2010). In Britain the situation for *A. pallipes* is critical and, without intervention, the disappearance of the species from most of its former natural range seems inevitable. The situation in SW England illustrates the reality of this decline but also a possible mechanism for its long-term survival. Steps are being taken to translocate populations at risk to protected sites (arks) according to a series of ecological protocols (see Peay this volume). Whether this approach becomes the norm for other parts of Britain in the future remains to be seen but it offers some hope for this endangered species.

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The current status of white-clawed crayfish in Ireland

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ABSTRACT

Ireland has no NICS but one widespread ICS, the white-clawed crayfish, *Austropotamobius pallipes*, protected under EU and national legislation. It can tolerate mild organic pollution, down to Q3, ASPT 4.4, but surveys in both jurisdictions on the island indicate a slow decline. Recent lake surveys tested sampling methodology (stone turning while snorkeling or wading was preferable to trapping) and found crayfish in 13 of 26 "crayfish lakes" in the Irish Republic. Northern Ireland surveys found crayfish in eight of 23 marl lakes. Reintroductions to midland lake SACs hit by crayfish plague were initially successful in Lough Lene for about a decade, while White Lake was slow to show positive results. An experimental crayfish farm near Mullingar was wiped out by the plague outbreak in 1987. Twenty years later a hatchery on the Moneycarragh stream in County Down has produced two generations of fast-growing juveniles. Also in Northern Ireland, the Ballinderry and Florencecourt crayfish projects include ark sites and public education about crayfish, and the NIEA has set up a Crayfish group, potentially all-Ireland. A better understanding of genetics of Northern Irish crayfish stocks is now needed, and a public education campaign about the dangers presented by NICS.

Keywords: ark sites, *Austropotamobius pallipes,* genetics, hatchery, lake stocks, reintroduction, white-clawed crayfish

INTRODUCTION

With the spread of non-indigenous crayfish species (NICS) across Europe (Souty-Grosset et al. 2006), Ireland, along with Andorra and Liechtenstein, is one of a few countries in Western Europe with no recorded NICS. However, Andorra and Liechtenstein are surrounded by countries possessing NICS (Souty-Grosset et al. 2006). Ireland has one widespread indigenous crayfish species (ICS), the white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet), which gives an impression of what populations of this species must have been like elsewhere in Europe before the introduction of crayfish plague with NICS.

Austropotamobius pallipes is widely distributed in Western Europe, in Ireland, England, Wales, France, Germany and Switzerland (Souty-Grosset et al. 2006). Genetic evidence has established that the white-clawed crayfish of Southern Europe (Spain and Portugal, southern France, Italy and the Balkans) form a group of closely related taxa of uncertain rank, together sometimes called *A. italicus* (Grandjean et al. 2002), but within the species complex the taxonomy is still not agreed (Souty-Grosset et al. 2006).

The origins of Irish *A. pallipes* stocks are not known, but it is unlikely that crayfish could have survived the Ice Ages in Ireland or nearby refugia. Genetic evidence of similarities to stocks in western France has led to the suggestion that stocks of *A. pallipes* may have been brought from there, perhaps by monks in the medieval period, when the continental monastic houses still had strong links with France (Reynolds 1997, Gouin et al. 2003, Wilson this volume); such links weakened after the 11^{th} C following the Norman conquest of Ireland. Other suggestions that the stocks may be Lusitanian in origin, or have been brought from Britain (Lucey 1999), have not been substantiated (Reynolds 2008).

Although *A. pallipes* is the crayfish species traditionally esteemed in Spain, Italy and France, its heritage importance is currently not strong in Ireland. Its protection under Annex II of the EU Habitats Directive, the Irish Wildlife Acts and the NI Wildlife & Countryside Act has also rendered it rather invisible; most people encounter it only rarely, and in most cases published records of crayfish presence date back only a few decades (Reynolds 1982).

THE CURRENT SITUATION

Irish Distribution, Ecology

In Ireland, recent studies have established that *A. pallipes* requires first a varied habitat that fulfils the requirements of both adults and juvenile crayfish, then reasonable water quality (Demers and Reynolds 2002, Demers et al. 2003, Gallagher et al. 2006). Crayfish stocks can survive in streams with mild or even moderate organic pollution, e.g. down to Q 3, ASPT 4 (Demers and Reynolds 2003), but organic carbon levels or other imperfectly understood factors may affect their occurrence (Trouilhé et al. 2007). *Austropotamobius pallipes*, being long-lived compared to most freshwater invertebrates and indeed fish species, have a long environmental memory; their disappearance may relate to infrequently occurring adverse events, and their recolonization is slow.

While *A. pallipes* does not reach the same densities as do NICS such as the signal crayfish *Pacifastacus leniusculus* (Dana) in Britain or elsewhere, they are nonetheless important ecosystem modifiers, acting both as ecological engineers and as keystone species in the ecosystem, controlling overgrowth of aquatic plants and regulating abundance of other benthic invertebrates (e.g. Matthews and Reynolds 1992), arguably enhancing aquatic biodiversity. In many Irish catchments crayfish are a food for salmonids and otters, at least seasonally.

River stocks

The national distribution and occurrence of crayfish in the Irish Republic was determined from several sources by Demers et al. (2006), providing the baseline for evaluation of its status for a review of EU Habitats Directive Annex II species in 2006 (National Parks and Wildlife Service 2008, Reynolds et al. 2009), and there have also been recent surveys of the species in Northern Ireland. Crayfish are still widespread in some tributaries of the Erne and Shannon, such as the Colebrook (Policar et al. 2008), but do not appear to occur in the main river and it is not known to what extent they were ever there. They are recovering slowly from a plague outbreak in the 1980s but remain very sparse in the Boyne though slightly more frequent in its major tributary the Kells Blackwater (Demers and Reynolds 2002). They are now absent or very sparse below a modern sewage treatment plant in the upper Liffey catchment (Demers and Reynolds 2002). In the southeast, the putative site of introduction for this species, good stocks are still to be found in the mainstream Suir and in much of the Barrow (Demers and Reynolds 2003), but are becoming scarce in the River Nore and its tributaries (Lyons and Kelly-Quinn 2003, Lucey 2008, pers. comm.). In the upper Shannon crayfish are very scarce or absent from some midlands tributaries including the Inny and Little Brosna, and also from near-border streams in the northeast. Conversely, a recent survey in NI showed that they occur in at least six sites in the lower Ballinderry (Bann system) (Wilson and Horton 2008).

The main causative factors for the declines in river stocks have not been definitively established, but are believed to include deterioration in water quality from farmland (Lyons and Kelly-Quinn 2003) and from industrial development, organic pollution from various sources including effluent from sewage treatment plants (Demers and Reynolds 2002), and pesticides such as sheep dip**.**

Lake stocks

Of two recent lake surveys in the Republic of Ireland; the first determined the most appropriate lake sampling methodology from surveys of six lakes of varying sizes (Reynolds 2006); the second applied these methods to a sample of 26 lakes believed to contain crayfish in the past, and found stocks in 13 (50%) of these (O'Connor 2007, O'Connor et al. 2009). In both surveys, crayfish were not predictably found by trapping. Recommended methods were stone turning while snorkeling or wading, also sweep-netting and night search. Surrogate evidence (e.g. otter spraints, anglers' evidence) is useful as part of a distributional survey. The most important crayfish lakes were Loughs Labe, Kilrooskey, Talt, Gowna and Owel, ranging in size from 6 to 1350 ha.

Surveys in 23 Marl Lakes in Northern Ireland showed crayfish in eight of these (Gallagher 2002). Recent surveys in some of these marl lakes found stocks in four (Gallagher 2009, pers. comm.), again indicating a decline for reasons unknown, although enrichment or eutrophication, farm pollution and fishing activity are suspected. However, in both jurisdictions the surveys showed that trapping is not a predictable method of surveying, and that sampling at different times of year can give different results (O'Connor et al. 2009, Gallagher 2009, pers. comm.). The Finn Valley lakes comprise a cross-border SAC (Magheraveely Lakes in Fermanagh; Kilrooskey Lakes in Monaghan), and good stocks are still present in Kilrooskey Lough, with residual stocks in Dummy's and Drumacrittin Loughs.

Reintroductions

Following the plague outbreak in 1987, which extinguished some midlands lake and river stocks, reintroductions to some suitable areas were planned. Reintroduction protocols are set out and described in Reynolds et al. (2002). Two reintroductions were carried out to midland lake SACs hit by plague. These were Lough Lene (430 ha), restocked in 1989 and 1991, and White Lake (a marl lake of 40 ha), restocked in 1999. Both scientific reintroductions followed a similar protocol; adult crayfish collected from adjacent catchments were placed to acclimatize in near-shore corrals before being released. The Lough Lene reintroduction was initially successful (Reynolds and Matthews 1997) with high growth rates seen, but when the lake was resurveyed in 2006 no crayfish were found and it was believed locally that they disappeared suddenly in about 2003, with no obvious cause.

The White Lake reintroduction (Reynolds et al. 2000) was much slower to show positive results, despite the dense and well-studied stocks in this lake before extinction, notable for their high proportion of large individuals over 9 cm TL (O'Keeffe 1986). However, some crayfish were eventually found in 2007 (O'Connor et al. 2009). White Lake is a marl lake, with relatively little stony cover along the shoreline, but dense beds of *Chara*, formerly heavily cropped, provided shelter. It is not obvious that the environment had changed adversely.

Rearing activity

An experimental crayfish farm was set up in near Mullingar in 1987, using Lough Lene stocks, with the intention of growing on and breeding from captured adults below marketable size (Reynolds and Matthews 1993). This was unfortunately wiped out by the plague outbreak later in that year. Following the protection conferred on the species by the EU Habitats Directive 1997 and Wildlife Acts and, given that wild stocks of *A. pallipes* were still widely available in Ireland, no further farms were attempted until 2008, when a hatchery was established on the Moneycarragh stream in County Down, using crayfish from the Colebrook in Co. Fermanagh (Erne system) (Policar et al. 2008). There are currently two other sites in Northern Ireland where stocked crayfish are being encouraged to breed, at Ballinderry and Florencecourt (see Horton this volume).

The Moneycarragh hatchery has successfully used best current technology to produce fast-growing juveniles, hatching out of season, with two generations produced in under three years (Policar 2008, pers. comm., Smyth 2009, pers. comm.). These rearing facilities could be a controlled source of hatchlings for restocking, and given that studied Irish crayfish stocks appear genetically rather uniform, it is probable that they may prove to be usable across the island rather than just in the same catchment. Under defined circumstances there is even potential for restocking *A. pallipes* beyond Ireland (Reynolds et al. 2002).

Conservation moves

While the Irish Republic has concentrated recently on defining distribution, in Northern Ireland there is a wave of activity concerning crayfish and their conservation, with obvious opportunities for synergies in operation. An intensive crayfish habitat survey was carried out in the Ballinderry River (Wilson and Horton 2008). The Ballinderry and Florencecourt projects include the development of ark sites while prioritizing public education about crayfish (see Horton this volume). Both the Florencecourt project and the Moneycarragh hatchery have cross-border links. There are also research projects based in Queens University Belfast, the whole overseen by the Northern Ireland Environment Agency, which has established a Northern Ireland Crayfish group with the potential to be all-Ireland (Wilson and Horton 2009).

DISCUSSION: FUTURE RESEARCH NEEDS

In the present UK climate of continued interest in the exploitation of the signal crayfish, *P. leniusculus* (see Holdich and Sibley this volume), there has anecdotally been an increase in informal translocations of stocks across Britain, where the current conservation priorities are fire-fighting the spread of *P. leniusculus* and establishing captive, isolated ark stocks of *A. pallipes* (Kindemba and Whitehouse, Nightingale, and Peay this volume). These policies are also being practiced in Northern Ireland. However, as *P. leniusculus* is not currently present in Ireland, there is more time to investigate and understand the general causes of decline in *A. pallipes* in the absence of NICS, such as the significance of organic carbon. This would potentially allow the halting or reversal of these declines, and provide a more secure basis for future restockings.

In Northern Ireland, where there is a possibility that some stocks at least may have originated in Britain, a better understanding of the genetics of *A. pallipes* stocks is needed, and some genetic studies of Northern Irish crayfish stocks are now underway in Ireland and France (Souty-Grosset 2009, pers. comm.). If a single origin of all Irish stocks is demonstrated, then the possibility can be developed of using Irish stocks as donor populations, preferably via controlled hatchery rearing, to prop up declining stocks across Ireland and also hard-pressed continental and British stocks.

Finally, a public education campaign about the dangers presented by NICS is vitally necessary at this time, and in the future, there may be possibilities to develop Irish protocols for ark sites, and perhaps to rear *A. pallipes* for the table in approved facilities.

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Signal crayfish in Scotland

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ABSTRACT

The spread of the non-indigenous North American signal crayfish (*Pacifastacus leniusculus*) in Scottish freshwater ecosystems is of major concern due to the threats that this species poses to biodiversity. In 2007, the Scottish Government listed signal crayfish under the Species Action Framework (SAF), a five-year strategy for species management in Scotland**.** One of its foremost objectives is to determine the distribution of signal crayfish in Scotland, thereby allowing control or containment efforts to be targeted appropriately. This paper outlines the recent work undertaken to fulfil this objective. Existing records of crayfish distribution were collated and validated prior to extensive field surveys. A standard crayfish detection protocol involving kick sampling, electrofishing and baited-traps was applied at all sites. Signal crayfish are now known to occupy at least 58 km of river length in Scotland. They are also present in a small number of standing waters, ranging in size from small ponds to large lochs. Field surveys confirmed and refined crayfish distribution records and identified sites where eradication of localised populations might be possible. At some sites the protocol failed to detect crayfish despite previous records. This lack of detection may be attributed to the completion of fieldwork at a time of year when crayfish activity is low and also the difficulty of detecting crayfish at low densities. Future surveys should take account of these limitations and where appropriate, modify the survey timings or methodologies to maximise the likelihood of crayfish detection.

Keywords: crayfish, distribution, Scotland, survey

INTRODUCTION

Unlike the rest of the British Isles, no crayfish species occur naturally in Scotland (Maitland 1996, Holdich et al. this volume). There are, however, two known introduced species. The white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet), inhabits Loch Croispol, Sutherland (Thomas 1992) and Whitemoss Reservoir, Renfrewshire (Maitland et al. 2001). The Loch Croispol population is thought to have originated from the introduction of crayfish to a feeder stream in 1945 (Thomas 1992). Local information suggests that the population at Whitemoss Reservoir has also been present for many decades (Maitland et al. 2001). The other crayfish species in Scotland, the North American signal crayfish, *Pacifastacus leniusculus* (Dana), was first recorded in the wild in Galloway in 1995 (Maitland 1996) and has become established in at least eight localities across the country (Bean et al. 2006).

White-clawed crayfish are protected under Schedule 5 of the Wildlife & Countryside Act 1981, Appendix III of the Bern Convention, Annexes IIa and Va of the EC Habitats Directive and The Nature Conservation (Scotland) Act 2004. Given the plight of white-clawed crayfish in the rest of Britain resulting from signal crayfish introductions and the subsequent spread of crayfish plague, these Scottish populations are likely to represent valuable refuge stocks for conservation in the future. Recent survey work has assessed and confirmed the suitability of Loch Croispol as an ark site for white-clawed crayfish, which is sufficiently isolated from the threat of invading signal crayfish and supports a healthy, recruiting population (the author 2009, pers. obs.). Future surveys will assess the status of the white-clawed crayfish population at Whitemoss Reservoir.

To date, there is no obvious evidence to suggest that white-clawed crayfish populations have negatively impacted native biota or have dispersed or been translocated from their sites of introduction. By contrast, the introduction and continued spread of signal crayfish has been highlighted as cause for concern in Scotland and is likely to have a significant impact on freshwater ecosystems. Previous research in Scotland has highlighted the potential for signal crayfish to impact Atlantic salmon stocks (Griffiths et al. 2004) and significantly alter the structure of invertebrate communities (Crawford et al. 2006). In 2007, the Scottish Government listed signal crayfish under the Species Action Framework (SAF) as an invasive species posing a significant threat to native freshwater biodiversity. This framework, developed and implemented by Scottish Natural Heritage (SNH) and partners, sets out a five-year long strategy for species management in Scotland (SNH 2007). One of the foremost objectives of the SAF Signal Crayfish Implementation Plan is to assess the distribution and status of signal crayfish in Scotland, which will allow control and containment programmes or other mitigation measures to be targeted appropriately.

The purpose of this paper is to outline the most recent efforts made by SNH and the Rivers and Fisheries Trusts of Scotland (RAFTS) to determine the fine-scale distribution of signal crayfish in Scotland. The merits and problems associated with this programme of work and implications for future projects are discussed.

MATERIALS and METHODS

Collating Records

Prior to field surveys, existing records of signal crayfish distribution were collected from published and unpublished literature. Additionally, Fisheries Trusts and District Salmon Fishery Boards (DSFBs) were contacted by letter to appeal for up-to-date information. In December 2008, a workshop was held to allow verification of crayfish records by delegates from the Rivers and Fisheries Trusts of Scotland (RAFTS), the United Clyde Angling Protective Association Ltd (UCAPA), SNH and seven different Fisheries Trusts. Marine Scotland (formerly the Fisheries Research Services, FRS) and the Scottish Environment Protection Agency (SEPA) were also asked to provide access to any data held by them.

Field Surveys

The locations of sites to be surveyed for crayfish were finalised based on the validity of previous records and the expert opinions of participating Fishery Trust and DSFB biologists. A list of sites surveyed during the exercise is provided in Table 1. In March 2009, a standard protocol for detecting signal crayfish (Gladman et al. *in prep.*) was applied at all survey sites. This active-search protocol was based upon the results of previous field experiments on the River Clyde and involved the sequential application of kick sampling, up to three runs of electro-fishing and baited-trap setting to determine crayfish presence. Sample timings and equipment including nets, traps, baits and field-recording sheets were standardised. Before and after use, equipment was thoroughly disinfected. All crayfish captured during the survey work were counted and killed on-site, prior to storage in 100% (Analar grade) alcohol.

Table 1. Locations of sites surveyed for signal crayfish in Scotland during 2008/9.

LOCATION	RIVER CATCHMENT	FISHERY TRUST UNDERTAKING THE SURVEY
Upper Clyde	Clyde	Clyde River Foundation
River North Esk (ponds); Lugar Burn/main stem	North Esk	Esks DSFBs
Pow Burn	South Esk	Esks DSFBs
Rankeillour Burn (Fife)	Eden	Forth Fisheries Trust
River Teith (pond and ditches)	Forth	Forth Fisheries Trust
River Tyne (stillwater fishery, East Lothian)	East Lothian Tyne	Forth Fisheries Trust
Tiel Burn (Fife)	Tiel	Forth Fisheries Trust
Murray Burn	Water of Leith	Forth Fisheries Trust
Kirkcudbrightshire	Dee	Galloway Fisheries Trust
Skyre Burn	Fleet	Galloway Fisheries Trust
River Nairn	Nairn	Ness and Beauly Fisheries Trust
Dighty Water (Dundee)	Dighty	Tay DSFB
River Earn	Earn	Tay DSFB
River Ardle (pond and small stream)	Ericht	Tay DSFB
Shee Water (pond and small stream)	Ericht	Tay DSFB
Rivers Ettrick and Till	Tweed	Tweed Foundation
Kirkbank (Teviot Water)	Tweed	Tweed Foundation

RESULTS and DISCUSSION

Fine-scale maps showing the distribution of signal crayfish in Scotland, based on the current surveys, are provided in Sinclair (2009). The main findings are summarised below:

Signal crayfish are now known to occupy at least 58 km of river length in Scotland. This figure represents a minimum estimate of crayfish distribution and does not include populations in large still waters such as Loch Ken in Galloway. Loch Ken is thought to contain the largest population of signal crayfish in Scotland and the Scottish Government has recently provided funding to undertake a major trapping research programme, which will include an assessment of crayfish distribution, population size and overall density. The present project has successfully confirmed and delimited signal crayfish distribution at a number of sites. It has also provided some indication of the relative density of crayfish within and between catchments and, in the case of the Clyde, helped determine the approximate upstream and downstream limit of crayfish distribution on the main stem and associated tributaries. New records of crayfish presence have been verified by surveys on the Arvie Burn in the Kirkcudbrightshire Dee catchment and on the Tiel Burn and its tributaries in Fife.

Based on the results, potential sites for eradication of localised populations on the Forth, Fleet, Tweed and Nairn catchments have been identified. By contrast, surveys have demonstrated that the cost-effective eradication of crayfish populations in some areas, such as the Clyde and Kirkcudbrightshire Dee, is now impossible. The upstream spread from the main stem to adjoining burns in these well-established populations appears to be relatively slow. The reasons for this are unknown and require investigation. On the Clyde there is a pressing need to apply targeted control of the crayfish currently occupying headwaters and take preventative measures to avoid cross-catchment spread to the nearby River Annan.

The sequential use of kick sampling, electrofishing and trapping as part of the crayfish detection protocol has proven effective, with electrofishing generally detecting crayfish in sites where kick sampling failed (but requiring greater effort in terms of the time taken to obtain the positive result), thus providing information on the relative density of crayfish within catchments. Very few crayfish were caught in traps, supporting the decision to favour active search methods over passive ones, such as trapping. Kick sampling and electrofishing were also shown to be adaptable for use in still water, detecting crayfish in ponds on the Forth catchment. Electrofishing was unsuitable, however, for use in deep, turbid water or areas with very strong currents. Practitioners regarded the protocol as cost and time-effective: kick sampling does not require expensive or specialist equipment (i.e. only pond nets and trays), nor does it require specialist training for surveyors to implement; electrofishing is already an integral part of fishery surveys that are carried out by Fisheries Trusts throughout Scotland and so equipment and trained staff were readily available; traps were easily assembled and deployed. For a team of two or three people, the estimated time to apply all three methods at one site was one hour.

Despite its practicalities, the protocol failed to detect signal crayfish on several occasions. In two catchments, the Esk and the Tweed, no crayfish were found during surveys despite previous records. The Esk Rivers and Fisheries Trust reported the capture of a single crayfish during juvenile fish surveys in the Pow Burn in 2008; crayfish were also found at Drumtochty pond in the same year. No crayfish were found at either location during the present study which involved taking six replicate kick samples at each site and setting five traps which were checked daily for eight days (Pow Burn) and seven days (Drumtochty). Similarly, surveys failed to confirm previous records of crayfish presence in areas within the Tweed, Tay and Kirkcudbrightshire Dee catchments. Ponds on the Tay and Esk, which were previously subject to chemical control trials (Peay et al. 2006), did not yield crayfish during the current surveys (Peay 2009, pers. comm.).

Reasons for the lack of positive records at sites where signal crayfish were previously found are likely to relate primarily to the time of year in which sampling was undertaken and also the difficulty of detecting crayfish low densities. Due to external pressures, this programme of fieldwork was completed in Quarter 1 of 2008, during a time of year that is suboptimal to crayfish detection. At Knocknairling Burn in the Kirkcudbrightshire Dee catchment, for example, a local landowner reported crayfish as being easily visible during low summer flows two years ago but no crayfish were detected during the present surveys in March. The efficacy of surveying is likely to increase, therefore, during the summer months when water temperatures and subsequent crayfish activity are higher. Detecting crayfish at low densities, particularly in larger water bodies is difficult, as observed on the Tweed. Variation in weather conditions and habitat type between catchments may also have impacted the efficiency of crayfish detection. During surveys on the Tay catchment, for example, sampling conditions were poor due to snowmelt and at some sites electrofishing was not possible due to high water. At two sites on the Nairn, kick sampling was not possible due to excessive depth within the sampling area or the presence of deep silts within the main river channel.

It is hoped that this project marks the beginning of a long-term monitoring plan for signal crayfish in Scotland. Data collected this year using the standardised method will serve as a baseline against which future changes in crayfish distribution can be assessed. Such work will provide a useful body of knowledge for use by SNH, SEPA and others involved in the monitoring and management of invasive non-native species in Scotland and other parts of the UK. Feedback from practitioners will aid improvements in the design of the signal crayfish detection protocol, which may already require modification to take account of variation in water body or habitat type, weather conditions and crayfish density between catchments. Increasing the number of kick sample and electrofishing replicates might help improve the reliability of the protocol as a detection method. The feasibility of incorporating crayfish surveying into routine fishery monitoring work during the summer, when crayfish activity is highest and most detectable, should be considered. Data relating to the distribution of this species must be kept up to date to ensure that an early warning of new populations is obtained whilst the opportunity still exists to initiate a rapid management or eradication programme. Developing and implementing the best strategy for such programmes has been the focus of previous research (Reeve 2002, Ribbens and Graham 2004) and is currently under review (Freeman et al. 2009); this will form the next step in fulfilling the aims of the SAF Signal Crayfish Implementation Plan.

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Porcelain disease in white-clawed and signal crayfish in the UK

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ABSTRACT

Porcelain disease caused by the microsporidian parasite *Thelohania contejeani* is common in noble and white-clawed crayfish populations throughout Europe. In the UK, prevalence of the disease is normally very low, 5% or less, in healthy white-clawed crayfish populations. However, there are several aspects of the disease that are of concern to conservationists. Signal crayfish have recently been confirmed as harbouring multiple microsporidian species, including *T. contejeani,* while remaining asymptomatic. Certain white-clawed crayfish populations are experiencing very high rates of porcelain disease for as yet unknown reasons. Ark sites are being increasingly made for indigenous crayfish populations at risk, and considerations must be made regarding porcelain disease rates in donor populations. Finally, the potential import of two alien *Thelohania* species in infected redclaw *Cherax quadricarinatus* or other Australian crayfish species is a concern, as it is not known if white-clawed crayfish are susceptible to porcelain disease caused by these microsporidians. Here we provide a basic introduction to porcelain disease and its impacts on crayfish, and address the above conservation concerns.

Keywords: *Thelohania contejeani,* porcelain disease, *Austropotamobius pallipes,* microsporidian parasites, *Pacifastacus leniusculus*.

WHAT IS PORCELAIN DISEASE?

Porcelain disease is the common name of a condition seen in crayfish that are heavily infected with microsporidian parasites. These parasites are typically of the genus *Thelohania* (Henneguy). Originally described with the type species *Thelohania giardi*, a parasite of a marine shrimp, the genus *Thelohania* currently includes parasites of freshwater and marine crustaceans throughout the world, and until recently included at least one ant-parasitising species as well (Brown and Adamson 2006, Sokolova and Fuxa 2008).

Microsporidians are intracellular parasites, which are single-celled, fungus-like, spore-forming eukaryotes. These parasites infect a wide range of hosts from invertebrates to humans, and many are generalists capable of infecting multiple host species (Canning and Lom 1986). A number of species infect aquatic invertebrates, including those from the genera *Nosema*, *Bacillidium*, *Pleistophora, Vittaforma*, and *Thelohania*.

In the UK, white-clawed crayfish (*Austropotamobius pallipes* (Lereboullet)) are susceptible to porcelain disease caused by the species *Thelohania contejeani* (Henneguy) and possibly other microsporidians (Pixell Goodrich 1956, Dunn et al. 2009). The disease is so named due to the opaque white "porcelain-like" colouration of the musculature (Fig. 1a) compared to the translucent muscle tissue of healthy specimens (Fig. 1b). Porcelain disease is a chronic yet lethal disease, with crayfish able to survive 1-2 years while visibly infected (Bowler and Brown 1977). However, crayfish may be able to carry microsporidian parasites and show no symptoms. Precisely how crayfish become infected with *Thelohania contejeani* remains unknown (Vogt 1999). For the remainder of the paper, "porcelain disease" will indicate visible microsporidian infection, with the species name *T. contejeani* used when the species has been confirmed molecularly.

Figures 1a and b. Ventral views of parasitized (a) and healthy (b) white-clawed crayfish.

IMPACT ON WHITE-CLAWED CRAYFISH

Physiological impacts

Microsporidians generally have a life cycle with two developmental phases consisting of the proliferative phase (merogony) and spore-forming stage (sporogony). During merogony, the parasite uses the host cell's resources to divide. In sporogony, sporophorous vesicles (SPVs) are formed within the host cell. The number of spores in the SPV is often used to identify the genus of microsporidia present, for example, species in the *Thelohania* genus have SPVs containing eight spores each. Microsporidian spores are normally very hardy and can endure in various environmental conditions outside the host (Canning and Lom 1986).

Thelohania contejeani reproduces inside crayfish muscle cells where it uses the host's muscle cell to create spores. These spores eventually fill the cell and result in the cell's death (Oidtmann et al. 1996). Cossins (1973) found the parasite in abdominal, limb, and various gastric muscles, as well as in the eyestalk. Further work (Cossins and Bowler 1974) found the parasite present in cells in the supra-oesophageal ganglion, as well as finding extracellular spores in the areas of the gills, hepatopancreas, and haemolymph. They suggest that the extracellular spores are the result of lysis of infected muscle cells, which may represent an intentional mechanism by which the parasite disperses throughout the crayfish's body to infect muscle cells in a variety of locations.

Moodie et al. (2003) suggest that death need not necessarily result from infection with *T. parastaci*, as no experiments have been done to track infection progress in individual crayfish from time of infection until death. That European crayfish species have lived 1-2 years (Bowler and Brown 1977, Mazylis 1978) with visible porcelain disease, and that various attempts to transmit the parasite experimentally have had little success in causing porcelain disease, adds credence to the idea that crayfish are, under some circumstances, able to resist or suppress microsporidian parasites. The potential mechanism of such an ability is unknown, as *T. contejeani* is not thought to provoke an immune response in crayfish (Oidtmann et al. 1996).

Moulting

Bowler and Brown (1977) found that white-clawed crayfish having porcelain disease were able to moult and grow, but that their growth rate was not as high as in healthy crayfish. On several occasions, crayfish kept in the authors' laboratory, which appeared healthy pre-moult were suddenly visibly infected immediately post-moult (pers. obs.) This suggests that the moulting process may trigger rapid replication, or release, of spores and facilitate the spread of the parasite through the crayfish's tissues.

Reproduction

Evidence suggests that infected crayfish are capable of mating and rearing young. Both male and female white-clawed crayfish with porcelain disease have been found in the autumn with spermatophore residue on their gonopods (Fig. 2a.) and ventral surface (Fig. 2b), respectively (pers. obs). Additionally, infected females have been found with normal-sized broods of eggs and hatchlings (Fig. 2c, pers. obs.). Infected berried females and females with hatchlings that were kept in the laboratory did successfully release their young. Molecular screening of female muscle tissue confirmed the presence of *T. contejeani*, but no eggs or deceased hatchlings screened contained the parasite. This suggests that vertical transmission of the parasite from mother to young does not occur (or occurs at a very low rate), but does not rule it out, as our sample size was small due to the low numbers of infected berried females available. Young of year have been found with porcelain disease, so if they have indeed not been infected by their mother, they must have been infected very shortly after hatching/release from the mother and the parasite replicated rapidly.

Figures 2a, b, c. Ventral views of parasitized white-clawed crayfish with spermatophore material adhering to the ventral surface of a male (a) and a female (b), and of a parasitized female with hatchlings (c).

Behaviour

Recent behavioural experiments in our laboratory have not found any difference between healthy white-clawed crayfish and those with porcelain disease in: activity level or type; preference for light or dark habitat; or walking speed (Imhoff et al., unpublished data). Currently an experiment is underway to examine the impact of infection on the tail-flipping escape behaviour of crayfish (speed and number of tail-flips). Even crayfish with very advanced cases of porcelain disease are capable of tail-flipping numerous times consecutively, but the response can be weaker and slower in crayfish with advanced infection. This is most probably due to the destruction of the muscle tissue resulting in lowered strength and endurance, rather than a neurological effect of the parasite, as *T. contejeani* has rarely been found in any nerve tissue (Cossins and Bowler 1974).

Prevalence

Porcelain disease normally occurs at prevalences ranging from 0.2 to 10% in white-clawed crayfish populations (Cossins and Bowler 1974, Brown and Bowler 1977, O'Keefe and Reynolds 1983, Vogt 1999, Mori and Salvidio 2000, Rogers 2005, Hutchings this volume), though higher rates have occasionally been found (Pixell Goodrich 1956, Evans and Edgerton 2002) and in aquaculture (Vey 1986). It is not normally considered problematic in aquaculture, however (Evans and Edgerton 2002). Two current populations in streams in West Yorkshire have porcelain disease prevalences of 18% and 50%, the latter of which is an almost unheard of rate for a wild population of white-clawed crayfish, and there is keen interest in determining the cause of this high burden.

The determinants of the disease's prevalence are not well understood. It has been suggested that the density of crayfish populations influences the prevalence of the disease (Cossins 1973), but a six-year study by Skurdal et al. (1990) did not find such an effect. General stress on the population is another possible influencing factor. Stress is caused by unsuitable water chemistry such as low pH (Graham and France 1985), urban runoff, or discrete pollution events. It can also be caused by habitat alterations such as loss of suitable shelters or changes in hydrology (this is explained in the following section). Further, if an intermediate host is required for the parasite to complete its life cycle (this is unknown), then disease prevalence may depend on the density of the intermediate host species. Finally, certain populations may simply be genetically predisposed to be more susceptible to the disease.

MICROSPORIDIANS IN NON-INDIGENOUS CRAYFISH IN THE UK

Thelohania contejeani is commonly found in noble crayfish (*Astacus astacus* (L.)) and white-clawed crayfish throughout Europe (Alderman and Polglase 1988, Diéguez-Uribeondo 2006). In the UK, white-clawed crayfish which are infected exhibit symptoms of porcelain disease and eventually die. It is important to ascertain if signal crayfish (*Pacifastacus leniusculus* (Dana)) can also be infected, as signal crayfish have been present in Britain for decades (see Holdich and Sibley this volume), and frequently displace white-clawed crayfish (Peay and Rogers 1999). This contact likely exposes signals to *T. contejeani*, and if signals are susceptible to infection or are able to act as carriers, they have the potential to act as a reservoir host.

Signal crayfish in the north-western USA, near their native range, have been found with porcelain disease, which was identified through microscopic examination as being caused by *Thelohania contejeani* (McGriff and Modin 1983). These were found in a newly-impounded reservoir, which had previously been a flowing river, and the authors suggest that the conversion from lotic to lentic habitat stressed the crayfish, making them more susceptible to infection. However, no molecular work has yet been done on these or any other American crayfish exhibiting symptoms of porcelain disease, so it is possible that there are further microsporidians species infecting crayfish in North America. Porcelain disease is still seen occasionally in some North American populations of signal crayfish (Koen Breedveld, pers. comm.), and our lab will be screening and sequencing samples from these crayfish in the near future to determine what species are present.

Signal crayfish in the UK are rarely seen with porcelain disease, the advanced stages of microsporidian infection. Recently, however, *Thelohania contejeani* and two other unidentified microsporidian species have been confirmed in signal crayfish from Yorkshire at rates even higher than those usually found in white-clawed crayfish (Dunn et al. 2009). Further work has shown that these crayfish harbour the parasite, as well as other microsporidian species, but show no visible sign of porcelain disease, even when held in the lab for several months (Imhoff et al. *in press*). Where UK signal crayfish do appear to show symptoms of porcelain disease, it is milder than in white-clawed crayfish, with the musculature still appearing somewhat translucent.

In areas where signal and white-clawed crayfish populations overlap, signal crayfish have the potential to act as a reservoir host for *T. contejeani* and any other microsporidians present, particularly if parasite prevalence is high in signals. This could be particularly harmful, as the molecularly-determined prevalence of *T. contejeani* in the signal crayfish (26-75%, Dunn et al. 2009; 10-61 %, Imhoff et al. in *press*) generally exceeded that of the white-clawed crayfish in the same water body (12%, pers. obs.). If the signal crayfish is capable of passing on the parasite to the indigenous crayfish, these high prevalences could result in increased parasitism of white-clawed crayfish in areas nearby in the future. Given that the mode of transmission is not fully understood, the actual likelihood of this occurring is unknown.

Cherax quadricarinatus (von Martens) (redclaw crayfish) is a popular aquarium pet in the UK. In its native range in northern Australia, it is susceptible to infection by *Thelohania* species (Herbert 1988), likely *T. parastaci* or *T. montirivulorum*, or both. Individuals imported from Australia could bring these parasites to the UK, as it is virtually undetectable in the early stages and so could pass a visual inspection for disease, if one were even required. This “tropical” species of crayfish is not thought to be capable of surviving and reproducing in the cold waters of the UK, but breeding populations have been found in northern Germany under climate conditions similar to those in the UK (see Holdich and Sibley this volume). Therefore, it is possible that discarded pets or escapees can survive and come into contact with indigenous white-clawed crayfish or, possibly more likely, signal crayfish. Since white-clawed crayfish are susceptible to one *Thelohania* species, *T. contejeani*, they may be susceptible to these others. Likewise, signal crayfish may become infected, and, as they seem able to act as carriers of microsporidians without suffering mortality themselves, they may likewise carry these Australasian microsporidian parasites and transmit the disease to indigenous white-clawed crayfish. It is also possible that white-clawed and/or signal crayfish would be even more susceptible, as they are naïve to the Australasian *Thelohania* species. Depending on susceptibility of the white-clawed crayfish, if these additional microsporidian species enter the indigenous crayfish populations, they could have considerable impact upon them.

CONSERVATION CONCERNS

Porcelain disease is often noticed by conservation practitioners, but due to its normally-low prevalence, it is sometimes ignored. However, it is important to keep an accurate record of porcelain disease prevalence in populations so that any increases in prevalence will be noticed. An increase in disease prevalence is undesirable in itself, and may also indicate a recent significantly stressful event to the crayfish population. Duffield (1933) considered that *T. contejeani* may possibly have been responsible for several crayfish epidemics in the late 1800s and into the early 1900s, which largely wiped out the white-clawed crayfish populations in some British rivers. There was no evidence obtainable at the time to confirm or deny this supposition, but this further emphasizes the importance of keeping records of visible disease prevalence in monitored crayfish populations.

Porcelain disease prevalence appears to increase with stress, though there may be other drivers as well. France and Graham (1985) found evidence that acidification increased porcelain disease rates in *O. virilis* (Hagen) in North American lakes. Also in North America, signal crayfish with visible porcelain disease were found in a recently-made reservoir, where the habitat and hydrology had been altered (McGriff and Modin 1983). The authors found very high (18-50%) porcelain disease rates in white-clawed crayfish in small urban streams, where populations face stress from human disturbance, urban runoff and sewage overflows, as well as periodic low flows in summer. Long-term studies of specific white-clawed crayfish populations and the habitats they inhabit, such as those being conducted by Adrian Hutchings (Hampshire) and Stephanie Peay (Yorkshire) will be particularly valuable in contributing to our understanding of the porcelain disease prevalence variation in crayfish populations. Sites having high porcelain disease prevalence, or a sudden increase in porcelain disease, should be assessed and if possible steps taken to increase site suitability for white-clawed crayfish.

The use of ark sites in white-clawed crayfish conservation is attracting a lot of interest (see Kindemba and Whitehouse, Nightingale, and Peay this volume). With limited numbers of ideal sites, it is important that each one have the greatest chance of success possible. Success will in part be determined by the suitability of a given site for white-clawed crayfish, but another important aspect is the crayfish themselves. Crayfish selected for an ark site should be healthy individuals, as the transplant is likely to be stressful for them and high survival rates are desired. Donor populations will almost always contain porcelain disease. Advanced porcelain disease is easily identified by visual inspection of individual crayfish. However, a significant number of individuals can carry the parasite while appearing healthy, so microscopic (O'Keeffe and Reynolds 1983) or molecular testing is ideal. The authors have developed a non-lethal method to screen adult crayfish for most microsporidian parasites, including those that cause porcelain disease, using small tissue samples (from leg or abdomen) and molecular techniques (Imhoff et al. *in press*), alternatively the samples taken can be examined microscopically. While it is impossible to be completely certain that every individual is not carrying *T. contejeani* or another microsporidian, screening a subset of a population prior to transplant to the ark site will give an estimate of how many healthy-appearing crayfish may be infected with microsporidian parasites.

If the donor population has a normal prevalence of porcelain disease (< 10%), when it comes time to move the crayfish, the unhealthy-appearing individuals can simply be left in the donor site. In the case of an ark site donor population with a very high prevalence of the disease (> 20%), it may be best to seek out a different donor population, particularly if potential ark sites in the area are limited and could be better filled with more fit individuals. Each situation will have its own unique considerations, so conservationists must use their best judgment in the matter until more research emerges on porcelain disease in post-transplant ark site populations. The authors urge all practitioners engaging in ark site creation and maintenance to keep a record of porcelain disease prevalence in the crayfish population both before and in the years following transplant to an ark site, in whatever way is available to them. Such records will provide valuable information to inform future conservation efforts.

A final concern, as mentioned in the previous section, is the potential introduction of additional *Thelohania* species to the UK. Two main points need to be addressed: whether the indigenous white-clawed crayfish is susceptible to these parasites, and whether either of the parasite species (*T. parastaci* and *T. montirivilorum*) are likely to be unintentionally imported with *C. quadricarinatus* and enter UK waterways. This is a concern not only for the UK, but continental Europe as well, where *C. destructor*, another Australian crayfish susceptible to *T. parastaci* and *T. montirivilorum*, and *C. quadricarinatus* have been introduced (Souty-Grosset et al. 2006).

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Assessing multiple paternity in the endangered white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet)

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ABSTRACT

Multiple paternity analysis was carried out on the white-clawed crayfish, *Austropotamobius pallipes*, in Northern Ireland. Two hundred and forty eggs from six females were tested using microsatellite primers available commercially and designed specifically for this research. Although analysis is still to be completed, no evidence as yet supports multiple paternity in the species. Due to the small sample size, multiple paternity cannot be ruled out. Looking at natural mating behaviour of *A. pallipes*, recommendations to conservation efforts in breeding the species in artificial conditions is to raise the male to female ratio to the level of 2:1.

Keywords: multiple paternity, white-clawed crayfish, microsatellites, conservation, artificial breeding

INTRODUCTION

The white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet) is thought to have been introduced to Ireland in the 12th century (Gouin et al. 2003). Since then, through natural dispersal and human translocation events, it has spread northwards (Gouin et al. 2001, 2003). Recently, its northern limit has been recorded in the Ballinderry River, County Tyrone (IGRH8583, Wilson and Horton 2008).

Analysis of Irish populations over the past decade suggests that the Irish *A. pallipes* originated from Western France (based on a unique shared haplotype; Gouin et al. 2001), a different origin to that which founded the British populations (Gouin et al. 2001). This analysis also supported the idea that *A. pallipes* was introduced to Ireland in the 12th century (Gouin et al. 2001). Despite being present in Ireland for nearly 900 years, and being found in many river catchments, there is low genetic variation throughout Ireland (Gouin et al. 2001). Gouin et al. (2001), using RFLP analysis (Random Fragment Length Polymorphisms) on mitochondrial DNA (mtDNA) and RAPDs (Random Amplification of Polymorphic DNA) (Gouin et al. 2003), found low genetic variation between sampled populations, indicating rapid spread of the species though freshwater systems, with each succeeding population being founded by a small number of individuals from the closest group (Gouin et al. 2003). However, *A. pallipes* in general shows poor variation between populations in other countries within its range, such as Italy (mtDNA evidence, Fratini et al. 2005, Zaccara et al. 2005), Great Britain (RAPD evidence, Gouin et al. 2003; mtDNA evidence, Grandjean and Souty-Grosset 2000; Trontelij et al. 2005) and France (using mtDNA, Grandjean and Souty-Grosset 2000), although France is divided into north and south in terms of the variation seen (Grandjean and Souty-Grosset 2000). This is a pattern that has been found in analyses of *A. pallipes* protein (Gouin et al. 2003), allozymes (Gouin et al. 2001), nuclear and mtDNA (Grandjean and Souty-Grosset 1996, Gouin et al. 2003, Fratini et al. 2005), and seems to be generic for crustacean species

(Grandjean et al. 1997, Gouin et al. 2001, Trontelij et al. 2005).

With the recent decline in the presence of *A. pallipes* in freshwaters throughout its range, there is much interest in developing means of breeding or artificially incubating eggs away from natural population sites for the purpose of enhancement and re-introduction at a later date (Reynolds 2002). From a conservation point of view, populations with high genetic variation are preferred due to the associated potential to be able to adapt to future environmental changes. Although there is recognized limited genetic variation between populations in Ireland, Britain and France (Grandjean and Souty-Grosset 2000), there may be adaptations within populations as a result of local conditions (Trontelij et al. 2005), or even the presence of distinct allele frequencies through inbreeding (due to small population sizes), especially if the population was founded by a small number of individuals (Grandjean and Souty-Grosset 2000, Gouin et al. 2001, 2003, Schulz and Grandjean 2005, Trontelij et al. 2005). Thus, with restocking, it should be preferable to source the crayfish from other populations in close proximity to the proposed site (Souty-Grosset 2005).

Even though there is limited variation with some of the above protocols, microsatellite DNA (small segments of DNA found repeated throughout the genome) can show variation within populations (Jones and Arden 2003). These have been found to be useful in exploring mating success in species where mating strategies are complex and often obscure (Jones and Avise 1997). Within populations, individuals that are closely related are more likely to share microsatellite patterns. Microsatellites have already been used in paternity testing. Jones and Avise (1997) used four specific microsatellite primers to investigate paternity in the Gulf pipefish, *Syngnathus scovelli*, while in crustaceans, McKeown and Shaw (2008) and Walker et al. (2002) found that the use of three microsatellite primers was sufficient to show multiple paternity in the brown crab, *Cancer pagurus* and the placid crayfish, *Orconectes placidus* respectively.

With genetic variation important in sustainability of populations, it is of value to see whether there is evidence of multiple paternity within *A. pallipes*. Female crayfish, after extrusion, carry their eggs in three distinct broods on the underside of the abdomen (Villanelli and Gherardi 1998, Walker et al. 2002), and with external fertilisation, several males could contribute to the paternity of a female's offspring. If females carry broods that are sired by more than one male, then this could potentially allow many males to contribute genes to the next generation, thus increasing the genetic diversity in the population. Crayfish, including the *A. pallipes* species complex, can carry spermatophores from more than one male at a time (Galeotti et al. 2007, 2009), and as mentioned above, multiple paternity broods has already been found in several crustacean species such as the American lobster, *Homarus americanus* (Gosselin et al. 2005), the crab, *Cancer pagurus* (McKeown and Shaw 2008), and another crayfish species, *Orconectes placidus* (Walker et al. 2002).

Ireland has been suggested as an ark site for *A. pallipes* (Holdich et al. 2004) due to the absence of invasive crayfish species on the island, and the absence of the crayfish plague since 1984 (Reynolds 2002). Steps have recently been taken to set a number of ark sites up (see Horton this volume, Reynolds this volume). To assess whether there is evidence of multiple paternity in *A. pallipes*, several berried females were collected from one site. Despite there being a high incidence of multiple paternity in other crustacean species (more than one male contributed to over 50% of *O. placidus* broods; Walker et al. 2002), this result was not expected for *A. pallipes*, due to its presence in Ireland in small isolated populations. If no evidence is found for multiple paternity, it should not be assumed that it does not exist in the species – it may exist at a very low level (McKeown and Shaw 2008).

METHODS

With *A. pallipes* being a threatened species, care was given not to adversely affect the recruitment of the next generation by removing all berried females from the population. Six berried females were collected from Maguiresbridge, County Fermanagh, Northern Ireland (IGRH347386). Tissue from the chelae of the female was used for DNA extraction (DNeasy protocol, Qiagen). Eggs collected from the females (40 per female, average 10 per brood, total 240 eggs) were subjected whole to DNA extraction. The same protocol used on the mothers was applied to the eggs, but with amendments suggested by Jones and Avise (1997). DNA extracts were diluted in preparation for PCR, females 1/20, eggs 1/50. Dilutions were checked by running them on 2% agarose gel.

Microsatellite primers specific for *A. pallipes* (AP 2 and 3, Gouin et al. 2000) were used on DNA extracts in PCR. Amplification was carried out in 10µl mixture using Go Taq solutions, containing 2µl DNA dilution, 0.1µl forward primer, 0.1µl reverse primer, 2µl buffer (Go Taq), 1µl dNTPs, 1µl $MgCl_2$, 0.05µl Taq, and 3.75µl ddH_2O (double distilled water). PCR program was set at 58ºC annealing temperature for 40 cycles (per cycle - 92ºC, 1 minute, 58ºC, 1 minute, 72ºC, 1 minute), after an initial denaturing cycle of 3 minutes at 92ºC. A final annealing cycle of 72ºC for 3 minutes occurred at the end of the cycles. PCR products were tested on 2% agarose gel.

Despite there being *A. pallipes* specific microsatellite primers available (AP1-6, Gouin et al. 2000), due to poor amplification of DNA from a tissue sample collected from a female in Lough Neagh by the available primers, attempts were made to create primers specific for Northern Ireland. DNA extracted from the Lough Neagh specimen was amplified with 3 ISSRs (Inter Simple Sequence Repeats) in a PCR (see Table 1). PCR (using same solutions as above) volumes were made up to 10µl with 2µl DNA extract, 2µl primer, 2µl buffer, 2µl $MgCl_2$, 0.2µl Taq polymerase, and 9.8 ddH_2O. The same PCR program as above was used. PCR extracts were purified (using Qiagen protocol), and ligated (3µl purified PCR product, 1µl GEM T Easy (50mg μl^{-1}), 1µl T_4 DNA ligase (3µM µl) and 5µl buffer; left overnight in fridge) to form the genome library. This was then transformed and cells grown out and sent for analysis. Thirteen microsatellite sets were found, and tested on 85 individuals sampled from Kilroosky lough, County Fermanagh (IGRH473274).

Table 1. ISSR sequences used in developing microsatellites.

ISSR primer sequence	Distance
$GCGC(AG)_8$	10µm
$GGCC(AG)_8$	10µm
$CCGG(AG)_8$	10µm

RESULTS

Analysis is still continuing on the samples. Results so far confirm the limited variation seen in other populations (Gouin et al. 2001). Preliminary findings using the two commercially available primers (Ap2 and 3, Gouin et al. 2000) has found no evidence for multiple paternity in *A. pallipes*. Microsatellite primers designed in the laboratory, despite showing polymorphism in the 65 individuals on which they were tested, failed to show variation in the females and their offspring.

DISCUSSION

Failure to find multiple paternity in *A. pallipes* is slightly surprising, particularly as this species shows polyandrous mating behaviour (Villanelli and Gherardi 1998). Evidence of spermatophores from multiple males on the female (Galeotti et al. 2007) would suggest that there is a possibility of multiple paternity existing in the species. With such a small sample size in this analysis (due to small size of sampled population, and consideration to the threatened status of the species), if multiple paternity does exist in the *A. pallipes* species complex, there was limited opportunity of finding it here. However, the prior work looking at multiple paternity has also used small sample sizes. Walker and Avise (2002) sampled 15 females to show the presence of this mating strategy in *O. placidus*, and McKeown and Shaw (2008) used 18 *C. pagurus* females. In contrast, Gosselin et al. (2005) sampled 108 females. If multiple paternity broods do exist in *A. pallipes*, it may be present in a low frequency (McKeown and Shaw 2008). For example, out of the 108 *H. americanus* females sampled by Gosselin et al. (2005), only 14 were found to carry broods that were fertilised by more than one male.

Austropotamobius pallipes is mostly present in Ireland in small populations (Gouin et al. 2003, Grandjean and Souty-Grousset 2000). Thus, the effective population sizes maybe reduced, with fewer males being able to contribute genes to the next generation. There is also evidence of larger males acquiring right of access to females (Villanelli and Gherardi 1998), and encounters with females in the presence of other males involving much time spent interacting with the males, rather than in copulation attempts with the females (Galeotti et al. 2009). This may have an impact on the male success of siring offspring, with the smaller more subordinate males being out-competed for access to females by the larger dominant males, of which there may be few in the population. If there are a small number of large males in the population, and with female preference for larger males (Villanelli and Gherardi 1998), only a small number of males may contribute genes onto the next generation. Thus, in a conservational context, if *A. pallipes* is to be bred in artificial conditions, it would be preferable to skew the sex ratio in favour of the males (possibly 2:1 male: female ratio) to increase the chances of the next generation having high genetic variation.

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Selection criteria for "ark sites" for white-clawed crayfish

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ABSTRACT

The white-clawed crayfish, *Austropotamobius pallipes*, is losing its range in England and Wales year by year due to invading populations of the American signal crayfish, *Pacifastacus leniusculus*, and crayfish plague. *Austropotamobius pallipes* can only survive in isolation from the invading species. The concept of safe, isolated ark sites is now widely accepted as a future necessity for indigenous crayfish. However, proper planning at both a local and a strategic level is essential if ark sites are to be successful in conserving *A. pallipes* in the long term. Careful selection of sites will maximise the chances of success. A set of selection criteria has been developed which offers a simple tool to help identify potential ark sites, for use at various scales and stages in the process of decision-making. It categorises the features of each site on a scale of "best, good, possible, poor" related to the risks. The level of risk considered to be acceptable will vary in different areas and circumstances. The tool allows for this, instead of requiring sites to meet a standard threshold for acceptance. Establishing many ark sites - and soon - will maximise the chances for survival of *Austropotamobius pallipes* in the long term.

Keywords: ark sites, criteria, white-clawed crayfish, conservation, guidance.

INTRODUCTION

The white-clawed crayfish *Austropotamobius pallipes* (Lereboullet) is our only indigenous freshwater crayfish and it is under threat in England and Wales (see Holdich et al. this volume), due to the introduction of non-indigenous species of crayfish (NICS), especially the American signal crayfish *Pacifastacus leniusculus* (Dana) (see Holdich and Sibley this volume). *Austropotamobius pallipes* are out-competed by *P. leniusculus* and they are also highly vulnerable to crayfish plague *Aphanomyces astaci* Schikora, which is often carried in populations of *P. leniusculus* and is completely lethal to all white-clawed crayfish. The progressive decline in populations of *A. pallipes* has been reported by Sibley et al. (2002) and Sibley (2003) and continues throughout England and Wales, with yet more white-clawed crayfish populations fragmented or lost due to outbreaks of crayfish plague or by competition from invading populations of non-indigenous crayfish. In many catchments where *A. pallipes* were formerly abundant, there are only a few remnant and threatened populations left. For example, only three catchments in Essex have any indigenous crayfish left (Pugh et al. 2008) and the last known population of white-clawed crayfish in Bedfordshire was lost in 2006 (Peay et al. 2006). Holdich and Sibley (this volume) show the inexorable spread of signal crayfish in South-west England since 1975, due to new introductions and progressive expansion of the established populations.

Once non-indigenous crayfish are established and expanding in a watercourse, there is limited scope, at best, to eradicate or control them. Whenever *P. leniusculus* establish in any part of a catchment *A. pallipes* will eventually be replaced by them in the long term, unless there are barriers preventing invasion of the whole catchment. The entire population of *Austropotamobius pallipes* in a catchment may be lost much sooner if it is infected with crayfish plague, which can eliminate white-clawed crayfish within weeks. This means that even where there are locally abundant populations of *A. pallipes* in watercourses at present they are all potentially vulnerable.

Sibley (2003) forecast that most rivers in England and Wales might lose their populations in the next 30 years. Local or regional extinction from river systems seems increasingly likely in even shorter time in some areas, including several rivers in South-west England (Holdich and Sibley this volume). *Austropotamobius pallipes* can only survive in isolation from *P. leniusculus* and other invasive non-indigenous crayfish species.

In developing a conservation strategy for *A. pallipes* we need to prevent any more introductions of NICS and provide isolation for *A. pallipes*. Holdich et al. (2004) recommended a strategy of introductions of *A. pallipes* to new, isolated sites that would provide a basis for conservation of the indigenous species, which they described as “ark sites”.

A protocol was developed for re-introduction of *A. pallipes* to rivers from which they had been lost historically (Kemp et al. 2003). At that time attention was being given to the potential to restock rivers where *A. pallipes* had been lost, for example due to pollution or outbreaks of crayfish plague due to contaminated fish or angling nets as part of the Life in UK Rivers initiative. However, Holdich et al. (2004) highlighted the threat of invading *P. leniusculus* in rivers and proposed introductions to isolated sites that had not had *A. pallipes* previously, especially relatively recently created still water sites. The potential of new minerals sites for this is being promoted by Buglife (Whitehouse et al. 2009, see Kindemba and Whitehouse this volume). Whilst the introduction protocol (Kemp et al. 2003) provided useful principles, more detail is needed about how to select potential ark sites in practice.

The aim of this work has been to provide a simple, but flexible tool for land managers and ecologists and other practitioners, to help them assess potential ark sites. It has been designed for use in England and Wales, although a similar approach may be of value in other parts of the range of white-clawed crayfish in Europe.

A simple set of selection criteria has been developed to help those seeking potential ark sites for *A. pallipes*. By avoiding unsuitable sites, efforts and resources can be concentrated on those most likely to succeed. This will benefit the conservation of *A. pallipes* locally, regionally and nationally. Potential ark sites will be found at local level as individual isolated sites, but they need to be considered in the context of individual catchments and within the region or River Basin District as a whole (as now used by the Environment Agency under the Water Framework Directive).

The search for ark sites is likely to proceed from region and catchment scales, based on information on the distribution of crayfish species. Where are the existing populations of *A. pallipes*? What are the threats to those existing populations? If NICS are invading a catchment how far and how fast can they spread? Are there any barriers to invasion in the medium to long term? What opportunities are available for potential ark sites, or can be actively sought? The regional approach is ideally represented by the South West Crayfish Conservation Strategy (Nightingale et al. 2009, Nightingale this volume).

At the same time as strategies are being developed for whole regions and catchments, individual sites may be suggested by landowners, or developers such as mineral operators who are aiming to provide benefits for nature conservation (see Horton this volume). Recently worked quarries and other mineral sites may offer excellent opportunities for new ark sites, as promoted by Buglife (Whitehouse et al. 2009, Kindemba and Whitehouse this volume).

But which sites have the best chance of succeeding in the long term? The approach is a risk-based one, as it is the risks that are most likely to determine the success of an ark site in the medium to long term. The key factors are:

- Is the site at risk from colonization by NICS?
- Is there a significant risk of crayfish plague?
- Are there any other adverse factors?

Guidance on selecting ark sites will be useful at different scales and stages. The intention is that users will utilise them for different purposes according to regional or local needs. Examples of potential uses are as follows:

- In initial desk studies at the scale of region, River Basin District, catchment or administrative district.
- To help select and prioritise potential sites identified from a desk study.
- As an aid to recording relevant features during an appraisal on site, for later evaluation of a potential ark site.
- To help assess the risks for a potential ark site and its likelihood of success.
- To help assess the risks for an existing population of *A. pallipes*, which may be in a site considered to be an existing ark site, or may be under threat – can those threats be reduced?
- To record the basis for deciding whether a site is considered to have potential to become an ark site. This information would be used in a more detailed feasibility study and could be included as part of the information supplied to support an application to statutory agencies to introduce *A. pallipes* into a potential ark site.
- To encourage recording of relevant features of sites as an aid to future reviews of success of ark sites, for an evidence-based approach to improving best practice guidance on ark sites in future.

The selection criteria are the same for different uses but the information about individual sites that is used in the process and the decision-making itself may differ.

DESCRIPTION OF THE SELECTION CRITERIA

Selection criteria for ark sites have been prepared as a spreadsheet tool, which guides a user through the criteria, compiling information about a site and its suitability. It then gives guidance on how to use the information, to decide whether to consider the site as a potential ark site. If the site is considered to be a potential ark site, the user will proceed to detailed assessment of the site and, if feasible, to preparation for the introduction of *A. pallipes* to the site. This detailed stage is not covered by the spreadsheet at present, but there is some existing guidance in Kemp et al. (2003).

The selection criteria are set up in two stages, followed by decision-making. A user wanting to use the selection criteria starts by obtaining information about a site. If done at a regional scale, information may be from maps, aerial photographs, local plans, information held by the Environment Agency and other sources on crayfish distribution, water quality etc. In other cases there will be more detailed information on a site and its environs from a recent field survey or local knowledge.

The first stage of the selection criteria is a coarse filter of five questions that allows any obviously unsuitable sites to be excluded, on grounds of: 1. the known presence of NICS, 2. lack of permanent water, 3. insufficient physical isolation to avoid colonization by NICS, or 4. poor water quality.

In addition, one question excludes sites that already have *A. pallipes* as they are not classed as <u>potential</u> ark sites. There is a presumption against the introduction of *A. pallipes* to any isolated site that already has a population present, mainly on grounds of biosecurity. The risks of multiple stockings were shown in Finland in re-stocking projects with noble crayfish *Astacus astacus (*Linnaeus) (Jussila et al. 2008). A site with an existing population of *A. pallipes* may be assessed as an <u>established</u> ark site, or it may be an existing population at risk. A user can utilize the criteria to help assess or re-assess the threats to the population.

The second stage of the selection criteria is a series of nine tables, each with a different topic, as listed in Table 1 below. In each table there is a series of descriptions, each of which is listed against a qualitative rating: Best, Good, Possible, Poor. The user selects the description that best matches the site being assessed and ticks the corresponding box, which assigns a rating and copies it to a summary table. There is space for a user to add descriptive text to explain the basis for the choice or any limitations. Each table has explanatory notes and references to guide the user. The criteria considered to be most important are listed early in the series of tables, so users can opt to screen out unfavourable sites early, or continue to a full assessment. The first three tables assess the likely effectiveness of barriers to colonization by NICS. The fourth table deals with the availability of water year round and its quality. The next four tables are mainly related to human activity and the likelihood that this will lead to introduction of crayfish plague or the release of NICS into the site. Broadly, sites with high levels of angling and other general public use are considered to have greater risks than sites with little public access, or where management has conservation objectives. The last table deals with physical habitat in six sections. Although these are rated, they are considered to be only minor elements in the decision-making process, because it is relatively simple to create or improve physical habitat for *A. pallipes* (Peay 2003) and other crayfish species with similar habitat preferences (Johnsen and Taugbøl 2008).

Table 1. Selection criteria for potential ark sites.

Criteria Table number	Topic
1	Degree of enclosure
2	Terrestrial barriers: proximity to watercourses with potential for colonization by NICS
3	Aquatic barriers: for sites not wholly enclosed
4	Water quality and quantity
5	NICS and crayfish plague – local status
6	Angling
7	Usage and risks from access
8	Ownership
9	Physical habitat

Once ratings for a site have been obtained, the user reviews the compiled summary table of ratings, together with two other tables, entitled “Action” and “Rationale”, which guide the decision-making process. The “Action” table recommends whether to proceed or not, based on the number of ratings from best to poor. It suggests “go”, “improve then go”, “possible go”, or “no go unless other options limited”. There is no strict threshold for accepting a site as a potential ark site; it depends on the acceptable level of risk. There is no numerical scoring or aggregation of the qualitative ratings from the tables, because this would risk masking relevant factors. In addition, a scoring system would encourage adoption of some threshold of pass or fail for potential ark sites instead of an evaluation of relative risk.

The “Rationale” table asks the user to consider the site in a local and regional context of risks and conservation objectives. Different levels of risk will be accepted depending on the circumstances and this is best determined as part of a local or regional conservation strategy for *A. pallipes* conservation. Current abundance of *A.*

pallipes varies markedly in different regions. The same threats apply everywhere, but the immediacy varies. In addition, the number of options for potential ark sites differs and the resources available to develop them.

Where users consider they have a largely suitable site but with some risk factors they can use a Table entitled ”Improvements” to set out their own plans for improvements to reduce risk or increase habitat quality at individual sites. This also allows a user to re-consider a site, which may be sub-optimal at present but may be more favourable if improvements are implemented. .

When the selection criteria have been used and a decision is made to proceed with a potential ark site, this does not mean a selected site should be stocked immediately. There should be a detailed feasibility study to: check that the introduction would not have any significant adverse impacts on existing features of high importance for biodiversity; secure the agreement of relevant stakeholders; identify an appropriate source of donor stock, and secure the resources necessary to set up the site and to monitor its success subsequently. Only if a potential ark site is confirmed as suitable at this detailed stage should an introduction be made. If the introduction is successful in achieving a breeding population it can then be classed as an established ark site.

The selection criteria have been issued as a spreadsheet tool, which can be downloaded from the Buglife website: http://www.buglife.org.uk/conservation/currentprojects/Species+Action/Conserving+our+Crayfish/Crayfish+Ark+Site+Selection+Criteria.htm or obtained from the author. Whilst reviewers have already carried out some field-testing and provided valuable comments on the criteria during their development, the spreadsheet has been issued as a draft initially so other users have the opportunity to use and comment on it.

DISCUSSION and FUTURE PROSPECTS

The selection criteria require users to consider the rationale for action on potential ark sites for *A. pallipes* and the level of risk that is appropriate to the local and regional circumstances. In many areas there will be few “best” sites and it will be necessary to accept some risks in efforts to conserve the indigenous crayfish. For example, in a catchment where existing populations of *A. pallipes* are small, fragmented and being lost rapidly, delaying starting ark sites until ideal potential ark sites are available may mean that there are few or no populations left from which donor stock can be obtained within a catchment by the time sites have been selected and approved. In those circumstances, it may be better to start one or more potential ark sites where barriers may not be effective in the medium to long term, but nonetheless stocks of crayfish can be maintained and increased in the wild so that there is donor stock available when more or better sites are found.

This approach has already been applied in North-west England in the Ribble catchment. *Austropotamobius pallipes* were formerly abundant and present in most parts of the upper catchment, but only three small partly isolated populations survived when crayfish plague swept through the catchment, apparently introduced as a contaminant with a consignment of stocked fish (Guthrie and Bradley 2006, pers. comm.). One of the surviving populations is being lost progressively, due to an apparently plague-free population of introduced *P. leniusculus* expanding down the small headwater stream. *Austropotamobius pallipes* were rescued from the leading edge of the invading *P. leniusculus* population in 2007 and stocked into another tributary, where *A. pallipes* had been lost some years previously due to crayfish plague. In the long term, that watercourse is not safe from colonization, but once the population develops, it can be used to stock other more secure sites once they are identified. An isolated length of watercourse was identified in 2008 as a good potential ark site in the catchment and after a feasibility study and the necessary approvals, another rescue operation was carried out to stock this site, which has lower risks in the long term. Crayfish populations in all three populations are being monitored (author, unpublished).

Wildlife Trusts, the Environment Agency, ecological consultants and others who may want to contribute to the conservation of *A. pallipes* need guidance about potential ark sites now. If we do not find potential ark sites and establish new populations quickly, we may find *A. pallipes* becomes extinct in individual catchments or whole River Basin Districts before we find alternative ark sites for the threatened populations. Only a handful of ark sites have been established so far, all of them recent (e.g. Sibley et al. 2006, Sibley et al. 2007, Peay and Hiley 2007a, 2007b, Peay and Guthrie 2008), which means it has not been possible to thoroughly field-test the selection criteria at this stage. The selection criteria have been compiled with the knowledge available at present, from the literature and the experience of the author and others working with *A. pallipes* in England, but there are uncertainties, which are acknowledged in the selection criteria. The purpose of providing the selection criteria now is to encourage people to take action locally and that completed assessments should be kept and compiled regionally. Over time when there are more established ark sites, the intention is to review the case studies and to revise the criteria and other guidance based on the evidence of outcomes.

Users who have used the selection criteria are recommended to lodge them with the Environment Agency locally. Completed assessments of sites and records of decisions taken would be of value. Which sites were screened out, and which were considered to be potential ark sites? Of those selected, which were taken forward to the introduction stage and what was the outcome for *A. pallipes*, both in the short term and long term? Answers to these questions from plenty of future case studies will help to develop evidence-based guidance and conservation strategies for *A. pallipes* in future.

It is clear that NICS will continue to expand their range in England and Wales and that much of the existing range of *A. pallipes* in watercourses and some still waters will be lost as NICS gain ground (Holdich and Sibley this volume, Sibley et al. 2009). However, identification of potential ark sites and setting up those confirmed as suitable gives grounds for some optimism that the indigenous crayfish *A. pallipes* will not be lost from the fauna of England and Wales. Ark projects are relatively simple to do and can provide achievable and measurable conservation benefits for indigenous crayfish. Action to find potential ark sites now will help to ensure *A. pallipes* are there for future generations to appreciate.

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Using GIS to identify and prioritize regional ark sites for white-clawed crayfish: aggregate and mineral extraction sites in South-west England

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ABSTRACT

With the white-clawed crayfish *Austropotamobius pallipes* declining throughout its range in England and Wales there is an urgent need for effective and sustainable conservation techniques such as ark sites (isolated refuge sites). This study demonstrates the enormous potential former aggregate and mineral extraction sites have for the establishment of ark sites; and how the analysis of spatial data using Geographical Information Systems (GIS) can be used as a starting point for building a regional network of ark sites for white-clawed crayfish. The study used GIS to analyse data on aggregate and mineral extraction sites, crayfish distribution and watercourses, to assess the potential for ark site creation in South-west England against agreed criteria.

The project has identified 39 potentially suitable sites for ark site establishment, all of which are isolated, have the right geology and are either part or fully wet. Analysis of the sites based on geology has identified 11 as “best” sites, eight as “good” and 20 as “possible” locations to establish an ark site. The sites identified can now feed directly into the South West White-clawed Crayfish Conservation Strategy (SWWCCCS) for more detailed “on the ground” site assessments.

Keywords: aggregate sites, mineral sites, ark sites, mapping, GIS, South-west England, spatial analysis, white-clawed crayfish

INTRODUCTION

This research was completed as part of a project by Buglife - The Invertebrate Conservation Trust entitled “Bringing Aggregates Sites to Life: the role of the aggregates industry in conserving the White-clawed crayfish”. This project aimed to raise the profile of crayfish conservation and promote the use of quarries and pits as ark sites within the aggregate and mineral industry. The project was carried out in 2009 in two phases: the first was a guidance document on the selection and establishment of crayfish ark sites on former aggregate extraction sites (Whitehouse et al. 2009), the second phase identified a set of candidate aggregate ark sites in South-west England (a pilot region).

White-clawed crayfish and ark sites

The white-clawed crayfish is declining throughout its range in England and Wales (Sibley 2003, Holdich et al. 2004) but the current situation differs from region to region. In some areas few populations remain, whilst in others there are still relatively extensive populations. However, even for some of these large populations future prospects may not be good, with imminent or future threats apparent (see Holdich and Sibley this volume). White-clawed crayfish, *Austropotamobius pallipes* (Lereboullet), cannot survive where there are non-indigenous crayfish species (NICS) and currently there are no practical methods for eradicating NICS from catchments. One approach to conserving the white-clawed crayfish is to establish isolated new refuge sites - known as “ark sites” - where new populations can be established, safe from non-indigenous crayfish and crayfish plague (Holdich et al. 2004, Horton this volume, Peay this volume). Ark sites are now recognized as an essential part of the white-clawed crayfish conservation strategy for the UK.

Aggregate and mineral sites

The aggregate and mineral extraction industry can make a significant contribution to UK Biodiversity Action Plan (BAP) targets through the management and creation of habitats (White and Gilbert 2003, Davies 2006, Whitehouse 2008). Extraction sites can make a significant contribution to the conservation of white-clawed crayfish as they are often ideal potential ark sites, being newly-created, isolated, permanent water bodies, providing a variety of different habitats.

Regional ark site assessment

Assessing potential ark sites on a regional scale provides a focus for conservation efforts by identifying those catchments with populations most under threat and so prioritizing populations for urgent conservation action. In regions where white-clawed crayfish populations are currently stable and at a lower threat level the identification of potential ark sites is not only an essential stage in preparing a long-term conservation strategy, but can also provide an “insurance policy” against total loss of populations through non-indigenous invasive crayfish or crayfish plague. Once desk studies have identified and prioritised suitable ark sites, subsequent site visits can be carried out to “ground-truth” this process. South-west England was chosen as a study area as it has around 20 populations remaining and these are declining rapidly and has lost three out of four of the most abundant populations in the last three years, and so there is an urgent need to instigate the creation of ark sites. The aim of this research was to identify a set of candidate ark sites in South-west England using GIS (MapInfo) to assess spatial data on mineral sites, crayfish distribution and environmental data. The project was conducted in collaboration with the South West White-clawed Crayfish Conservation Strategy (SWWCCCS) (Nightingale et al. 2008, Nightingale this volume*)*, feeding into the strategy action to identify potential ark sites within the region.

MATERIALS and METHODS

This work used the South-west region as a case study to assess the effectiveness of Geographical Information Systems (GIS) as a tool for identifying potential ark sites within a region. GIS-based analyses identified those catchments with white-clawed crayfish populations most in need of conservation action and then assessed active aggregate and mineral extraction sites for their suitability as ark sites for these threatened populations. The assessment criteria focused on four key criteria for ark sites that could be assessed using GIS: site geology, threat from non-indigenous crayfish species, site water status (degree of wetting), and isolation (as defined by Peay this volume).

Datasets

The analysis utilised a range of datasets obtained from collaborating organizations; these are described below:

Aggregate and mineral extraction datasets were sourced from the RSPB Nature After Minerals programme (www.afterminerals.com) under licence. This information was collated and analysed in 2005 from mineral planning authorities and includes data on all active extraction sites in the region including name, ownership, location, area, materials extracted, site water status and restoration plans.

Hydrological datasets for South-west England was sourced from the Environment Agency, South-west Region under licence, including data on the location of rivers, catchment boundaries, and reservoir and lake polygons. Data were also provided for the boundary of the South-west region and the constituent counties.

South-west crayfish datasets were also sourced from the Environment Agency. These provided distribution data for white-clawed crayfish and non-indigenous crayfish species as well as the location of crayfish surveys and areas where white-clawed crayfish populations have been lost (see Fig. 1). This information was collected between 1970 and 2008. It should be noted that survey effort has not been entirely consistent across the region during this period. A number of records for white-clawed crayfish in the Bristol Avon catchment are believed absent and are awaiting field confirmation. This apart, the dataset comprises the most up-to-date information available when the analysis was carried out (the ‘Astacidae’ records shown were taken before crayfish species were routinely identified to species level).

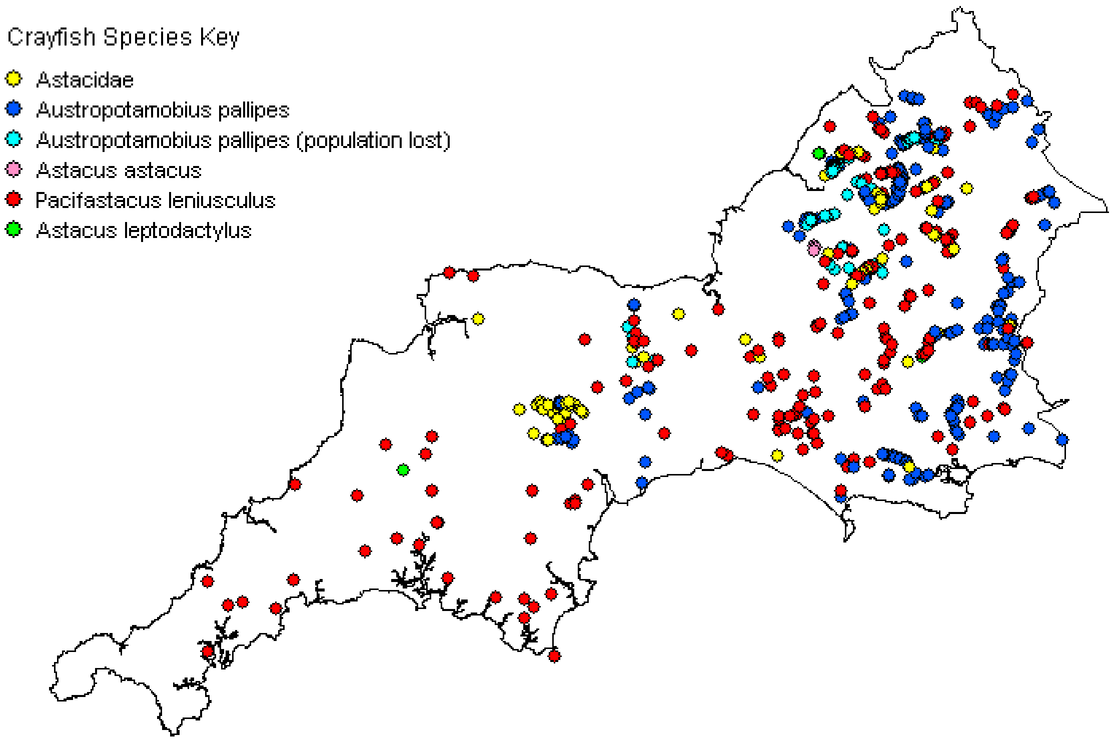

Figure 1. Distribution of crayfish species records in the South-west (reproduced by permission of the Environment Agency©, Environment Agency 2009).

Analysis

The GIS program used to analyse the data was MapInfo. Below are the steps followed when analysing the data. The resulting sites identified are presented in Tables 1-3.

Step 1 – Non-indigenous crayfish threat

River catchments were classified by the presence or absence of non-indigenous and indigenous crayfish species. Five catchment categories were defined and mapped (see Fig. 2); these categories are described below, along with statistics for the region:

- Indigenous crayfish catchment (has only white-clawed crayfish records – 14 catchments in the South-west)
- Mixed non-indigenous and indigenous catchment (has both white-clawed and

non-indigenous crayfish records – 36 catchments in the South-west)

- Mixed non-indigenous and indigenous (lost populations) catchment (has both white-clawed population that have been lost and non-indigenous crayfish records – two catchments in the South-west).
- Non-indigenous catchment (only non-indigenous species records – 52 catchments in the South-west)
- Empty catchment (no crayfish records present – 92 catchments in the South-west)

This analysis broadly highlights the degree of threat to existing white-clawed crayfish populations from non-indigenous (i.e. in the mixed catchments) using a similar technique to Sibley (2003). The assessment operated on the basis that if non-indigenous crayfish were present in a catchment any indigenous populations present would be under threat (unless physically isolated from potential invasion). The catchments were also grouped into connected catchments and re-categorised (Fig. 3). The level of threat could be analysed in more detail for some areas of the region where greater survey effort has taken place (and therefore data is of higher quality). However, this could not be completed throughout the region.

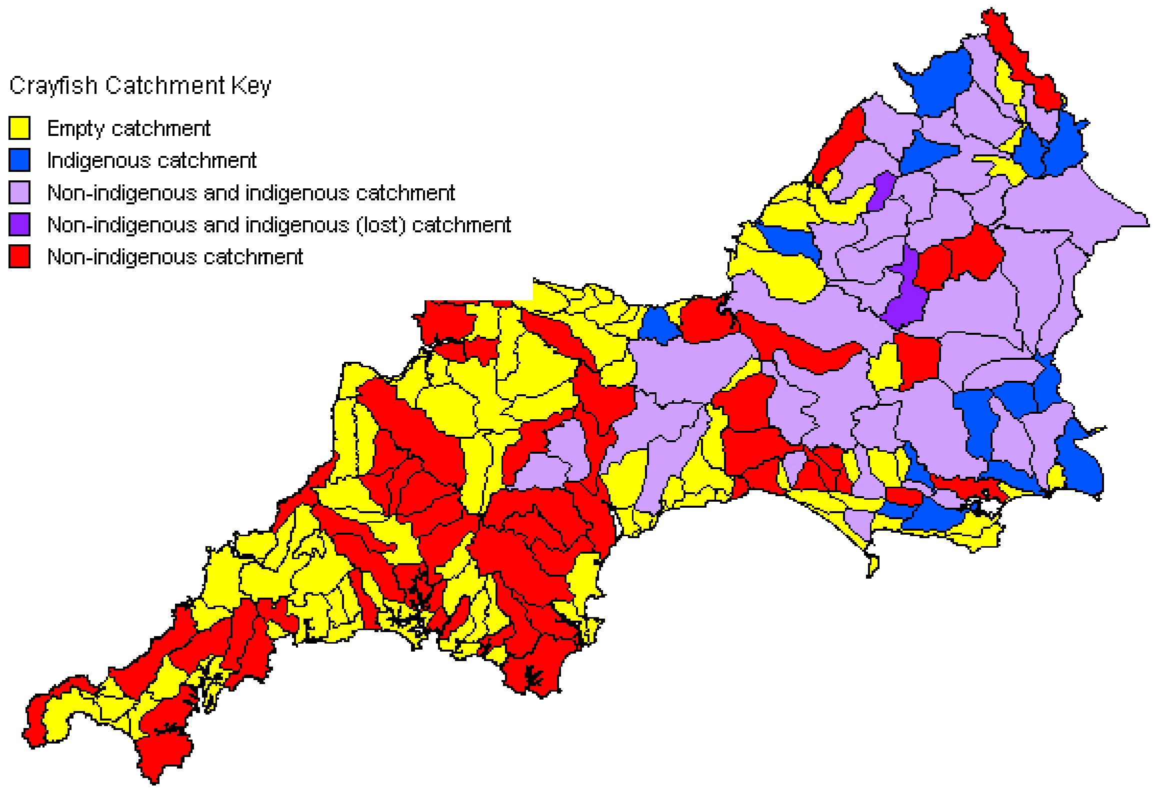

Figure 2. Catchments categorised by presence and absence of indigenous and non-indigenous crayfish species (reproduced by permission of the Environment Agency©, Environment Agency 2009).

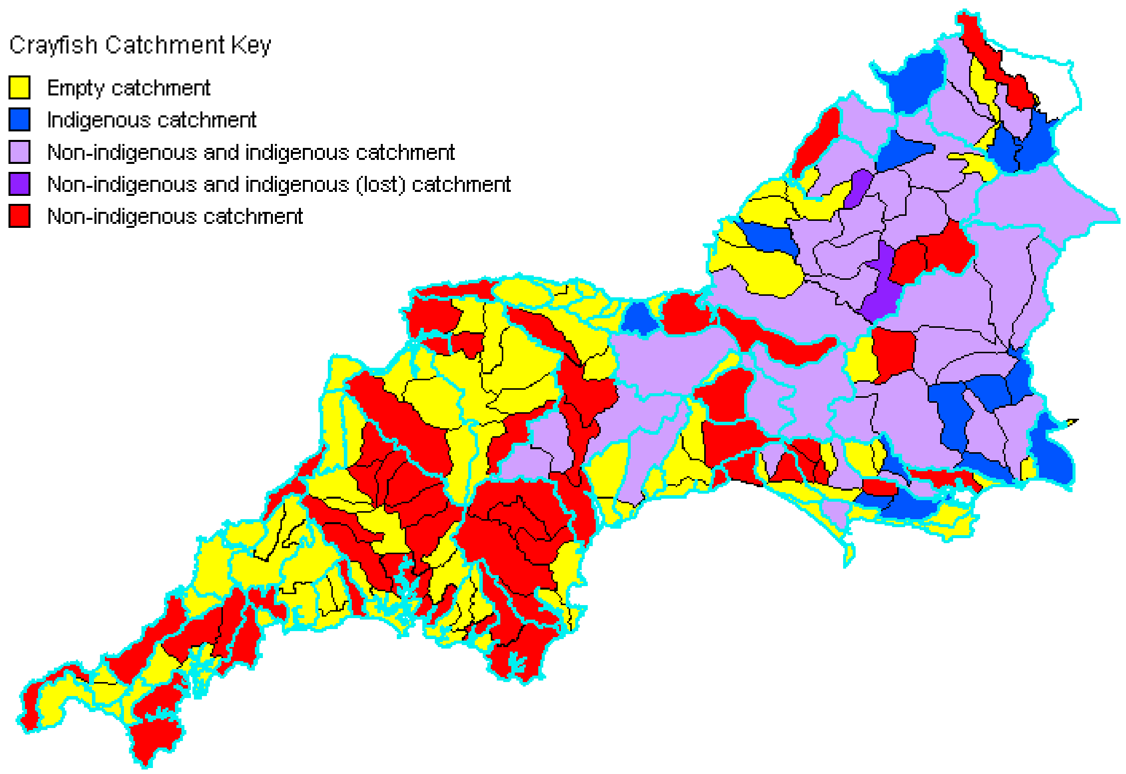

Figure 3. Catchments categorised by presence and absence of indigenous and non-indigenous crayfish species. Light blue line shows groupings of connected catchments – for reclassification of catchments based on connectedness see Tables 1-3 (reproduced by permission of the Environment Agency©, Environment Agency 2009).

Step 2 – Site water status

Aggregate and mineral sites throughout the region were classified according to the degree of wetting on each site; "fully dry" sites were filtered out from the "fully wet" and "part wet sites", "fully dry" sites were removed at this stage, as a water body would not be easily created on these site.

Step 3 – Site geology

Sites were separated into three types defined by the type of aggregate or mineral they were extracting:

- Limestone (and chalk) sites – likely to give rise to most suitable conditions for white-clawed crayfish, classed as "best" potential ark sites.
- Geology two sites (clay sites, sandstone, shales, slate and mudstones) – classed as "good" potential ark sites.
- Geology three sites (sand, gravel and metamorphic/igneous rock) - classed as "possible" potential ark sites.

Some sandstone sites and sites with igneous rock may be too acidic for white-clawed crayfish and so would require a water chemistry analysis when further site assessments take place. Sand and gravel sites are less ideal sites as refuge habitat may be sparse, but the quality of these sites can easily be improved through habitat creation, see the aggregate industry ark site guidance (Whitehouse et al. 2009) for more information.

Step 4 - Isolation

Sites were then further split into two sets through buffering and then assessing site isolation from watercourses. These were then filtered so those sites which included water courses within the 50 m or the 100 m buffer zones were removed leaving only two sets of isolated sites: 50 m buffered sites and 100 m buffered sites. Some of the larger extraction sites were included despite having water courses within the sites, these were large sites that had a significant area of the site that was isolated, these were labelled as “part isolate”.

Ranking results

The sites were filtered and categorised through GIS, the sites were then split into geological type as a defining factor of site suitability for white-clawed crayfish ark sites, within these geological classifications (see Analysis – Step 3) the sites have been given a quality number based on other attributes need for ark sites (isolation and water presence) this is defined by:

Quality 1 sites: fully wet, without a water course within a 100 m buffer
Quality 2 sites: part wet, without a water course within a 100 m buffer
Quality 3 sites: fully wet, without a water course within a 50 m buffer
Quality 4 sites: part wet, without a water course within a 50 m buffer

RESULTS

The authors analyzed 231 extraction sites in the South-west, which included 85 limestone sites, 44 geology “two” sites, 61 geology “three”’ sites and 39 poor sites (unsuitable geology). Of these, 78 sites are either wet or part wet, which makes them suitable for the creation of reasonably-sized water bodies. Thirty-nine sites (17% of sites analyzed) were identified as sufficiently isolated and either fully-wet or part-wet sites and so had potential as ark sites, of these there were 11 best, eight good, and 20 possible ark sites (based on geology). These sites are scattered across the South-west region.

The analysis identified three sites as the best potential ark sites in the region. These sites are all in South Gloucestershire and comprise three linked sites adjacent to each other. These are all limestone sites, they are isolated from watercourses by more than 100m, and they are fully wet (or will be after the extraction operations have ceased). They are also present in a mixed “non-indigenous and indigenous” crayfish catchment and so could provide important ark sites for the potentially threatened white-clawed crayfish population in this area.

The other sites vary in their attributes as ark sites as shown by the tables below (Tables 1-3). The limestone sites are considered the best potential ark sites (Fig. 4), Geology 2 sites are classed as “good” (Fig. 5) and Geology 3 are “possible” future ark sites (Fig. 6). Nested within the geological types there are four quality levels added as a further guide to the suitability of the sites.

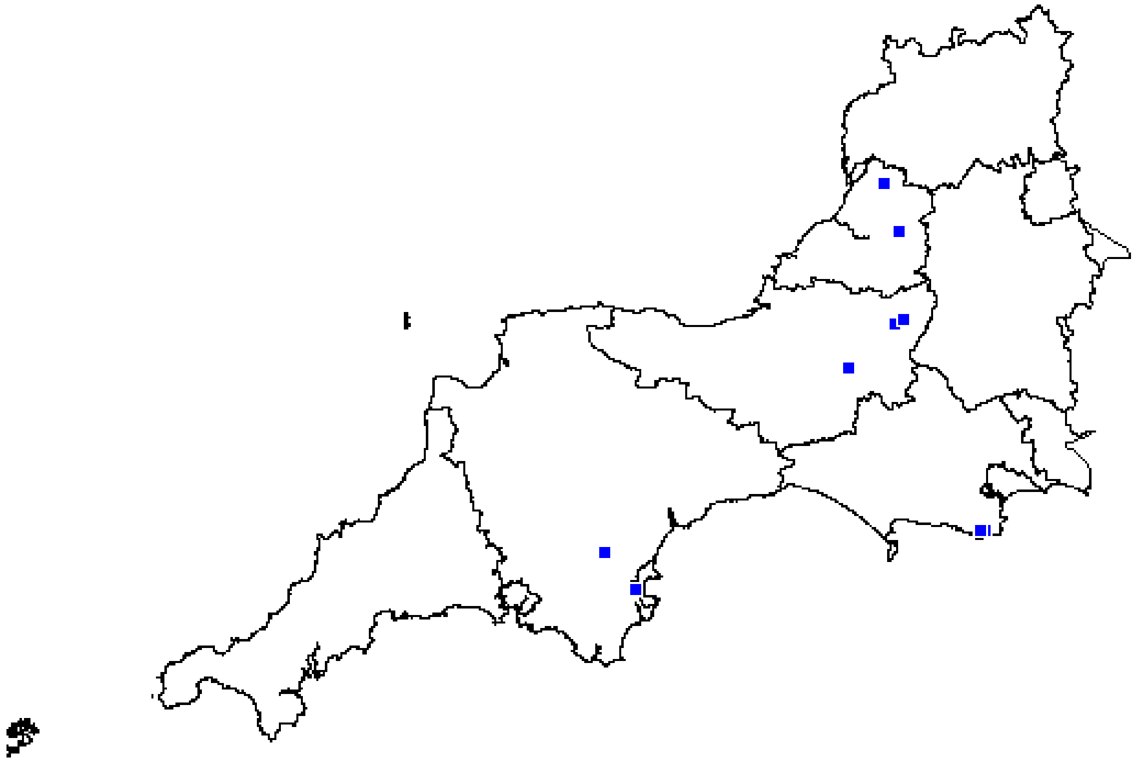

Figure 4. Points showing the location of potential ark sites on limestone mineral sites, (reproduced by permission of RSPB©, RSPB 2009 and the Environment Agency©, Environment Agency 2009).

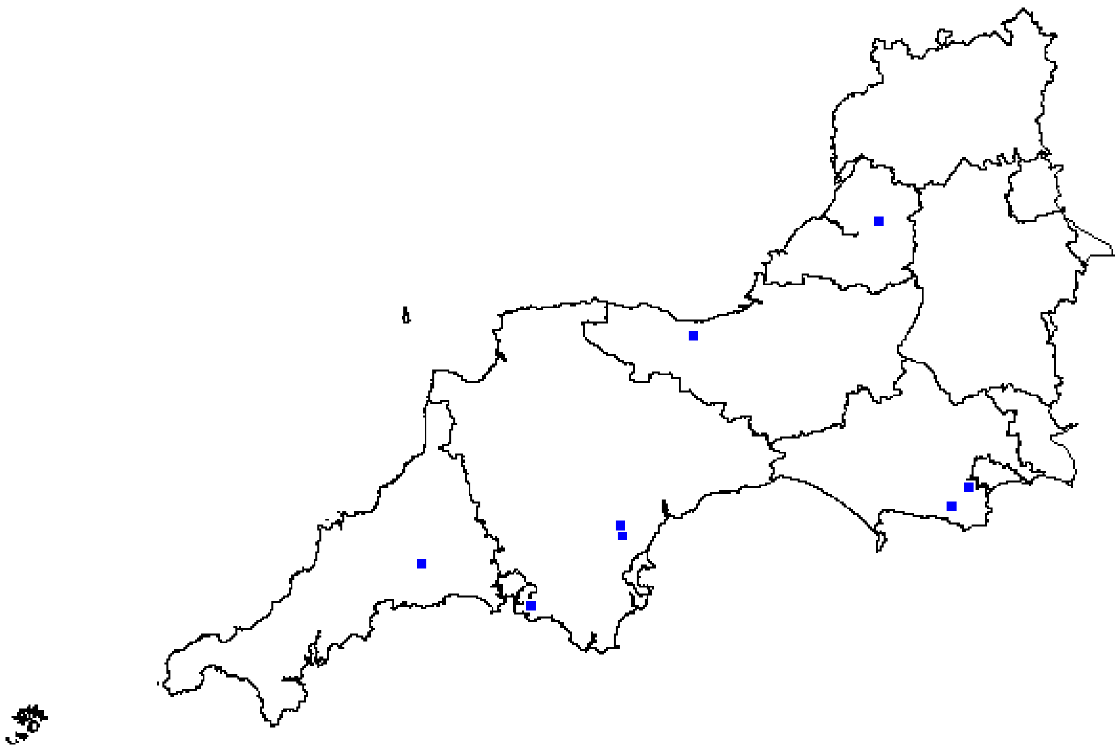

Figure 5. Points showing the location of potential ark sites on geology 2 mineral sites (reproduced by permission of RSPB©, RSPB 2009 and the Environment Agency©, Environment Agency 2009).

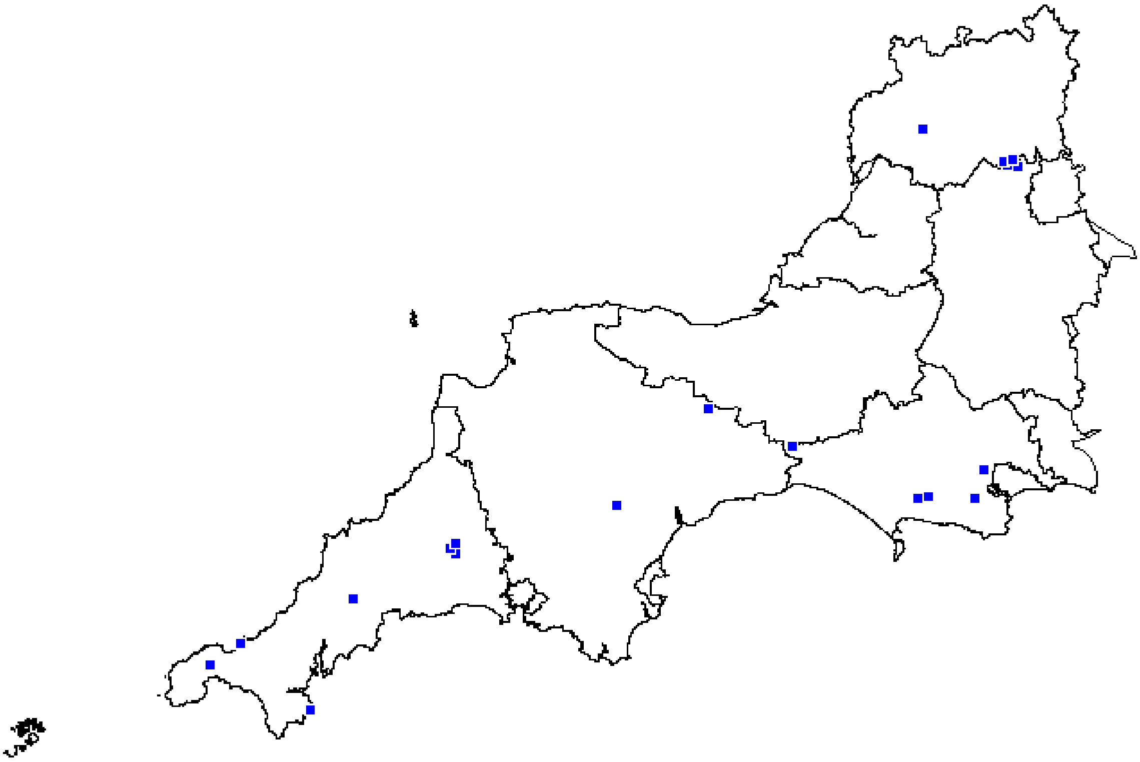

Figure 6. Points showing the location of potential ark sites on geology 3 mineral sites (reproduced by permission of RSPB©, RSPB 2009 and the Environment Agency©, Environment Agency 2009).

DISCUSSION

The suitability of South West aggregates and mineral sites

The project produced an initial assessment of aggregate and mineral sites in South-west England and showed their suitability as ark sites. There were three "best" sites based on this initial assessment present in South Gloucestershire. The other sites vary in their suitability having a range of "best" to "possible" ark site attributes, see Tables 1 to 3. The existing report on phase two of the project, the report this paper was extracted from, (Kindemba et al. 2009) provides a large amount of information on the individual sites, allowing flexibility when selecting an appropriate ark site, as the type of ark site chosen will vary depending on the local situation.

The 39 potential ark sites identified will also need an "on the ground" site assessment that takes into consideration other undiscovered merits and issues for each site, which will further work towards identifying the most suitable ark sites for the South-west. For example, isolation of a site will need further assessment as the GIS analysis assessed distance from watercourses and larger waterbodies but not isolation in relation to other aquatic habitats such as wetlands.

A site assessment should start by working through the "coarse filter for ark site selection", which is outlined in the aggregate industry ark site guidance (Whitehouse et al. 2009) and then follow more detailed site assessment criteria, which are currently being developed for further site assessment (Peay this volume). Further publications are cited at the end of this report regarding habitat management, reintroduction and monitoring for white-clawed crayfish (Holdich 2003; Holdich and Sibley 2003; Kemp et al. 2003; Robbins and Sibley 2009a, 2009b, 2009c; Peay 2003a, 2003b).

The habitat features of a site may not initially seem to be suitable as a white-clawed crayfish ark site; however, habitat creation and enhancement can be used to create suitable conditions (Peay 2003). With careful planning ark sites are easily integrated with other after uses for aggregate sites, such as nature conservation, angling, amenity and education. More information on these topics is available in the Aggregates industry Ark site guidance (Whitehouse et al. 2009).

The operators/owners of all the priority sites identified by this work will be contacted to initiate the next stage of the project and to inform them of the possible significance of their site for white-clawed crayfish. If an inspection of the site and more detailed survey confirms the suitability and the operator/owners are willing to participate, information will be provided on how to proceed with further assessment and development of an ark site.

White-clawed crayfish are protected under UK wildlife and fisheries legislation (see Holdich et al. this volume), which means that a number of licenses are required to catch white-clawed crayfish and/or move them to new sites, so professional advice must be sought when planning ark sites.

This report was developed through collaboration with the SWWCCCS steering group. The SWWCCCS is working towards the preservation of populations of white-clawed crayfish in the region, and one of the strategy's specific aims is the identification of potential ark sites. This report and further information about suitable ark sites in the South-west will feed directly into The Strategy and will be taken forward.

CONCLUSIONS

This study clearly demonstrates the enormous potential for the establishment of ark sites on former aggregate and mineral extraction sites. The current analysis has identified 39 potential ark sites from currently active workings, graded (using geology) as 11 best sites, eight good sites and 20 possible sites. The sites identified can now be taken forward for further on-site assessment, by operators/owners or through the SWWCCCS. A range of other criteria will need to be considered, one of the most important being adequate isolation at a local scale.

This study has been carried out at a regional scale. A further iteration could be carried out at catchment scale within a region or River Basin District, which would allow some additional details to be obtained, e.g. using aerial photography or information on land use.

This pilot study demonstrates how analysis of spatial data using GIS can be used as a first step towards building a regional network of ark sites for white-clawed crayfish. The analysis can be broadened to sites other than extraction sites (although they alone do have the potential to generate a large number of potential sites), such as lakes, reservoirs and other water bodies. The authors recommend that this approach is used in other regions to provide a starting point for identifying a network of potential ark sites across England and Wales.

ACKNOWLEDGEMENTS

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APPENDICES

Appendix 1

Table 1. Potential ark sites on aggregate and mineral sites – Limestone sites (reproduced by permission of RSPB©, RSPB 2009 and the Environment Agency©, Environment Agency 2009).

Quality No. [a]	Site Name and Operator	County	Material Extracted	Isola-ted[b]	Wet (Fully/ Part)[c]	Catchment Type *(Connected catchments)*[d]
1	Tytherington Extension - Hanson Aggregates – South	South Gloucestershire	Limestone	Yes	Fully	Indigenous and non-indigenous *(Non and non indigenous)*
1	Tytherington – Hanson Aggregates – South	South Gloucestershire	Limestone	Yes	Fully	Indigenous and non-indigenous *(Non and non-indigenous)*
1	Tytherington Extension - Hanson Aggregates – South	South Gloucestershire	Limestone	Yes	Fully	Indigenous and non indigenous *(Non and non-indigenous)*
2	Linhay Hill - E & JW Glendinning Ltd	Devon	Limestone	Yes	Part	Non-indigenous *(Non-indigenous)*
2	Lewis Acton – Lewis & Son	Dorset	Limestone	Yes	Part	Empty *(Empty)*
2	Swanworth – Tarmac Southern Ltd	Dorset	Limestone	Yes	Part	Empty *(Empty)*
2	Colemans – Bardon Aggregates – South West	Somerset	Limestone	Part	Part	Indigenous and non indigenous *(Indigenous and non-indigenous)*
2	Lake View - Nigel Cox	Somerset	Limestone	Yes	Part	Non Indigenous *(Non-indigenous)*
3	Wick - RMC Western	South Gloucestershire	Limestone	Part	Fully	Indigenous and non indigenous *(Indigenous and non-indigenous)*
4	Yalberton – Talisman Solutions Ltd	Devon	Limestone	Yes	Part	Empty *(Non-indigenous)*
4	Merehead Quarry - Foster, Yeoman Ltd	Somerset	Limestone	Part	Part	Indigenous and non indigenous *(Indigenous and non-indigenous)*

a. For quality number definitions see Methods – *Ranking results*
b. Sites were either 'fully' isolated by a 50 m or 100 m buffer from a watercourse or for larger sites part isolated i.e. some of the at least part of the site was 50m or 100m from a watercourse
c. For wet definitions see Methods – *Analysis*: Step 2 - Site water status
d. For catchment definitions see Methods – *Analysis*: Step 1 – Non-indigenous crayfish threat

Appendix 2

Table 2. Potential ark sites on aggregate and mineral sites – Geology 2 sites (reproduced by permission of RSPB © RSPB 2009 and the Environment Agency©, Environment Agency 2009).

Quality No.[a].	**Site Name and Operator**	**County**	**Mineral Extracted**	**Isola-ted[b]**	**Wet (Fully /Part)[c]**	**Catchment Type *(Connected catchments)*[d]**
2	Stover - IMERYS Minerals Ltd, Dorset	Devon	Ball Clay	Yes	Part	Non-indigenous *(Non-indigenous)*
2	Steerpoint - The Brick Business Ltd	Devon	Clay & Shale	Yes	Part	Empty *(Non-indigenous)*
2	Arne - IMERYS Minerals Ltd, Dorset	Dorset	Ball Clay	Yes	Part	Indigenous *(Indigenous and non-indigenous)*
2	Furzeyground - IMERYS Mineral Ltd, Dorset	Dorset	Ball Clay	Yes	Part	Indigenous *(Indigenous and non-indigenous)*
2	Shortwood - Ibstock Brick Ltd	South Gloucestershire	Clay & Shale	Yes	Part	Indigenous and non-indigenous *(Indigenous and non-indigenous)*
4	Westwood - Lantoom Ltd	Cornwall	Slate	Yes	Part	Empty *(Empty)*
4	Chudleigh Knighton - WBB Minerals	Devon	Ball Clay	Yes	Part	Non indigenous *(Non-indigenous)*
4	Capton Sandstone - Capton Sandstone Quarry	Somerset	Sandstone	Yes	Part	Indigenous *(Indigenous)*

a. For quality number definitions see Methods – *Ranking results*
b. Sites were either 'fully' isolated by a 50 m or 100 m buffer from a watercourse or for larger sites part isolated i.e. some of the at least part of the site was 50m or 100m from a watercourse
c. For wet definitions see Methods – *Analysis*: Step 2 - Site water status
d. For catchment definitions see Methods – *Analysis*: Step 1 – Non-indigenous crayfish threat

Appendix 3

Table 3. Potential ark sites on aggregate and mineral sites – Geology 3 sites (reproduced by permission of RSPB©, RSPB 2009 and the Environment Agency©, Environment Agency 2009).

Quality No.[a].	Pit Name and Operator	County	Mineral Extracted	Isol-ated[b]	Fully Wet/ Part Wet[c]	Catchment Type *(Connected catchments)*[d]
1	Caradon - Lantoom Ltd	Cornwall	Igneous and Metamorphic Rock	Yes	Fully	Non-indigenous (*Non–indigenous*)
1	Goldiggings - Lantoom Ltd	Cornwall	Igneous and Metamorphic Rock	Yes	Fully	Non-indigenous (*Non-indigenous*)
1	Spratsgate Lane - Grasshopper 2000 Ltd	Gloucestershire	Sand and Gravel	Yes	Fully	Indigenous and non-indigenous (*Indigenous and non-indigenous*)
2	Treviscoe - IMERYS Mineral Ltd, Cornwall	Cornwall	China Clay	Yes	Part	Non-indigenous *(Non indigenous)*
2	South Cerney - Aggregate Industries	Gloucestershire	Sand and Gravel	Part	Fully	Indigenous and non-indigenous (*Indigenous and non-indigenous*)
2	Castle-an-Dinas – Castle Granite Ltd	Cornwall	Igneous and Metamorphic Rock	Yes	Part	Empty (*Empty*)
2	Darley Ford – Mr Dilworth	Cornwall	Igneous and Metamorphic Rock	Yes	Part	Non-indigenous (*Non-indigenous*)
2	Frampton - Moreton C Cullimore (Gravels) Ltd	Gloucestershire	Sand and Gravel	Yes	Part	Indigenous (*Indigenous*)
2	Town Farm - Hanson Aggregates - South	Devon	Sand and Gravel	Yes	Part	Indigenous and non-indigenous (*Indigenous and non-indigenous*)
2	Moreton Pit - Hanson Aggregates - South	Dorset	Sand	Yes	Part	Non-indigenous (*Indigenous and non-indigenous*)
3	Cotswold Community - Hills Minerals and Waste Ltd	Gloucestershire	Sand and Gravel	Yes	Fully	Indigenous and non-indigenous (*Indigenous and non-indigenous*)
3	Blackenstone - Blackenstone Quarry	Devon	Igneous and Metamorphic Rock	Yes	Fully	Non-indigenous (*Non-indigenous*)
3	Manor Farm North - Moreton C Cullimore (Gravels) Ltd	Wiltshire	Sand and Gravel	Part	Part	Indigenous and non-indigenous (*Indigenous and non-indigenous*)

4	Dean – RMC Western	Cornwall	Igneous and Metamorphic Rock	Yes	Part	Non-indigenous (*Non-indigenous*)
4	Gwithian - Towans Sandpit - Hanson Aggregates – South	Cornwall	Sand	Part	Part	Non-indigenous (*Non-indigenous*)
4	Bestwall - Hanson Aggregates – South West	Dorset	Sand and Gravel	Yes	Part	Indigenous and non indigenous (*Indigenous and non-indigenous*)
4	Chard Junction - Hanson Aggregates – South West	Dorset	Sand and Gravel	Part	Part	Non indigenous (*Non-indigenous*)
4	Henbury - M B Wilkes Ltd	Dorset	Sand and Gravel	Part	Part	Indigenous and non indigenous (*Indigenous and non-indigenous*)
4	Warmwell - Bardon Aggregates – South West	Dorset	Sand and Gravel	Part	Part	Indigenous and non-indigenous (*Indigenous and non-indigenous*)
4	Cleveland Farm - Bardon Aggregates – South West	Wiltshire	Sand and Gravel	Part	Part	Indigenous and non-indigenous (*Indigenous and non-indigenous*)

a. For quality number definitions see Methods – *Ranking results*
b. Sites were either ‘fully’ isolated by a 50 m or 100 m buffer from a watercourse or for larger sites part isolated i.e. some of the at least part of the site was 50m or 100m from a watercourse
c. For wet definitions see Methods – *Analysis*: Step 2 - Site water status
d. For catchment definitions see Methods – *Analysis*: Step 1 – Non-indigenous crayfish threat

Conservation of white-clawed crayfish in South-west England

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The white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet), is Britain's only indigenous crayfish species (ICS) (see Holdich et al. this volume) and has suffered severe declines, most devastatingly in recent decades due to the spread of non-indigenous crayfish species (NICS) and associated crayfish plague. In Britain the number of 10 km grid squares occupied by NICS overtook those occupied by white-clawed crayfish in 2003 (Sibley 2003). In particular, South-west England (where NICS were first farmed for food) has experienced a rapid decline, for example three out of four of its most abundant remaining populations have been lost in the past three years alone and now fewer than 20 discrete populations are thought to remain in the region (see Holdich and Sibley this volume).

In October 2008, England's statutory nature conservation organization Natural England, awarded funding to a partnership led by Bristol Zoo Gardens in conjunction with Avon Wildlife Trust and including the Environment Agency in an advisory role on the Steering Group. The bid was for a 3-year project to implement, at landscape scale, active mitigation from the threat of NICS by identifying a number of suitable refuge or ark sites in the region so as to safeguard the species' future. The work builds on efforts by the Environment Agency and Avon Wildlife Trust over the past 10 years to assess the distribution and status of indigenous crayfish in the region, which also included the first known white-clawed crayfish translocation to a lotic ark site in England in 2006 (Sibley et al. 2007).

It is crucial to the success of this work that it takes place at river catchment scale and links with other relevant initiatives. The work is also in line with supporting measures in River Basin Management Plans for the Water Framework Directive, though it is outside the scope of the project to attempt any form of direct control against populations of NICS. The project will also trial a captive breeding programme at Bristol Zoo, as this aspect could be crucial in future conservation efforts.

The primary aim of the project is to identify all remaining white-clawed crayfish in South-west England and prioritize them in terms of threat. Ark sites will then be identified by working through detailed ark site selection criteria looking at habitat suitability, isolation from NICS, water flow, conservation status etc. (see Peay this volume) and then potential donor populations will be linked to provisional ark receptor sites throughout South-west England. Buglife have carried out a complimentary, tandem project assessing all former aggregate sites within the south-west as potential white-clawed crayfish ark sites (see Kindemba and Whitehouse this volume). A series of translocations are planned in order to try and safeguard remaining threatened white-clawed crayfish populations.

The secondary aim of the project is to establish and maintain viable breeding populations of white-clawed crayfish *ex situ* to provide plague free brood stock. This system will be installed within Bristol Zoo Gardens and linked to an on-show exhibit within the Zoo Aquarium. Another key element of this captive breeding project is to raise public awareness by engaging visitors in this initiative.

A targeted education programme will run alongside the project highlighting key white-clawed crayfish threats and publicly promoting measures for their conservation. This will include the development of a regional awareness campaign including outreach programmes to fisheries and landowners, Bristol Zoo education sessions and interpretation panels, the development of a media campaign and production of updated publicity materials. As part of the communication strategy, the project will be hosting an international crayfish conference in the autumn of 2010.

Critical success factors required for translocations and captive breeding will be identified, recorded, published and disseminated to stake holders and partners responsible for the maintenance of the species and its habitat. The project will also drive UK BAP conservation targets and contribute to EU white-clawed crayfish conservation targets such as increasing the range of this species. Existing and potential white-clawed crayfish habitats in South-west England will be looked at to work towards creating new site designations where possible, for example creating white-clawed crayfish ark sites designated as Special Areas of Conservation.

Other partners include Buglife, the UK's invertebrate charity, (see Kindemba and Whitehouse this volume), Bristol Water plc (utilities company) and expert consultants. In addition, as the project develops, valuable assistance and input has been forthcoming from a range of other organizations such as county Wildlife Trusts and local Government Authorities.

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Keywords: ark sites, captive breeding, conservation, crayfish, education programme, partners, translocation

Establishing the island of Ireland's first ark site for the white-clawed crayfish *Austropotamobius pallipes* in the Ballinderry river system, Co. Tyrone

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ABSTRACT

In 2006, the Ballinderry River Enhancement Association secured two years funding to establish the "Ballinderry White-clawed Crayfish *Austropotamobius pallipes* Breeding and Reintroduction Programme". The project has established Ireland's first ark site for *A. pallipes* in a natural lake. The lake is used as the last in a series of settling ponds in the Acheson & Glover Group's Pomeroy Sand Pit, near the headwaters of the Ballinderry River, Co. Tyrone. An artificial habitat bay was created and 150 Ballinderry *A. pallipes* introduced. Since the introduction of *A. pallipes* to the ark site, trapping has shown that the population is healthy, breeding and occupying available habitat in the lake. It is hoped that in the future, *A. pallipes* can be re-introduced to parts of the river where the species is currently absent but previously known to have occurred.

Keywords: ark site, Ireland, *Austropotamobius pallipes*, Ballinderry, conservation, habitat, reintroduction

INTRODUCTION

The white-clawed crayfish *Austropotamobius pallipes* (Lereboullet) was once widespread across mainland Europe, the UK and Ireland (Gallagher et al. 2006), but are now confined to a diminishing number of areas as a result of poor water quality (Holdich, 1991), habitat degradation, disease and competition from NICS (Holdich and Ghererdi 1999, Holdich 2000, Holdich and Sibley this volume).

Austropotamobius pallipes is listed in Appendix III of the Bern Convention, Annexes II and V of the EC Habitats Directive and is classed as Globally Threatened by IUCN; appearing on the red data book list of many of the European countries in which it is found (Souty-Grosset et al. 2006). *Austropotamobius pallipes* is also recognised as a Great Britain and Northern Ireland Priority Species and Biodiversity Action Plans (BAP's) have been produced in both jurisdictions.

The bio-geographical region of Ireland is the last landmass in Europe to host no other crayfish species apart from *A. pallipes* (Souty-Grosset et al. 2006), which, for the most part, has created a safe haven for this particular subspecies (Reynolds 1998, Reynolds this volume). However, recent surveys in Ireland, including population condition assessments for the Magheraveely Marl Loughs Special Area of Conservation (SAC) in County Fermanagh (Bradley 2008, Wilson and Horton 2008), have shown a decline in previously stable Irish populations, raising concerns over the future status of *A. pallipes* in Ireland.

The Ballinderry River, County Tyrone, rises on the eastern slopes of the Sperrin Mountains, at Camlough near Evishanoran Mountain, and flows 47 km to the western shore of Lough Neagh, the largest freshwater lake in the British Isles. The catchment (430 km^2) drains an area containing some of the richest sand and gravel deposits in Ireland. Whilst the headwaters of the Ballinderry drain acidic upland peat bog, down-cutting through this underlying drift geology, and areas of clay, limestone and shale on the southern side of the catchment, gives the Ballinderry River an alkaline to neutral water chemistry, suitable for *A. pallipes*.

In 1998, a survey reported that no crayfish were found at sites sampled in the Ballinderry River and its tributaries (AERC 1998); however, the Ballinderry River Enhancement Association (BREA) and local landowners in the catchment had noted them in various locations throughout the catchment (BREA 2007, pers. comm.). A detailed survey of 68 sites in 2008 found crayfish at six sites suggesting that *A. pallipes* are not as widely distributed in the catchment as anecdotal historical reports suggest (Wilson and Horton 2008). This is thought to be due largely to a combination of factors including degraded water quality as a result of the post-war intensification of agriculture, impact from industry, increasing pressure placed on waste water treatment works; and damaged habitat resulting from ongoing intensive drainage schemes for flood mitigation (Wilson and Horton 2008).

In 2006, the Ballinderry River Enhancement Association secured funding for the “Ballinderry White-clawed Crayfish Breeding and Re-introduction Programme” in order to conserve the river’s crayfish population and educate the public on the status of this species. One of the aims of the project was to establish an ark site in which an indigenous crayfish population could be established and protected. The ark site provides a safe reserve for the Ballinderry *A. pallipes* and a growing population, which in future could be harvested and reintroduced to parts of the river where crayfish were historically know to have occurred.

METHODS and RESULTS

Identifying a suitable ark site

As the Ballinderry River catchment sits on the richest sand and gravel deposits in Ireland, and is heavily quarried. Ballinderry Fish Hatchery, BREA’s hatchery, sought to identify a gravel and sand pit that could be used to establish an ark site for *A. pallipes*.

Five sites, available for potential ark site development, were selected for assessment of suitability for supporting *A. pallipes*. Each site was assessed in terms of its appropriate water chemistry, availability of suitable habitat, potential for crayfish to escape from the site and pollution risk.

As the first two considerations, water chemistry and habitat, are limiting factors on the natural presence and survival of *A. pallipes* (Holdich 2003), they were given a greater weighting in determining the suitability of the site. Of these two factors, given that habitat could be created if suitable natural features were not available; water chemistry was treated as the most limiting factor on crayfish survival.

Following the assessment of site suitability it was deemed that Evishanoran Lake was the most appropriate location for an ark site, due to its suitable alkaline water chemistry, its low escapement potential and the low risk of pollution as a result of its closed water system.

Ark site description

Evishanoran Lake (Fig. 1) is located 0.5 km from Camlough, the source of the Ballinderry River, and is situated in the Sperrin Mountains, west of Lough Neagh.

The lake is ~2.5 ha in size and sits 211 m above sea level. It is thought to be spring and rainfall fed as the lake is landlocked and has no in-flowing or out-flowing channels. The lake margin slopes gently towards a deep centre, with lake depth ranging between 0 and 10 m.

Whilst never formally classified, the lake is most probably oligo/mesotrophic and supports plant communities of *Juncus* rush and *Potamogeton* broad-leaved pondweed. The lake has a healthy population of brown trout, probably introduced during the last century, as well as eels.

Figure 1. Evishanoran Lake (photograph taken from the north shore looking south) in the Sperrin Mountains, near the source of the Ballinderry River.

Although natural, Evishanoran Lake is the last in a series of settling ponds in the Pomeroy Sand Pit, owned and operated by the Acheson & Glover Group. A steeply sided bank running along the eastern shore of the lake retains two, much higher, manmade settling ponds, to which water is pumped from the sand washing operation below. Much of the silt, in suspension, is precipitated out in these two ponds before the water flows down to Evishanoran, through a steep pipe. It is thought that it is this process which has resulted in lakes alkaline water chemistry, which is relatively high in comparison to that of the neighbouring Camlough that shares the same geology and has the same drift and soil topology, but has a higher pH.

Due to the recirculation usage of water in the sand washing process, at times of sustained low rainfall, water levels in the lake may fall as much as 1 m, however, the depth of the lake means that a large wetted perimeter is maintained at all times.

At the time of the initial survey, it was noted that the lake had few habitat features suitable for crayfish; however, on speaking with the Acheson & Glover Group, it became clear that in addition to providing a secure ark site, they were also able to assist with habitat creation.

Creation of the habitat bay

The Acheson and Glover Group provided plants, materials and staff to create a sweeping habitat bay at the northern end of the lake.

Under the instruction of Ballinderry Fish Hatchery Ltd, staff at the Pomeroy sand pit used 1500 tonnes of broken concrete slabs to build a shelved bay, creating a 60 m long shore of varied water depth, with a complex network of tiny nooks and crannies for crayfish to live in (Fig. 2). The bay forms a protected breeding area for *A. pallipes*, which can feed naturally and rear their young in a natural and safe environment.

A number of habitat types were created along the face of the bay firstly to provide greater refuge variability for the introduced crayfish, and also to see if the crayfish would show any preference for particular habitat types.

Figure 2. The habitat bay, created on the north shore of Evishanoran Lake.

Five different habitat areas were created on the bay:

1. House bricks, manufactured by the Acheson & Glover group were used as these are very similar to crayfish habitat units that are used in commercial farming operations. The holes provide excellent refuges for individual crayfish as well as increasing the surface area over which algae can form to support invertebrate populations.

2. Broken stone was used in the second area providing a complex structure of nooks and crevasses into which crayfish could retreat. The varying size of stone created habitat suitable for both adult and juvenile crayfish.

3. Top soil was poured into the third area creating a soft burrowing area on the shelved bay. This was also near a patch of natural pondweed in the lake, which should be able to easily colonize and stabilise the soil bank.

4. Bundles of woody debris were used to create an area reminiscent of tangled tree roots and fallen branches. Local willow was cut and dried before being bundled and weighted down. Once saturated, the bundles sank along the face of the bay providing both suitable refuges and a source of food for the crayfish.

5. AquaMats™ were used to create areas for shade and macro-invertebrate colonization. AquaMats™ encourage and support the production of a natural, regenerative food

source. Designed to float upward from a weighted base these provided cover similar to that of submerged weeds. The mats were used along the front of the bay and in areas around the Lough, creating habitat features that are capable of supporting crayfish. Furthermore, the mats provide shade from the sun in the shallow areas of the Lough where natural vegetation is not established. The AquaMats™ will also bring benefits to other lake taxa, including the trout and eels, as the food biomass available to these species increases.

Trapping of A. pallipes for the ark site

With the permission of the Northern Ireland statutory authorities, 178 *A. pallipes* were captured during the period of summer 2006 to autumn 2007. Baited creels were deployed at two sites in the lower Ballinderry River system, Hardy's Mill (IGR H 926 924) and Ballinderry Bridge (IGR H 927 798), where significant crayfish populations were known to exist. The creels were baited with pierced cat food pouches and checked for crayfish every two to three days. Trapping commenced on 16th July 2006 and continued intermittently until 18th October 2007. Trapping continued through the winter months due to an unseasonably mild winter when it was possible to attract berried females into the traps, with a view to kick starting the population at the ark site.

In all, 178 crayfish were captured over the trapping period, 98 females, 78 males and two juveniles of indeterminable sex. The capture of eight additional crayfish, above the quota of 170 granted, was done to replace the loss of eight crayfish in the holding tank at the hatchery, most likely as a result of either natural wastage or fatal injury sustained from fighting.

The population represented various age classes of crayfish as indicated by their total body length. The largest male measured 108.4 mm and the largest female 103.8 mm. The smallest male measured 33 mm and the smallest female 26 mm. The variation in size and thus age range in the captured colony provided a good representation of a stable population structure with young, near and newly sexually mature males and females, as well as larger, older individuals.

Holding tank

In order to protect the sustainability of the donor populations, half the males and half the females in each catch were returned to the stretch, with the remainder being collected for transfer to a hatchery holding tank whilst the habitat bay was being completed. Three rectangular holding tanks were employed, each 1.5 m^2 in area and with river gravel and large stones as refuges (Fig. 3). Unfiltered river water flowed through the tanks. Each crayfish taken to the hatchery was measured (total body length), sexed, checked for signs of disease and a list of any injuries noted. Crayfish were held in the holding tank for at least two weeks before being transferred to the lake at Evishanoran. This allowed the crayfish to be monitored for developing signs of disease as well as providing a holding facility until sufficient numbers were gathered to be transferred to the lake. Crayfish were supplied with yearling fish carcases (which had died in the hatchery) to feed on, in addition to the natural inflow of invertebrates through the water supply pipe.

Figure 3. One of the holding tanks.

Introduction of A. pallipes to the ark site

On completion of the habitat bay, *A. pallipes* held in the hatchery, including berried females (berried over winter 2006-07), were transferred to the ark site. In total 150 crayfish were transferred to Evishanoran and introduced across the face of the habitat bay. All crayfish were introduced by 27th August 2007.

Assessing breeding success at the ark site

In order to assess breeding success, trapping took place at Evishanoran in May 2008. Nineteen baited creels were placed around the lake and checked daily for two weeks. Crayfish were caught in three traps, one on the habitat bay, one on the eastern shore of the lake and one on the western shore. Three berried females were trapped as well as two males; one additional male was seen near a trap half way along the eastern shore of the lake. Half the crayfish caught were caught in the trap on the habitat bay, near the house brick habitat area. No other crayfish were caught on the bay. The berried females were each carrying clutches of between 60-80 healthy eggs. All crayfish caught had moulted successfully and had clean olive green carapaces with cream abdomens. Further trapping has been conducted in June 2009. Thirty-three traps were deployed around the lake and were checked every 2-3 days. Twenty crayfish were trapped at sites around the lake shore. Three of the captors were juveniles and, based on carapace length, it can be inferred that two originate from the 2007 breeding period and one from 2008 (Fig. 4). On subsequent visits to the lake at least 11 more juveniles have been observed occupying various areas on the habitat bay.

Figure 4. Right, an adult *A. pallipes* introduced to the ark site and left, a juvenile *A. pallipes* born in the ark site.

DISCUSSION

The success of the current project has had a far reaching effect on the conservation of *A. pallipes*, both in Northern Ireland and further afield. A second ark site, established at Florencecourt in Co. Fermanagh, is providing a reserve population of *A. pallipes* in the Sillies River, whilst contributions to guidance material for the creation of new ark sites by the aggregates industry will encourage others to take action for the conservation of the white-clawed crayfish, both here and further afield (see Kindemba and Whitehouse this volume, Peay this volume).

A subsequent river survey of 68 sites in the Ballinderry River system, undertaken during the summer of 2008 (Wilson and Horton 2008), has greatly increased our understanding on the distribution of crayfish in the river system and the habitat features associated with their presence. Through this survey, a number of potential re-introduction sites have been identified in the river system, into which juvenile crayfish from the ark site can be released once sufficient numbers have been established in the lake.

It is hoped that, from the growing interest in crayfish, as a result of this project and others in Northern Ireland, a working group can be established, building on the successes so far and providing a dedicated and coordinated effort for the conservation of *A. pallipes* on the island of Ireland

The project has provided all of the elements required for the long-term conservation of *A. pallipes* in the Ballinderry and adjacent Lough Neagh wetlands. Through the investments made and partnerships established, a legacy has been created for the survival of this globally threatened species in the Ballinderry River system.

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Microhabitat use and recolonization in white-clawed crayfish: relevance to conservation

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The white-clawed crayfish *Austropotamobius pallipes* (Lereboullet) is listed as vulnerable on the IUCN red list and British populations represent one of the greatest concentrations of this species in Europe (Gallagher et al. 2006, IUCN 2009). White-clawed crayfish still remain at risk in Britain due to habitat degradation, pollution and non-indigenous crayfish and disease (Holdich 2003, Holdich and Sibley this volume). In order to conserve this species a thorough understanding of habitat and microhabitat requirements is needed to enable effective protection of habitats, rehabilitation of degraded sites and to identify sites where reintroductions are likely to be successful. Large scale mortality events are a serious risk to white-clawed crayfish populations and knowledge concerning rates and mechanisms of recolonization after such events can help improve conservation and provide advice for reintroductions to rivers.

The aims of this study were to characterise the microhabitat use of juveniles and adult white-clawed crayfish and quantify the rate and pattern of recolonization into an unoccupied reach of river. The microhabitat study was carried out over a 1-km stretch of the River Wansbeck, North-east England, where white-clawed crayfish are the only crayfish species and densities are among the highest recorded in the UK (Rogers 2005). Recolonization was studied in the lower 3 km of the Hart Burn, a major tributary of the Wansbeck. On 14 May 2004 a pollution-related mass mortality occurred, resulting in the near-complete eradication of crayfish from a 3 km stretch but with dense populations upstream and in the Wansbeck.

Microhabitat data was collected during late summer period 2008 where a modified Surber sampler (0.49 m^2, n=75) was randomly placed and crayfish were sampled quantitatively along with depth (five values), water velocity (five values), distance from bank, substrate composition and shade. A substrate index, a measure of the contribution of different substrate sizes, was calculated, with 100 being full coverage by silt/sand, rising to 600 (full coverage by boulders). For the analysis crayfish were split into size groups where the age 0+ group comprised 0-10 mm carapace length (CL), the 1+ group was 10-17 mm CL and those larger than 17 mm CL were 2 years and older and included the adult crayfish in the population. Analysis of microhabitat use by the different age groups was carried out by univariate non-parametric tests, complemented by multivariate Principal Components Analysis (PCA).

Surveying of crayfish populations in the Hart Burn was carried out between summer 2004 and 2008. Standardised effort hand-searching of streambed refuges was carried out by experienced surveyors during clear, low-water conditions where crayfish were counted sexed and measured.

Univariate analysis of microhabitat data showed that the microhabitat of crayfish aged 0+ and 1+ comprised significantly smaller substrates than crayfish that were 2 years and older. This was due to 0+ and 1+ crayfish inhabiting areas that had a greater proportion of small pebble substrate. Crayfish aged 0+ and 1+ were also found significantly nearer to the bank and the microhabitat of crayfish aged 0+ had significantly less moss cover than crayfish aged 1+ and 2 years and older.

For the multivariate analysis of the microhabitat data four variables: distance, velocity, velocity heterogeneity and substrate index were incorporated into a PCA. Moss was not found to be an important variable as it was not included in the multivariate analysis so this questions the importance of the significant difference in moss cover. Minimum convex polygons representing the range of microhabitat use were drawn on a PCA biplot (PC1 = velocity heterogeneity, velocity and distance from bank; PC2 = substrate index and distance from bank). Crayfish aged 1+ and 2 years and older inhabited a similar range of microhabitats. However 0+ crayfish had a much more restricted range, which was only 30% of the range of 1+ crayfish and 32% of the range of crayfish that were 2 years and older.

The recolonisation data showed that the relative densities of crayfish in the affected stretch of the river reached similar numbers to those observed upstream of the pollution and in the Wansbeck by 2008. The two most upstream sites showed early signs of recolonization within months of the pollution event. In comparison, the downstream sites took a lot longer for the crayfish numbers to increase with low numbers of crayfish still being observed in 2007.

Crayfish of different ages had different microhabitat requirements where juveniles, in particular 0+ crayfish, were found in close proximity to the bank possibly due to the protection provided by the lower velocities found in bank side habitats. The frequent use of small substrate where interstices are too small for larger adult crayfish, and avoidance of large substrate, which adult crayfish can inhabit, suggests that juvenile crayfish are restricted to finer substrate due to competition. Surprisingly 0+ crayfish were largely absent from sites dominated by the finest of substrate unlike 1+ crayfish and crayfish of 2 years and older. This may be because larger crayfish can create their own shelters by burrowing into the silt whereas 0+ crayfish are too small and weak to do so.

Our recolonisation data highlights the impact acute mass mortality events such as pollution can have on crayfish populations, where it took four years of no further pollution for the population to recover even when there was suitable habitat available, and negligible competition. Our data provided a recolonization rate of 750 m yr^{-1} in comparison to within population dispersal, which previous studies found took place at a rate of between ≈ 90 m yr^{-1} (Bubb et al. 2008) and ≈ 920 m yr^{-1} (Gherardi et al. 1998). The faster rates are less reliable as dispersal rates were only recorded during summer months, so it seems that recolonization rates may occur faster than within population dispersal. Passive downstream dispersal seemed to be a more important recolonization process and further analysis of our data may provide some invaluable information on passive and active recolonization processes.

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Keywords: conservation, microhabitat, recolonisation, white-clawed crayfish

Monitoring *Austropotamobius pallipes* (Lereboullet) in a chalk stream in southern England

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ABSTRACT

Austropotamobius pallipes in Hampshire are confined to three small sub-populations in the River Itchen. A monitoring programme, which focuses on the most extensive of these, has been under way now for over 10 years (1996 – 2008). The approach to monitoring has been devised specifically for the small, remnant populations now found only in the shallow chalk stream headwaters of the River Itchen. Results have revealed information on the behaviour and composition of the population over this time period and have facilitated a range of associated studies. The work has also initiated debate on the effectiveness and necessity of monitoring itself.

Keywords: chalk stream, crayfish, habitat, Hampshire, long term monitoring.

INTRODUCTION and BACKGROUND

Many population studies have been carried out on the white-clawed or indigenous crayfish *Austropotamobius pallipes* (Lereboullet), particularly in Ireland and northern, central and southern England (Brewis and Bowler 1983; Mees 1983; Matthews and Reynolds 1995). There are few examples, however, of long term monitoring studies for *A. pallipes* in the UK (Brown and Bowler 1977, Pratten 1980). This paper reports on the findings of one such study and provides information of the effectiveness of monitoring and the detection of change in a small remnant population of crayfish in a southern Hampshire chalk stream.

A substantial amount of information has been acquired on the distribution of both indigenous and non-indigenous crayfish in the Hampshire rivers and waterbodies since the late 1980s. This has been achieved initially through the work of the “Hampshire crayfish project” based at Sparsholt College near Winchester, and then by the formation of a Species Action Plan (SAP) Group and recently through projects funded by the Environment Agency (Southern Region). These initiatives have presided over a substantial change in the fortunes of indigenous crayfish in Hampshire with a dramatic decline from their presence in four river systems in the early 1990s to only one today, including the loss of the last remaining population in the New Forest.

The only known population of *A. pallipes* in Hampshire is now confined to two upper tributaries of the River Itchen. This river is a classic chalk stream, rising near Alresford in the Hampshire Downs and flowing through Winchester and Eastleigh before discharging into Southampton Water. The R. Itchen is characterized by its stable temperature and flow regime, good quality water, base-rich and of high clarity. Its national and European conservation status is recognized by the designations as a Site of Special Scientific Interest (SSSI) and, more recently, as a Special Area of Conservation (SAC). The R. Itchen SAC is designated for its water crowfoot (*Ranunculus*) communities and southern damselfly population. *Austropotamobius pallipes*, an Annex II species, is a qualifying feature, but not a primary reason for SAC selection.

In contrast, the non-indigenous signal crayfish, *Pacifastacus leniusculus* (Dana), inhabits most river systems in the County. Maps of the distribution of both the indigenous and signal crayfish in Hampshire are given in Figs 1 and 2 respectively (see also Rushbrook this volume).

There has been, until recently, some speculation why the population in the upper tributaries has survived when indigenous crayfish in the remaining part of the R. Itchen are absent. Historical records show this species to have been widespread in the River until the late 1980s. Reports from river managers and owners, however, suggests a catastrophic decline in indigenous crayfish at about this time and this prompted the first catchment-wide survey in Hampshire to establish the status of crayfish in the R Itchen. The available evidence suggests that the main river was struck by crayfish plague *Aphanomyces astaci* Schikora in 1989/90 and it is now known that this was a result of the introduction of signal crayfish. Characteristically the signal crayfish population has remained hidden and evaded detection until 2009, when by chance a population was located in a small offline stream. It has been noted that crayfish populations can theoretically survive at very low abundance and commonly used survey techniques often only detect populations at much higher densities (Scott Wilson 2001). The presence of non-indigenous crayfish in the River Itchen has long been suspected and has now been confirmed (Hutchings 1997).

The R. Itchen currently supports three sub-populations of *A. pallipes* in two upper tributaries. Two of these populations are small, indeed one inhabits the root system of a single large ash tree, whilst the third is distributed over a 1500 m stretch of stream. The two small populations are checked annually for presence/absence only. The latter is the subject of this paper.

MONITORING

Introduction

The monitoring programme for the largest population began as a pilot study in 1995/96, being refined and trialled over this period and starting formally in 1997. Monitoring has now been carried out annually for 10 years from 1997 until 2008.

The primary driver for the monitoring programme was a desire to investigate the last remaining population of *A. pallipes* in a Hampshire chalk stream. Little was known at that stage about the ecology and requirements of this species in the local rivers and the monitoring programme set out to fill this information gap. Sparsholt College established a captive rearing project *A. pallipes* in 1995 and it was considered important that the donor population was monitored both pre and post transfer of animals (Hutchings 1999). A healthy self sustaining donor population was considered a primary prerequisite as source for stock for this project (Ingle 1995). Specific targets for monitoring have also been set out in both National and Local Species Action Plans for *A. pallipes* and this monitoring programme also worked towards this goal.

There was therefore a need to devise a standard monitoring methodology relevant to the populations in the small southern chalk streams and one that would be sustainable in the long term. It should be noted that this monitoring methodology was devised before the recognised standard for monitoring *A. pallipes* developed by the Life in UK Rivers Project (Peay 2003).

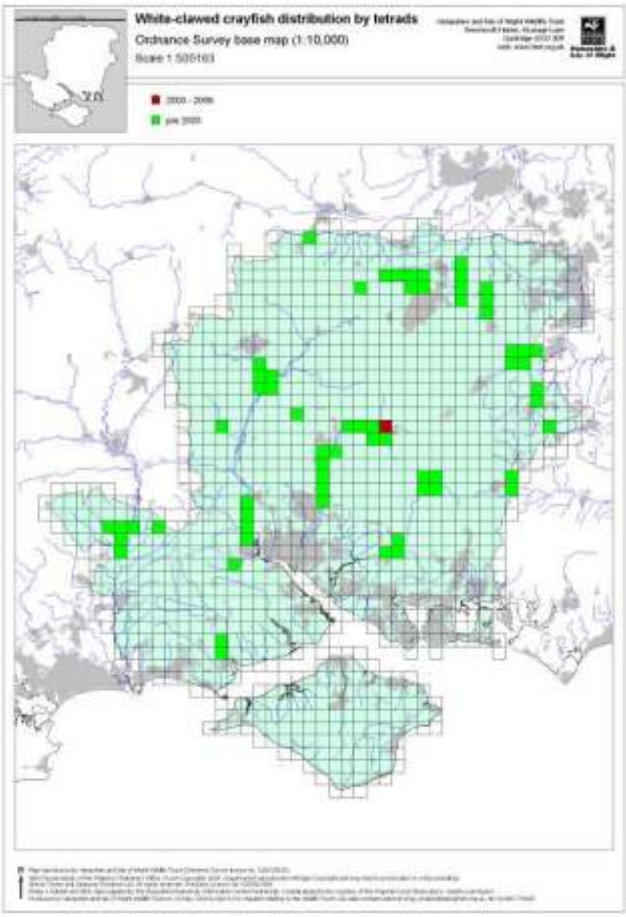

Figure 1. The distribution of *A. pallipes* in Hampshire pre-2003 (green squares) and for the period 2003-2008 (red square).

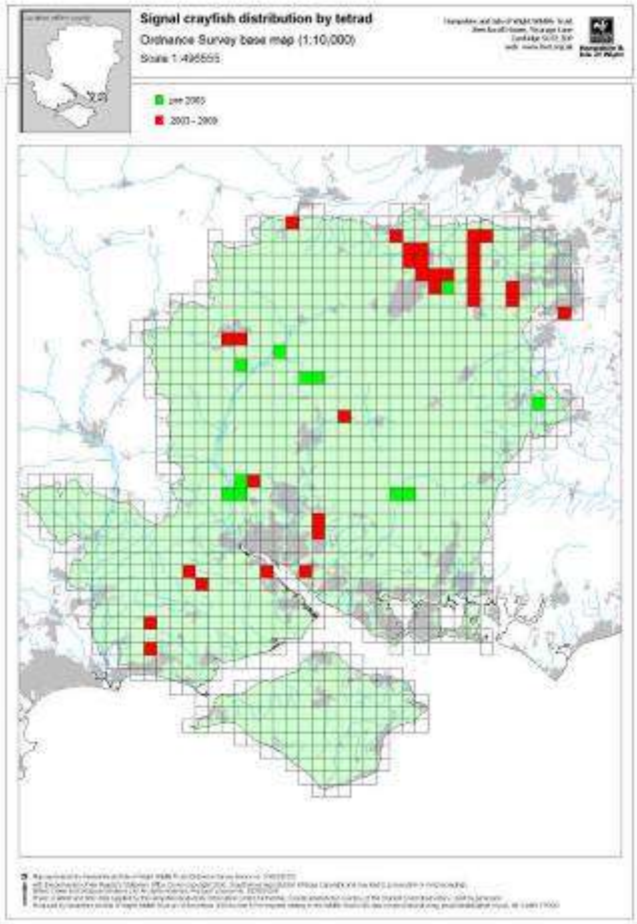

Figure 2. The distribution of *P. leniusculus* in Hampshire pre-2003 (green squares) and for the period 2003-2009 (red squares).

Methodology

A transect methodology was adopted for this monitoring programme and follows the basic “Pollard walk” approach (Pollard 1977). The method applied is described below.

A number of monitoring sections were identified encompassing the full extent of the crayfish population along the 1500 m stretch. These sections were defined primarily on the basis of changes in habitat structure and density of the crayfish population. Ten sections were initially identified and extended to 12 in year 2000 to include further upstream stretches that had been the subject of a crayfish habitat enhancement scheme (see below, Fig. 3). The sections identified included the full extent of the population, as well as stretches immediately above and below it to investigate any spatial movement over time. Within each section characteristic crayfish habitat patches were identified based on the experiences of the trial period. The length of monitoring sections varies and the numbers of habitat patches within sections range from 4-6 (see Fig. 5 for an example of patch locations in Sections 7 and 8). The patches within each section were then hand-searched for crayfish with the assistance of a “viewing tube” (a 150 mm diam. glass ended tube) over a period of 30 minutes. It was important that the timing was strictly adhered to ensuring a consistent “Catch Per Unit Effort” (CPUE) and thereby an estimate of relative abundance.

A consistent approach to sampling was achieved by the author undertaking most of the monitoring work, but also by supervising and training volunteers. To ensure a standardized 30 minute search in each section the time was apportioned equally among the monitoring team. The following biometrical data was recorded for each crayfish:

- Carapace length (mm).
- Sex.
- Weight (grams).
- Moulting stage (defined as intermoult, premoult, moult, and post moult).
- Signs of disease, especially porcelain disease *Thelohania contejeani* (Henneguy).

Annual visits to the monitoring site were made in July from 1997 until 2004 and then every other year (2006 and 2008). In 2005 and 2007 a brief check on presence/absence was made. Normally, and depending on the size of the monitoring team, the monitoring each year over the full length of the stretch varied in duration from a single day to two days maximum. Stringent biohygiene practices were exercised throughout the monitoring episodes.

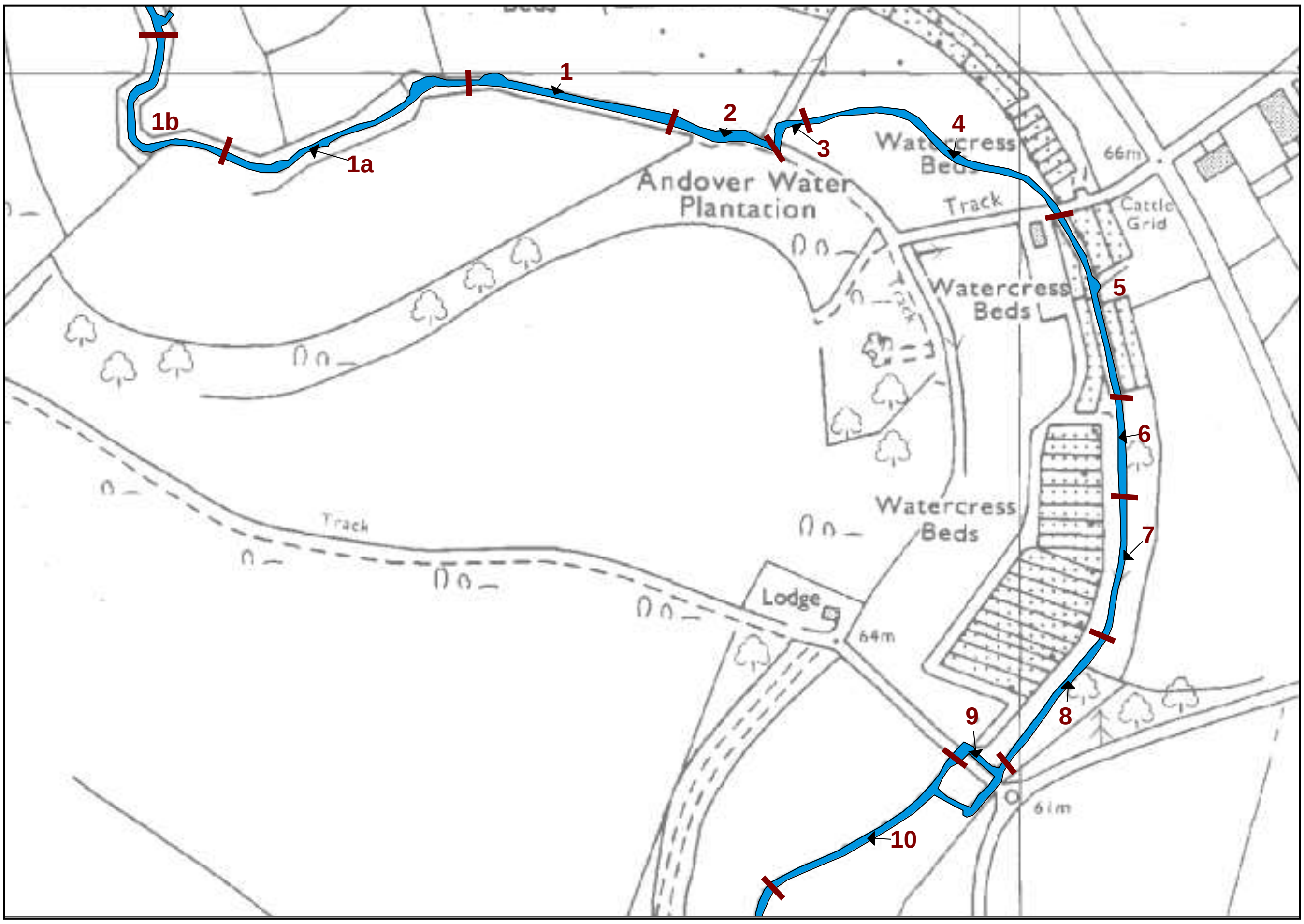

Figure 3. Monitoring sections along the 1500 m stretch.

Data analysis and management

The data acquired was analyzed using standard statistical techniques. For example to investigate any possible population change over time and between monitoring sections a two-way analysis of variance (ANOVA) was adopted. The data was ordered and sorted with the use of an Excel (MS Office) spreadsheet. From 2002 the location of crayfish recorded in each section was captured by GPS, stored and then mapped using a MapInfo integrated Geographical Information System (GIS).

Habitat characterization

A crayfish habitat enhancement programme was initiated in the upper R. Itchen in 1996 by the Environment Agency, which involved reducing the grazing pressure on the banks and stream and the creation of favourable habitat conditions up and downstream of the known crayfish population. To inform the design and development of this scheme a separate study was initiated, which set out to characterize and describe the typical crayfish habitat found in the monitored stretch. A transect and quadrat sampling approach was applied to investigate the nature of the banks and stream bed along the monitored stretch where crayfish were known to inhabit. The type of substrate and position in the channel were the focus of this study (nomenclature followed that used in the Environment Agency's River Habitat Survey methodology (after Naura 1998)). The resulting data was numerically classified and ordinated using TWINSPAN (Hill 1979) and CANOCO (Ter Braak 1988) software programs.

Why this monitoring approach?

The upper tributaries of the R. Itchen are characteristically narrow and shallow and in favourable conditions crayfish are often located across the full width of the stream rather than just the margins. All the 1500 m stretch is wadeable and accessible, and the habitat patches within monitoring sections are therefore relatively easy to locate and relocate every year. The physical characteristics of the stream assisted in applying a consistent approach to monitoring – each year the same habitat patches within sections are monitored by a team with consistently applied expertise and skills. The application of a standardized and consistently–applied approach is an essential component in any monitoring programme (Eyre 1996). A subsidiary, but nonetheless important, aim of the method is to enable volunteers and non-specialists to undertake this work. Therefore a method that can be clearly followed and is rapid in execution was required. The traditional transect approach is also familiar to many ecologists.

Figure 4. Habitat patches monitored within Sections 7 and 8.

RESULTS

Captures

Over the 10 year period 1055 *A. pallipes* were observed and recorded. Of this number 31% avoided capture and were simply recorded as either a juvenile or adult escapees (the ratio of juvenile to adult escapees was 50:50). However, biometric data was acquired for 732 crayfish over the 10 year period. An average of 100 crayfish were recorded at each monitoring visit.

Variation between years and sections

During the years 1997-2008 no significant change in numbers of crayfish were recorded along the stretch as a whole (see Fig. 5). This reflects the observation during field work that the population is generally stable in terms of abundance over time. Anecdotal observations in the field however, suggest a large variation in cohorts in recent years (from 2006 to 2008) and this is can be seen in Fig. 6. The possible explanations for this change are discussed later.

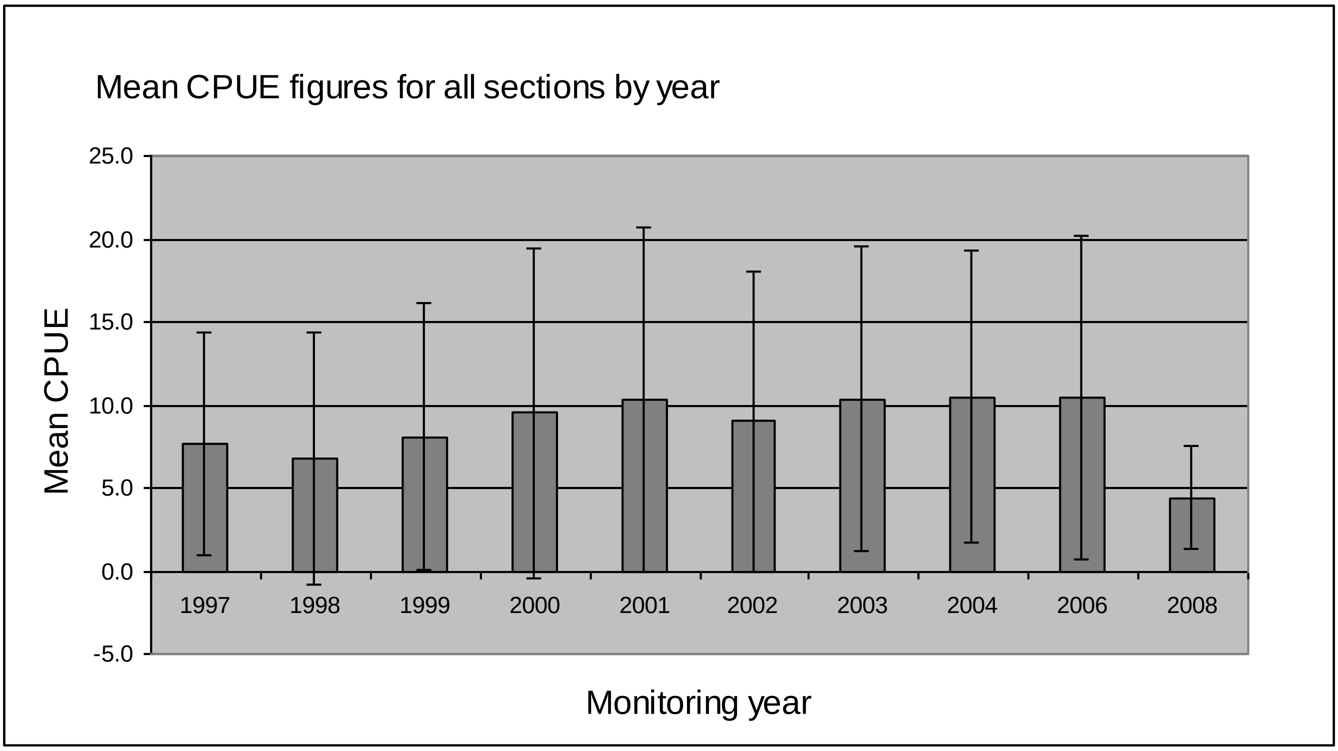

Figure 5. CPUE results for all sections per year (1 std. dev.).

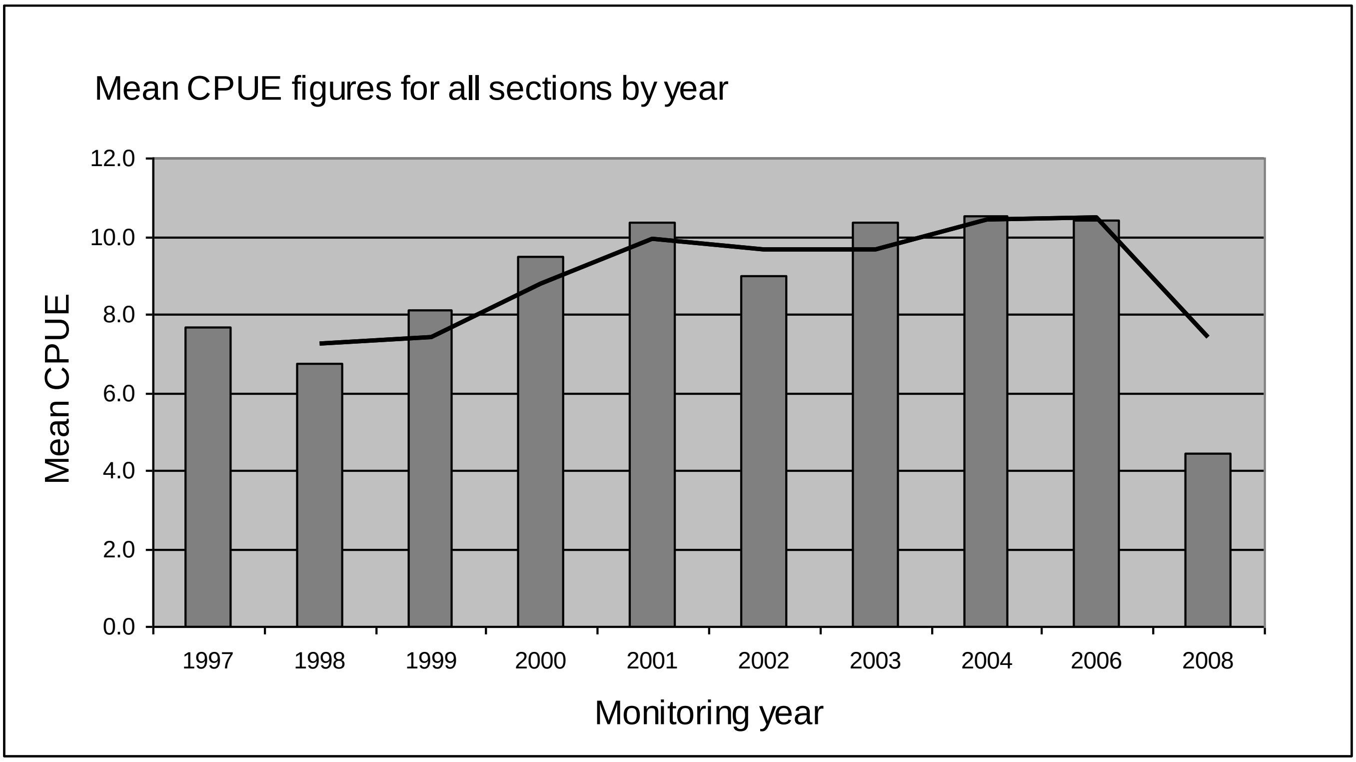

Figure 6. CPUE results for all sections per year with running mean.

The greatest variation in the abundance of this population is related to the differences between sections monitored along the stretch and this was found to be significant (F9.81 = 2.877 *P*=0.01). Figures 7 and 8 give the results from the total counts (CPUE) per section over time and mean counts for all years per section respectively.

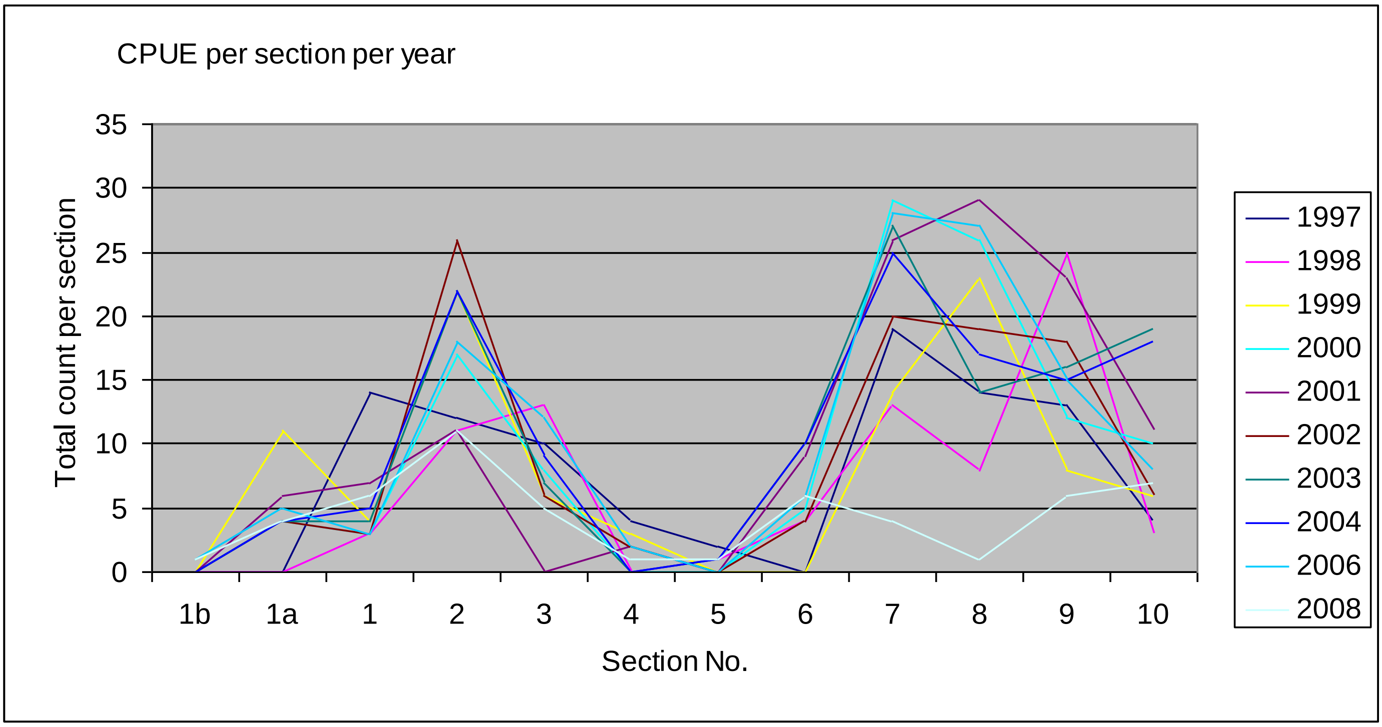

Figure 7. Total counts (CPUE) per section per year.

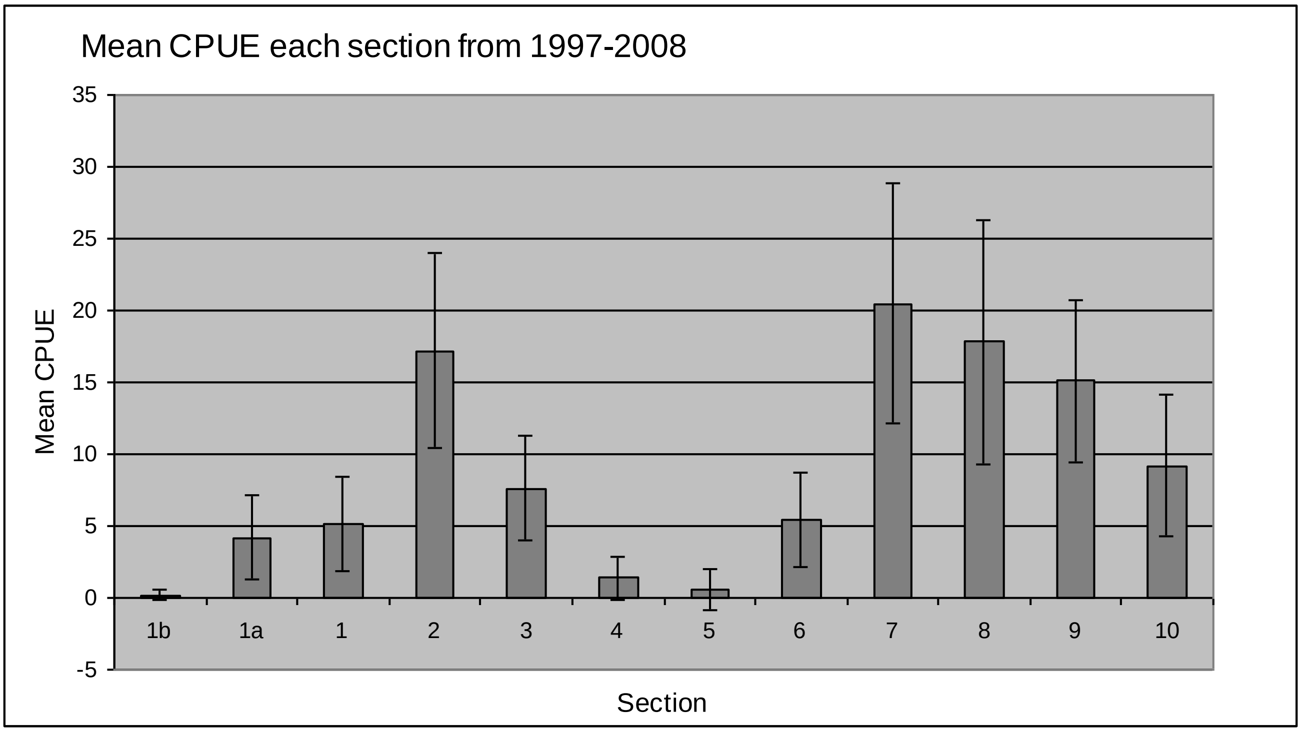

Figure 8. Mean CPUE per section for all years (1 std. dev.).

The results reflect a very clustered or contagious distribution along the monitored stretch with crayfish concentrated into relatively short sections of favourable habitat. Some sections have consistently performed better than others in terms of total and mean numbers (CPUE) of crayfish, e.g. sections 4, 5 and 6 in the middle of the monitoring stretch have consistently held small numbers, while the upstream and downstream sections, e.g. 2, 3, 7, 8 and 9 form the main strongholds for white-clawed crayfish in this stream. Sections 1a and 1b are the recently enhanced sections and the counts reflect the slow progress of colonization into these new habitat areas. Section 10 is at the downstream limit and consistently performed poorly throughout the ten years.

Within the prolific sections crayfish reach densities of characteristically 5-8 per m^2 and this is relatively high compared with published figures from other studies in England (Brown 1979, Mees 1983). There is some variation in CPUE within each section every year, but this is considered to be within normal limits (Fig. 8).

Mapping the distribution of crayfish along the monitored stretch

The mapping of records along the 1500 m stretch also provides an insight into the distribution of crayfish in this upper tributary. The patchy nature of this distribution as described above is shown in both Figures 9 and 10 for years 2002 and 2008 respectively.

The recent perceived change in abundance is also graphically represented when these records are mapped. The spatial position of the population has remained the same despite possible external pressures placed on the population (see Figs 11 and 12 below). There generally appears to be limited spatial mobility of this population and this again is reflected in the mapped distribution. The reason for this is certainly habitat related and this is discussed below.

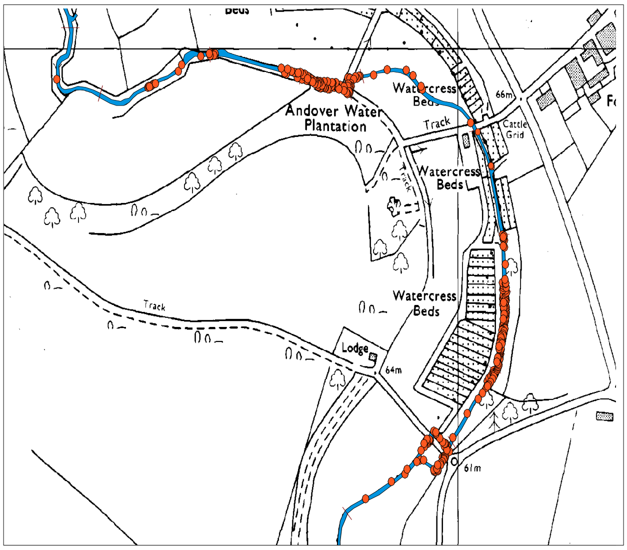

Figure 9. Distribution of records along the monitored stretch in 2002.

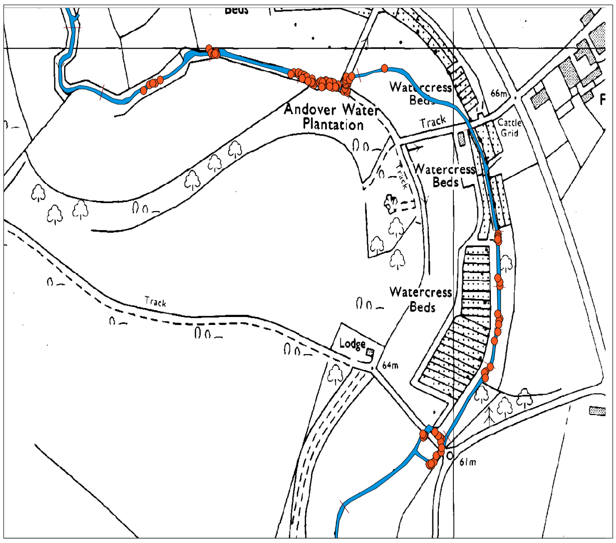

Figure 10. Distribution of records along the monitored stretch in 2008.

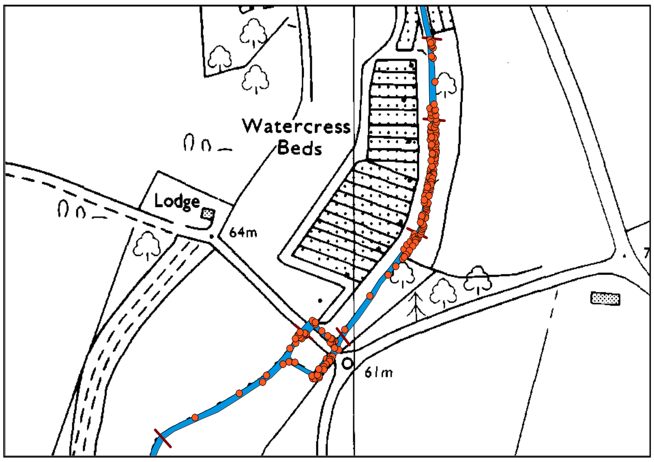

Figure 11. Distribution of records in Sections 6-10 in 2002.

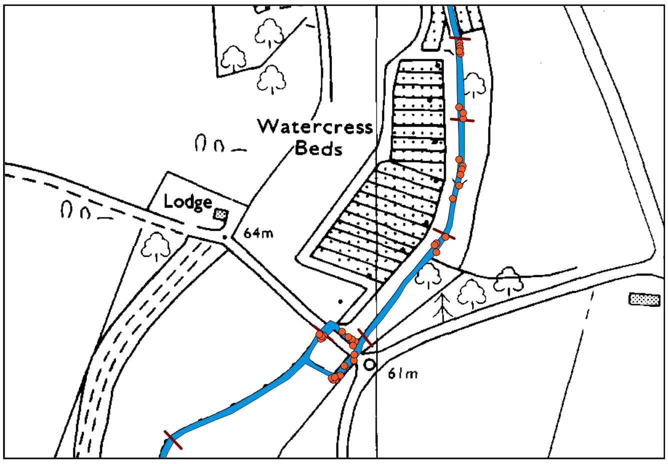

Figure 12. Distribution of records in Sections 6-10 2008.

Population structure

The monitoring has also provided a broad understanding of the structure of the crayfish population in the upper R. Itchen. The distribution of age classes across all sections during the monitoring period is given in Figure 13 and reflects a relatively normal distribution as would be expected, but with small numbers of 0+ (yearling) and year 1 juveniles. The latter is almost certainly a result of sampling bias, small juveniles being difficult to locate with the hand searching method.

A strong relationship between crayfish weight and carapace length (R^2 0.8187) was found, again as would be expected. After 2003 the recording of weight as a parameter was discarded on the basis of the strength of this correlation and hence unnecessary effort in the field. Figure 14 also shows the small number of large adults and the high proportion of Year 4-8 adults (Fig. 14) representing the main breeding cohort. The variation each side of the trendline possibly reflects the moulting stage of individuals.

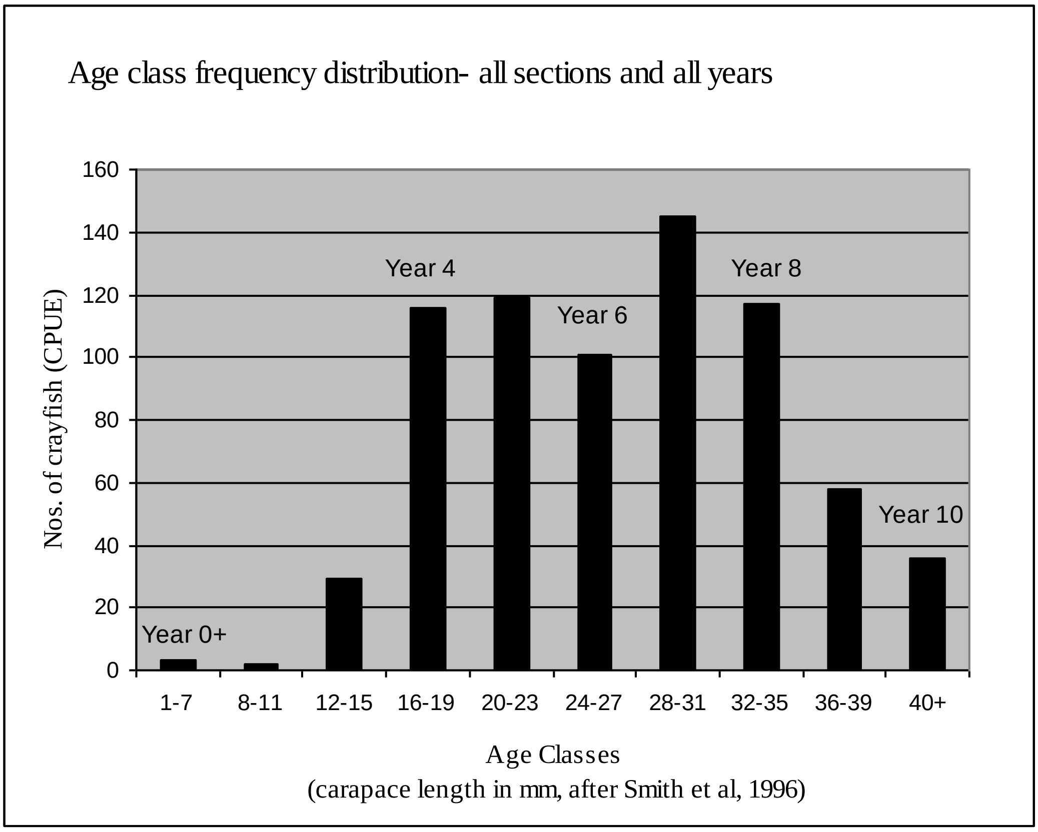

Figure 13. Age class distribution with approximate year number.

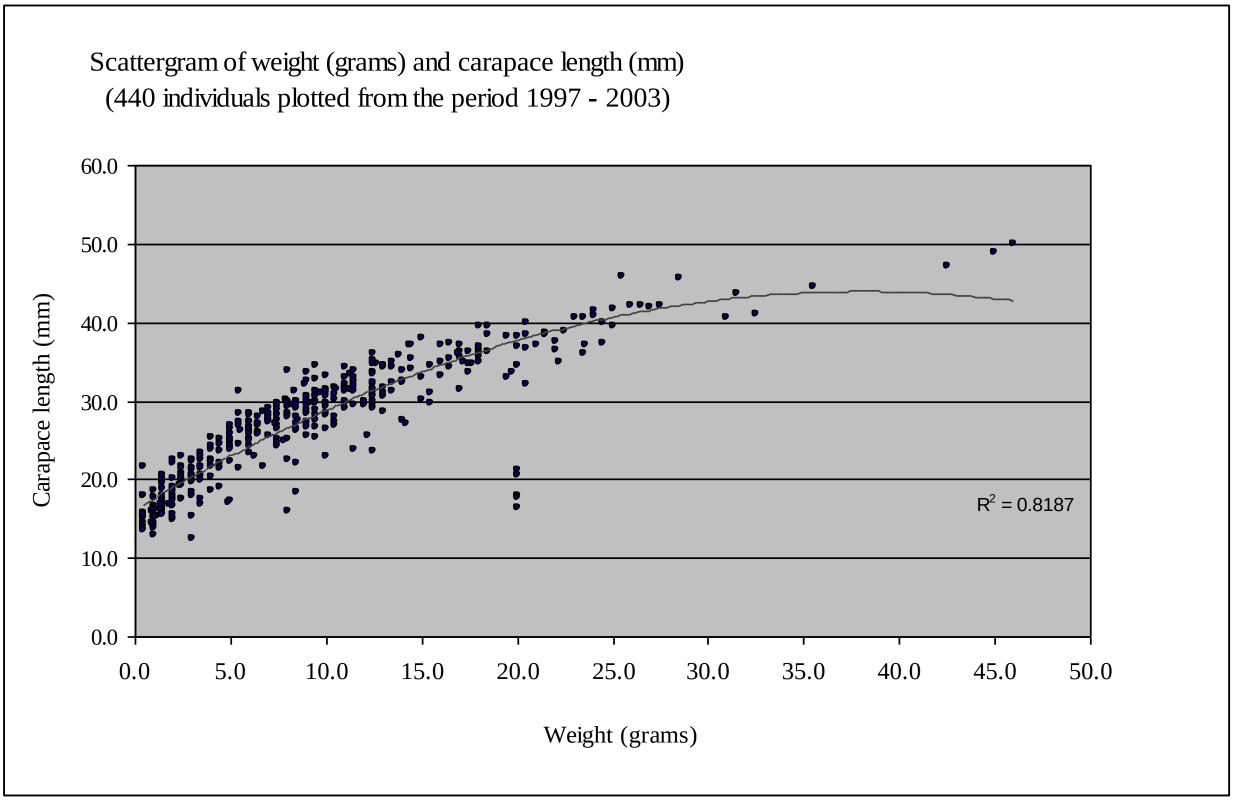

Figure 14. Relationship between weight and carapace length.

The age class distribution of the whole population varies from year to year along the full monitoring stretch. Figure 15 for example, shows this variation for two monitoring years, highlighting the reduced catch per unit effort in 2008 and the loss of the older age classes. Similar age class distributions are also found within the monitoring sections (see Figs 16 and 17), but there are apparent differences from year to year (Years 1997 and 2008 are given as an example of this). A trend from a normal distribution of age classes in the early years of monitoring to one which is skewed towards the predominantly younger age classes is possibly emerging in recent years.

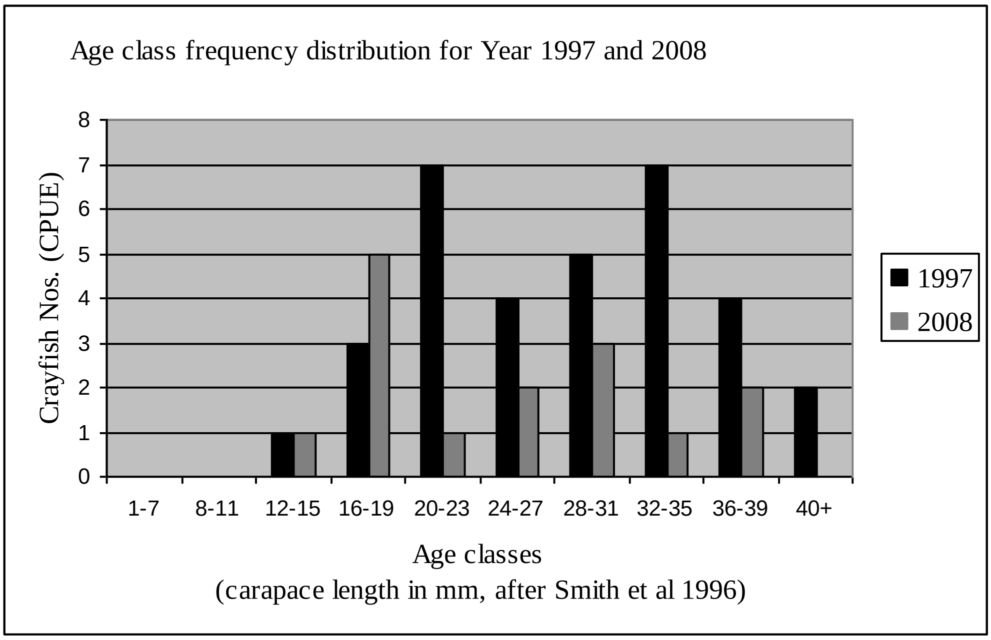

Figure 15. Age class distribution for 1997 and 2008.

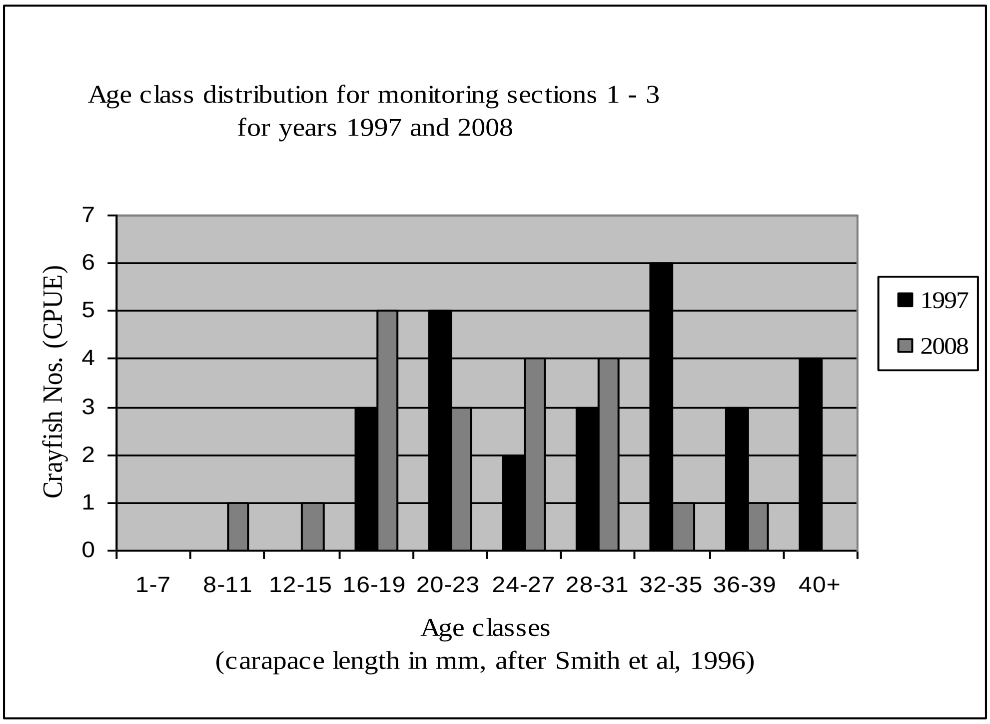

Figure 16. Age class distribution for the prolific sections 1-3 in 1997 and 2008.

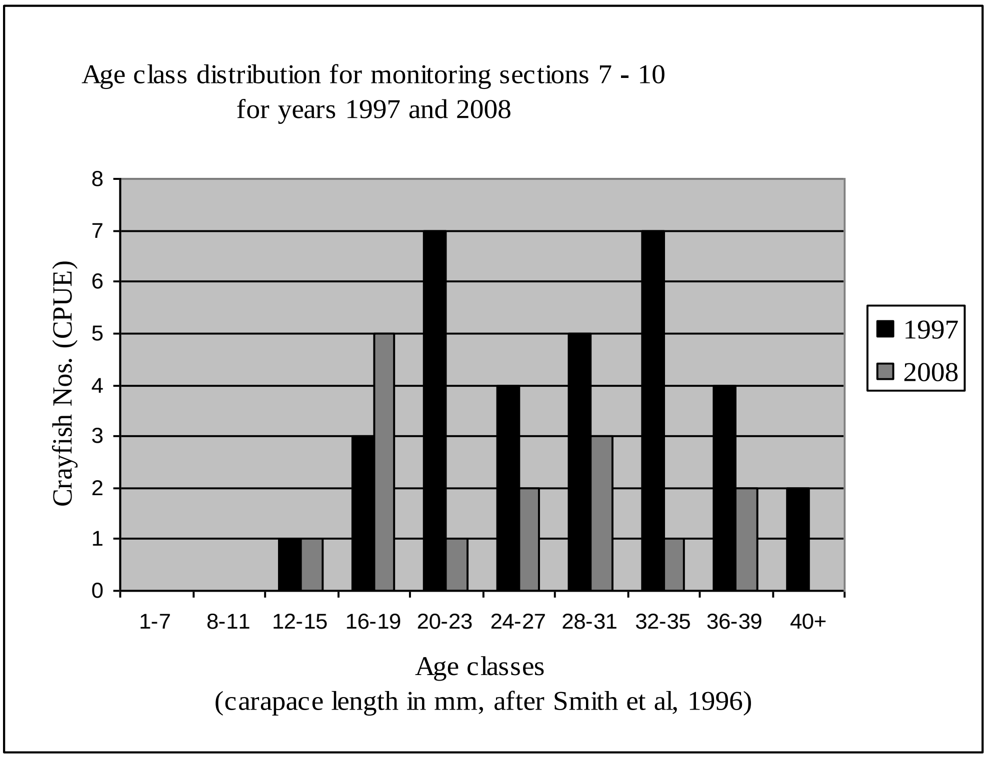

Figure 17. Age class distribution for the prolific sections 7-10 in 1997 and 2008.

The relative abundance of specific age classes also shows variation over time and the results have highlighted good recruitment years (2001 and 2008) and an indication of possible regular fluctuations or cycling in the adult and juvenile cohorts (see Fig. 18 and 19). Year 7 and 8 adults appear to build in numbers to 2002 and then decline. There is a suggestion that two levels of population flux are being experienced – in some cohorts there is a steady increase in numbers and an equally steady decline over a 5 – 8 year period (adult age classes), whilst others cycle more frequently over a matter of 2-3 years (juveniles). This phenomenon requires confirmation and more investigation over subsequent years.

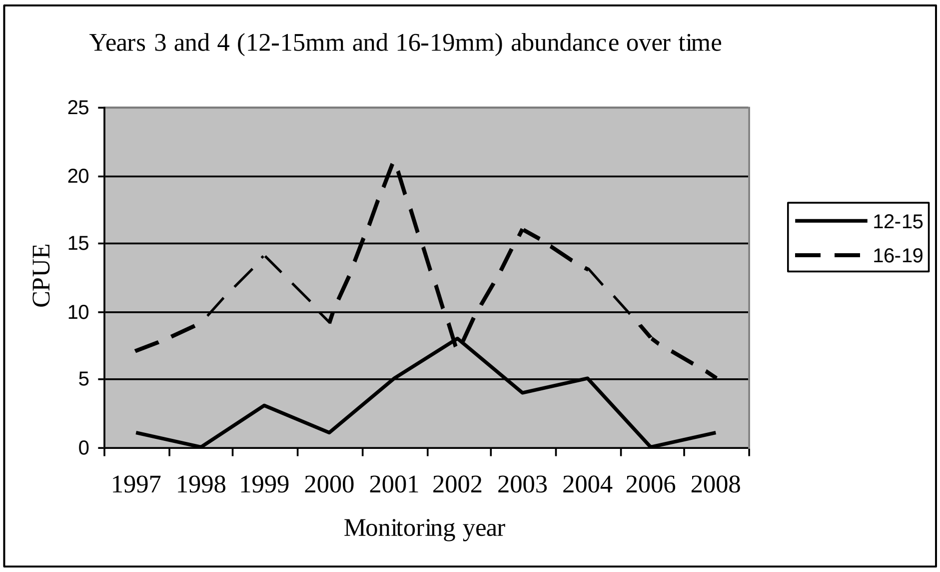

Figure 18. Juvenile (Year 3 and 4 classes) abundance over time.

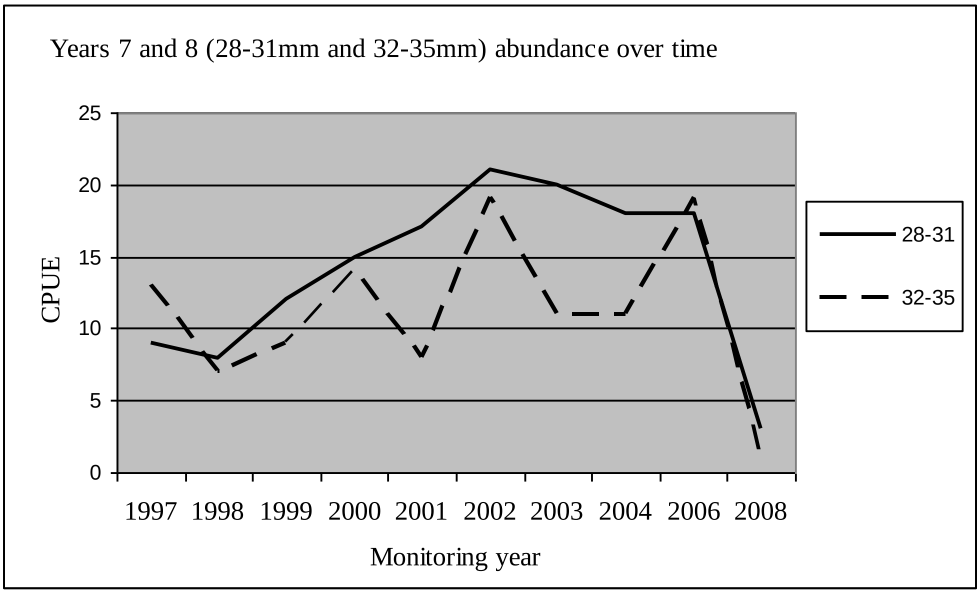

Figure 19. Adult (Years 7 and 8 classes) abundance over time.

There is a strong visual relationship between good recruitment years and relative abundance of adults in the subsequent 2-4 year period (see Fig. 20), but the correlation is not statistically significant. For example, the good recruitment year of 2001 may influence the abundance of the Year 7/8 age classes from years 2002 to 2006.

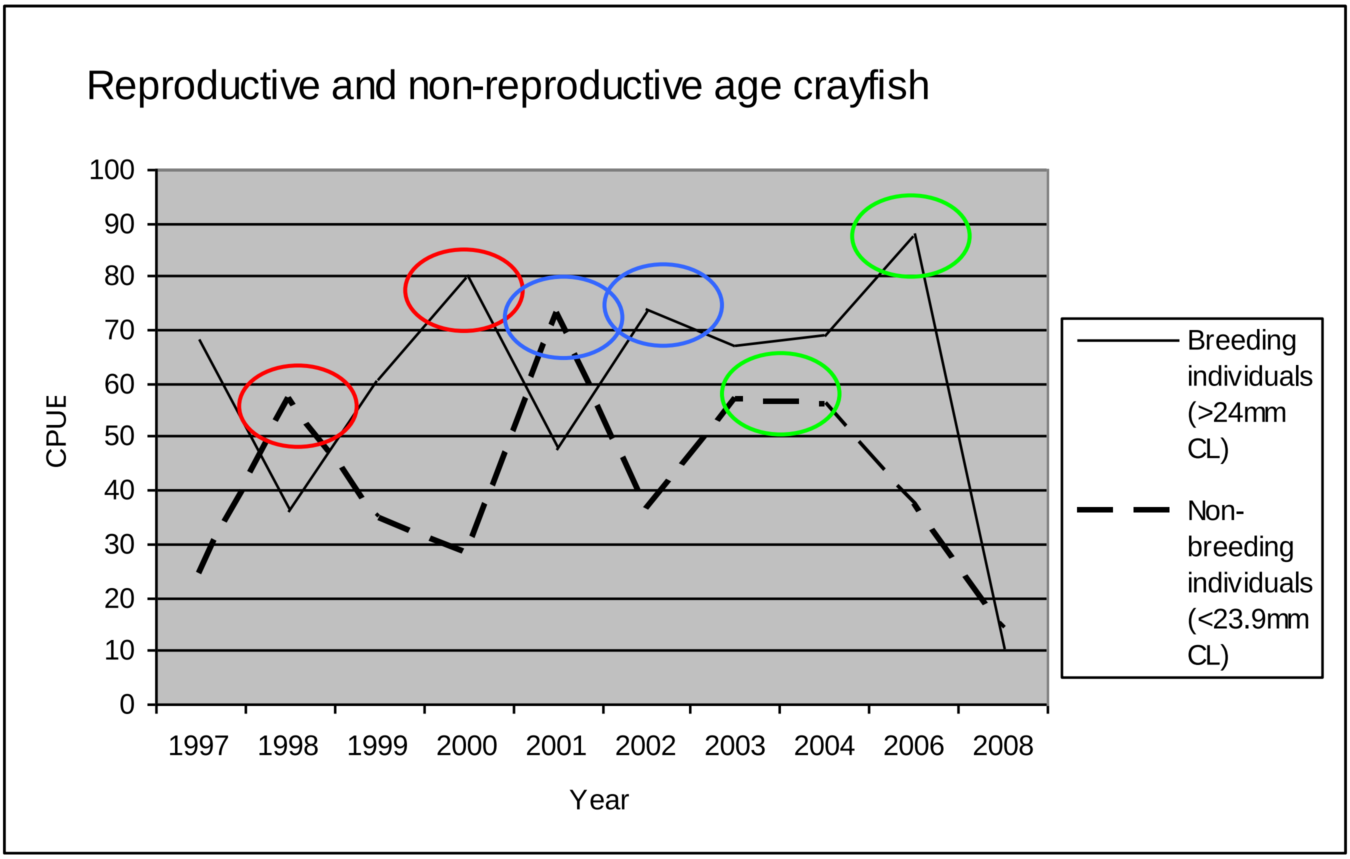

Figure 20. Numbers of reproductive and non-reproductive age individuals (similar colours represent the corresponding peaks in abundance).

Sex ratios have remained similar throughout the monitoring years and when all crayfish records are examined across all years a mean of 1 male to 1.3 females is found, but varying from almost parity in 2001 to 1:2 in 1997 (see Fig. 21). Within sections however, the variation is greater, with for example, monitoring Section 6 achieving the highest ratio of 1:3, with a mean of 1:1.5.

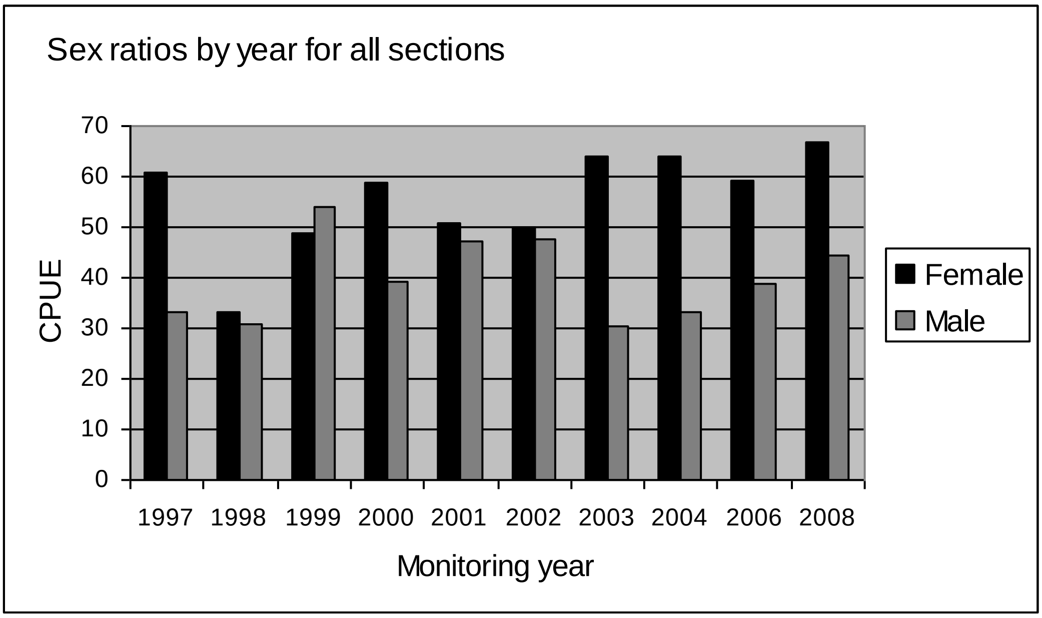

Figure 21. Sex ratios across all monitoring years.

Disease occurrence

Few microsporidial diseases have been observed in the crayfish population during monitoring, but burn spot and porcelain disease appear most prolific. Porcelain disease is consistently present in the population but in low proportions with a mean occurrence of 1.5%. Two exceptional years where this disease appears to have been more abundant are 1998 and 2008 (2.4 and 2.3 % respectively), which also coincide with the lowest catch per unit effort years. Year 5 age class (>24mm carapace length) adults with an mean of 28.6 mm carapace length appear to suffer most with 85% incidence rate, while 19% of all porcelain disease records are found in non-reproductive age juveniles (see Imhoff et al. this volume).

Table 1. Incidence of porcelain disease in all crayfish recorded during the monitoring period 1997 – 2008.

Year	1997	1998	1999	2000	2001	2002	2003	2004	2006	2008	Mean
%	1.6	2.4	1.3	1.2	1.2	1.2	1.3	1.4	1.2	2.3	1.5

Moulting stage

Limited information was gleaned from the recording of moulting stages since 95% of all individuals were in intermoult. It is uncertain whether this suggests some form of synchronicity in moulting activity, but given the close alignment of monitoring dates every year, this is likely.

Habitat characterization within the monitoring stretch

Over the ten year monitoring period a substantial amount of information on the habitat preferences of *A. pallipes* in the R. Itchen has been collected, indeed the monitoring patches in each section were identified on the basis of supporting favourable crayfish habitat.

The study characterizing the habitat of the monitored stretch is only briefly reported and discussed in this paper. The habitat sample (stand) data collected within the prolific monitoring sections were numerically classified and ordinated. The classification revealed three major groupings of favourable habitat types where crayfish are located in this stream:

- Sand-Cobble-Boulders (Flint dominated patches and complex banks).
- Gravel-Pebbles-Macrophytes (main in-channel group).
- Detritus-silt (marginal group).

These habitat types form a continuum both longitudinally and across the stream profile, rather than occupying discrete areas of the channel. The Ordination plot reflects this grading between habitat types (see Fig. 22). The TWINSPAN classification groupings have been overlaid on this continuous data to give an indication of where the main habitat types lie within the stream profile.

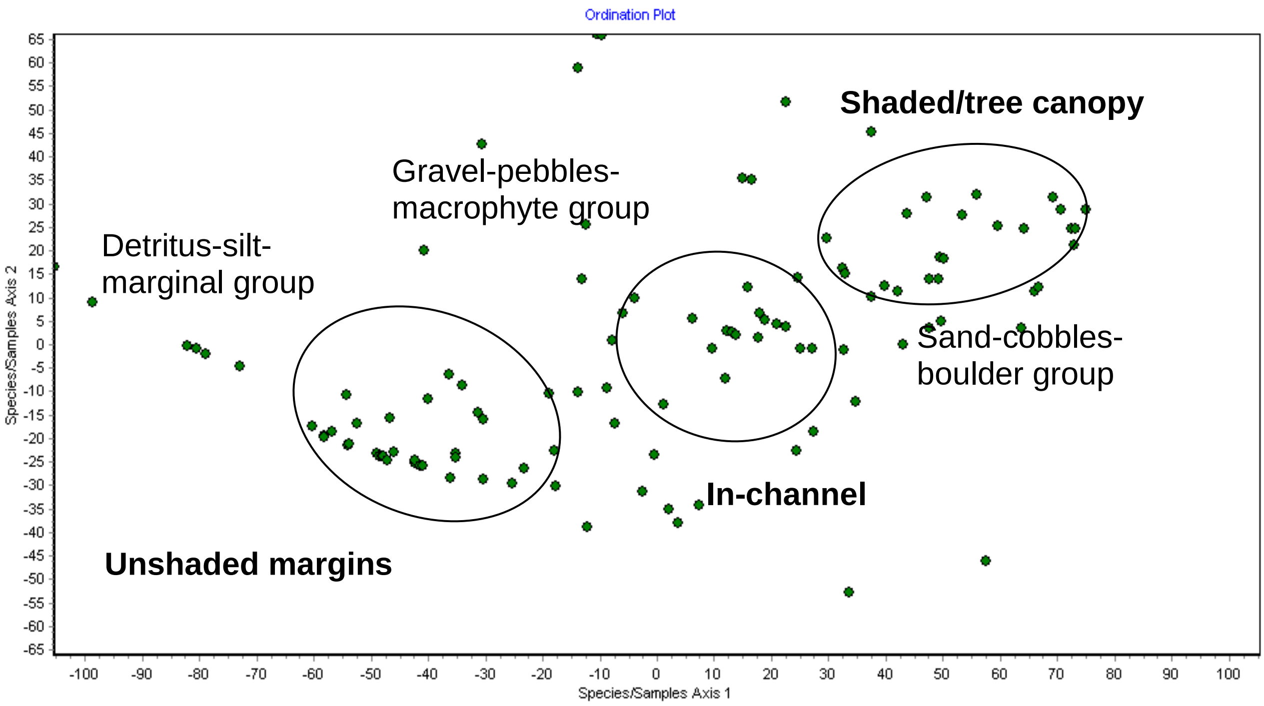

Figure 22. Stand/quadrat biplot of the habitat data from abundant crayfish sections (Canonical correspondence analysis after Ter Braak 1988).

As a result of this study and anecdotal information collected over the 10 year period a number of key habitat characteristics are known to be important for the R. Itchen crayfish, these include:

- Stable flow regime.
- Narrow stream width (3-5 m) and shallow water (10-50 cm).
- Chalk flint (boulder size > 250 mm) over gravel and pebbles (range 15-100 mm size) substrate.
- Complex bank structures – often man made including rubble and chalk flints.
- Discontinuous shaded banks and occasional open unshaded margins.
- Warm shallow margins, which comprises late summer juvenile habitat.
- Low grazing pressure on banks and surrounding land use zone.

These findings generally accord with the habitat characteristics recorded in other studies on *A.pallipes* (Naura and Robinson 1998; Foster 1995; Smith et al 1996). Figures 23 and 24 show typical habitat conditions in the monitored stretch.

DISCUSSION

During the monitoring period the population of *A. pallipes* in the upper R. Itchen remained stable and showed no overall significant variation in relative abundance from year to year, apart from a perceived change during 2008. Similarly the spatial distribution of this population has remained stable over time with very little movement up or downstream regardless of the efforts of habitat enhancement projects.

It is considered that a number of factors have contributed towards this stability:

- The stable hydrological regime characteristic of upper tributary chalk streams.
- The absence of abnormal habitat disturbance - the stretch has experienced a consistent management regime over the ten years.
- The presence of highly favourable habitat patches which are bordered by structurally uniform sections limiting the movement of the population.
- The diverse age structure of the population may invoke an inherent stability in the population over long periods of time despite natural fluctuations.

Two major factors are worthy of further discussion in this respect – the distribution of crayfish and the influence of habitat structure, and the way a population of crayfish varies over long periods of time.

The heterogeneity and quality of the aquatic and semi-aquatic habitat in the sections where crayfish are prolific is outstanding. The monitored stretch generally comprises highly favourable conditions for crayfish, including shading from overhanging trees and shrubs (hazel *Corylus avellana*, ash *Fraxinus excelsior* and sycamore *Acer pseudoplatanus*), clear gravel of varying particle sizes underlying large flints and cobbles, complex bank zone structure (often man-made with brick rubble and flints) and a stable moderate flow of water throughout the year (Figs 23 and 24). The sections where this combination occurs are classic examples of prime habitat for *A. pallipes* in the southern chalk streams.

It is due to the diverse stream bed and bank zone habitat that the upper R. Itchen crayfish hardly ever build burrows as seen in other river systems. Indeed, there is only one known crayfish burrow system in the upper R. Itchen, a small collection of characteristic holes in a steep sided bank comprising alluvial/organic substrate. The upper R. Itchen crayfish more readily construct “crypt-type” refuges in the stream bed and utilise the gaps and fissures in the flint and brick banks. The holes in flints and the crevices created by their non-uniform shape also provide important refuges. The “crypt” refuge consistently comprises a shallow hole, often beneath a “keystone” or slightly larger stone in the gravel bed and covered by a large flint or cobble. Even juveniles construct this type of refuge in the stream bed.

The monitoring results certainly suggest that *A. pallipes* in the upper R. Itchen are very sensitive to habitat change. Some of the monitoring sections are in a relatively new channel created in the mid-1980s, here crayfish numbers have consistently been very low. To date very little colonization has occurred into these sections regardless of the habitat enhancement works and prolific crayfish sub-populations both up and downstream.

Generally over the 10 year period, the sub-populations seem to react in a similar way rather than independently along the stretch, but there appears to be little interaction and interchange between sub-populations. There will inevitably be some drift of crayfish, particularly juveniles, between sections, but the evidence suggests that this is at a very low level. Further evidence is provided in the consistently low numbers of crayfish observed in the last monitored section downstream.

Two conclusions can be drawn from the above. The discreteness of the sub-populations along the stretch and the favourable habitat in which crayfish live has undoubtedly led to their survival in the R. Itchen - the probable crayfish plague outbreak having failed to move across to the discrete upper R. Itchen sub-populations. Lastly, the presence of separate discrete sub-populations does make the power of monitoring very effective.

Little information exists and limited research has been undertaken on how a population of crayfish varies over long periods of time. The upper R. Itchen study has revealed some information in this respect. An apparent stable population in terms of relative abundance from year to year is evident, but, when viewed at a finer resolution within each monitoring section and by age class, changes are apparent. There are indications that the population fluctuates on a regular basis in some cohorts (juveniles) with possible longer term trends and cycles in others. It is interesting to note that these fluctuations in the R. Itchen population are not large as have been recorded in other river systems, e.g. in the Yorkshire Ouse numbers rose to high abundance over several years, sufficient to be noticed by anglers, but then fell to much lower abundance (Hiley pers. comm. in Peay 2002). Early work in the River Ock, Berkshire (now Oxfordshire) also revealed similar population changes in *A. pallipes* (Duffield 1933, 1936). In both cases these changes were not attributable to crayfish plague or pollution and the cause is generally unknown, although porcelain disease and moulting stress during certain environmental conditions has been suggested as possible reasons (Duffield 1936; Holdich pers. comm. in Peay 2002).

It is not known whether the sharp change in abundance during 2008 is part of a natural cycle or a result of external pressures on the population. The population numbers and older age classes appear to be depressed for some sections, but for others there has been little change. This does suggest some form of localized external pressure on the population and predation may be the cause.

There has been increasing evidence since 2007 of otters (*Lutra lutra*) along the stretch, including a probable active artificial holt located in one of the downstream monitoring sections. Most otter spraints located in the monitored sections hold abundant crayfish remains and this is a good indication of this prey item being targeted locally (Slater and Rayner 1993). This may account for the reduction in the counts along the whole stretch in 2008 and the localized loss of Year 7-10 age classes in the downstream sections. Juvenile recruitment to the population will be effected by excessive predation, but it is usually only a short term influence on a population and may have little overall effect on crayfish abundance in the long term. The holding capacity of the habitat is more important in controlling population size (Hogger 1988).

There has been some detectable change in bank zone management in recent years along the monitored stretch. The banks have been left to grow tall in many places, which tends to shade the margins of the stream in summer. Anecdotal observations suggest that the warm margins are important for 0+ juveniles during August for growth and as places to avoid predation and cannibalism. The combined pressures of juvenile habitat loss and predation could have a significant effect on the population in the medium term. Continued monitoring will reveal whether the perceived change in 2008 is indeed part of a natural population flux or a result of other pressures.

CONCLUSIONS

Over the ten year monitoring period a substantial amount of general ecology and more specific population information has been gathered for *A. pallipes* in the upper R. Itchen. Monitoring has served as a tool to focus observations of this population down to a fine level and useful quantitative information has been gathered on which to assess change. Probably one of the most important aspects of this work has been the opportunity to study in some detail one of the few remaining crayfish populations in southern England. The monitoring exercise has provided the motivation to get to know the crayfish population very well.

The monitoring results have provided a baseline of information from which a range of other studies have been able to take place and on which important decisions have been made about how the R. Itchen should be conserved and managed. This work has included Appropriate Assessments under the Habitat Regulations (Directive on the Conservation of Natural Habitats and Wild Fauna and Flora, Council Directive 92/43/EEC), including the stocking of fish and the risks associated with the transmission of the crayfish plague disease and the ecological impact of the upper R. Itchen flow augmentation scheme (Hutchings 2003b, 2004). The work has also provided a scientific basis on which to enhance and create stream and bank zone habitats for crayfish and other notable species such as bullhead (*Cottus gobio*).

This work has also initiated some debate about the effectiveness and sustainability of monitoring programmes for *A. pallipes*. The monitoring methodology devised is purposefully relatively simple, since it is well recognized that such schemes are likely to be the most successful – simplicity in terms of ease of collection of data, ease of analysis, ease of interpretation (Usher 1991). Yet a number of questions arise, does the method have the fidelity to detect small changes as well as longer term trends in a crayfish population? Can we be certain that any changes detected are natural ones as a result of intraspecific and external pressures placed on the population or an aberration of the monitoring methodology alone? It is important to remember that, like any monitoring scheme, it is a snap shot of the overall picture. How representative is the information gathered of the full life cycle of crayfish in this stream?

The key to answering these questions probably lies in the methodology itself and in the nature of the population distribution. A consistent and standard approach to monitoring and the ability to replicate and apply it to the same areas, or in this case habitat patches, will bolster confidence in the results and the subsequent interpretation. Equally, monitoring results will be significantly affected by the competence of the team in the field. Monitoring will always only provide a “snap shot”, but generally it is the best that can be achieved with the resources and time available.

The last question relates to the dilemma of fulfillment. At what point do you stop a monitoring programme? There will always be pressures to continue given the desire to know more, but should there be an end point? Monitoring schemes usually stop at a predefined point based on some criteria or when the aims of monitoring have been fulfilled (Usher 1991). In this case, the aim is to detect change and since change is continuous, perhaps monitoring should continue into at least the foreseeable future. The reality is such that the end is usually determined by the availability of time and resources, rather than the fulfillment of a predefined ecological aim. The complete loss of the crayfish population would also be another reason. The main nature conservation agencies in the UK have few resources to devote to work such as this and in the future volunteers and local enthusiasts will continue to be the main drivers in maintaining this important monitoring effort.

ACKNOWLEDGMENTS

The author wishes to thank Vitacress Salads Ltd for their cooperation and the many dedicated volunteers, too many to mention here, who have assisted over the ten years of monitoring.

Figures 23 and 24. Characteristic crayfish habitat in the upper River Itchen.

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Crayfish and River Users

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ABSTRACT

The decline of the white-clawed crayfish *Austropotamobius pallipes* in Hampshire has been particularly dramatic over the past two decades. Hampshire's rivers are utilised by a wide range of interest groups, whose activities often unintentionally or inadvertently pose a major risk to the preservation of this species, particularly through the movement of signal crayfish and/or crayfish plague. To better inform these groups and therefore reduce these risks, the Chalkstream Invertebrates Project (a partnership between the Hampshire and Isle of Wight Wildlife Trust and the Environment Agency) has produced an informative booklet to be distributed to the target audience. This paper represents a modified version of this booklet.

Keywords: *Austropotamobius pallipes*, conservation, threats, *Pacifastacus leniusculus*, crayfish plague, invasive species management, Hampshire

INTRODUCTION

Chalkstream Invertebrates Project

The Chalkstream Invertebrates Project is a partnership between the Hampshire and Isle of Wight Wildlife Trust and the Environment Agency to protect and raise the profile of our threatened chalk river invertebrates. The project has a specific focus on two nationally and internationally threatened species, the southern damselfly, *Coenagrion mercuriale* (Charpentier), and the white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet). Furthermore, due to it is intrinsic role within the dramatic decline of the white-clawed crayfish in Hampshire (Hutchings this volume), the project is also focusing on the introduced and highly invasive American signal crayfish**,** *Pacifastacus leniusculus* (Dana).

Crayfish in Hampshire

The decline of the white-clawed crayfish in Britain during the past 30 years is well documented (Holdich et al. 1995, Holdich 2003, Sibley 2003), and the loss of this species within Hampshire over the past two decades has been particularly dramatic (Hutchings 1998, Hutchings this volume). It is currently considered that only three viable sub-populations remain in Hampshire, which are isolated in two upper tributaries of the River Itchen catchment (Hutchings this volume). This decline has been mirrored by a steady increase in the number and distribution of signal crayfish populations, which have now been recorded across the major river systems within Hampshire, with the first positive confirmation of this species on the River Itchen recorded this year.

A number of causal factors have been identified in the decline of the white-clawed crayfish including habitat loss and land use change, changes in water quality and quantity and the introduction of signal crayfish and resulting eventual exclusion of the white-clawed crayfish via interspecific competition. However, both nationally and within Hampshire, the single-most influential factor causing mass or widespread mortalities of the white-clawed crayfish since the 1980s has been outbreaks of the pathogen *Aphanomyces astaci* or “crayfish plague” (Holdich et al. 1995, Hutchings 1998).

The highly localised distribution of the white-clawed crayfish in Hampshire, the widespread presence of the signal crayfish and historic (albeit often anecdotal) outbreaks of crayfish plague means this species is highly vulnerable to localised extinction. The Chalkstream Invertebrates Project is working to protect and conserve these indigenous crayfish populations through three key objectives:

- **Working with land and river owners and managers** to encourage habitat enhancement and sympathetic management of rivers and the adjacent land where the white-clawed crayfish is found.
- **Improve knowledge** of the ecology and distribution of both crayfish species in Hampshire.
- **Raise awareness** of the issues threatening the white-clawed crayfish.

Furthermore, it is considered that as a consequence of recent limitations in readily available public information and a resulting lack of knowledge and appreciation, the activities of many river users pose unintentional risks to the white-clawed crayfish, particularly via the (accidental or ill-informed) introduction of non-indigenous crayfish or the transmission of crayfish plague. It was therefore decided that the production of an informative booklet with a targeted distribution would be an effective mechanism to minimize some of these risks. The remainder of this paper is a **modified** version of that booklet, which is available for downloading in its original form at: http://www.hwt.org.uk/data/files/Water4wildlife/crayfish_and_river_users_booklet_web_version.pdf

White-clawed crayfish

Latin Name: *Austropotamobius pallipes* (Fig. 1).
Origin: Only crayfish species indigenous to Britain. It is found across Europe, and is at the northern and western edge of its range in Britain.
Body Length: Up to 12 cm (excluding claws), although usually no more than 10 cm.
Colour: Usually pale-dark brown to olive.
Claws: Underside off-white colour (Fig. 2[1]), may be pink in juveniles.
Habits: Generally docile.
Habitat: Streams, rivers, lakes. A widespread but localized distribution in central and northern England, increasingly rare in the south, sparse in Wales. Declining throughout Europe.
Diet: Omnivorous – feeding on macroinvertebrates, carrion, calcified plants and detritus.

Figure 1. Left. Adult male white-clawed crayfish.

Figure 2. Right. Underside of claw.

Signal crayfish

Latin Name: *Pacifastacus leniusculus* (Fig. 3).
Origin: Native to North America, but introduced to Britain from Sweden in the 1970s for harvesting to mainly supply the Scandinavian food market.
Body Length: Up to 30 cm (excluding claws), though more often 15 cm.
Colour: Bluish-brown or reddish-brown.
Claws: Very large and heavy, red underside (Fig. 3[2]) with a turquoise or white patch (Fig. 4[3]) on the upper side.
Habits: Aggressive and invasive.
Habitat: Lives in similar habitats to the indigenous species but will also burrow extensively into the banks, often resulting in localized bankside failure. Widespread in England, particularly in the south, having escaped from crayfish farms and live food markets.
Diet: Omnivorous - will eat the indigenous crayfish species and in large populations will predate heavily on fish eggs.

Figure 3. Left. Male signal crayfish showing red underside to claws.
Figure 4. Right. Front view of an adult signal crayfish showing the patch on the claws that gives it its common name.

It can be **difficult to distinguish between** crayfish **species**, particularly when young (see Holdich this volume). If you **see or catch** a crayfish, please **contact** the Hampshire and IOW Wildlife Trust or Environment Agency for **advice** on identification and disposal of non-indigenous species. It should be noted that Britain has seven species of crayfish, including six non-indigenous species (see Holdich and Sibley this volume).

WHY THEY NEED OUR HELP

Threats to our indigenous species

The greatest threat comes from the non-indigenous signal crayfish.

The signals, and other non-indigenous North American species, carry a virulent disease - **crayfish plague** – caused by a fungus-like organism that is deadly to our indigenous species. This disease can be transferred between rivers on fish, aquatic vegetation and equipment.

The fungal-like spores can remain **viable** for **up to** about **16 days** under humid and cool conditions (Oidtmann 2000).

Signal, and all **other non-indigenous crayfish species** (e.g. red swamp crayfish, spiny-cheek crayfish), are larger, more invasive (Fig. 5), and more aggressive than our indigenous species and will out-compete and even feed on them.

Other serious threats include **habitat degradation** and **pollution**.

Figure 5. Adult signal crayfish can readily move both down and upstream.

This booklet aims to highlight the potential **threats** that different groups of **river users** pose to our **indigenous crayfish**, and the steps that can be taken to **minimise any** potential **risks**.

WHAT WE CAN DO

Crayfish in Hampshire

White-clawed crayfish were formerly widespread in Hampshire's chalk rivers but, following the introduction of signal crayfish, are now restricted to three sub-populations (Hutchings this volume) as a result of competition and mass mortalities from crayfish plague. Signal crayfish are widely distributed throughout Hampshire (see Fig. 6) and are considered to be under-recorded. This suggestion is supported by the increase in the recorded distribution of signal crayfish in 2009 following the inception of the Chalkstream Invertebrates Project, which has provided a mechanism for the collation of previously unrecorded sightings.

The Hampshire and Isle of Wight Wildlife Trust, in partnership with the Environment Agency, is seeking to protect our remaining white-clawed populations through the **Chalkstream Invertebrates Project**. This will involve:

- Surveying / monitoring both white-clawed and signal crayfish
- Assisting the Environment Agency with habitat enhancement
- Raising awareness

Reporting your **crayfish sightings** to the Hampshire and Isle of Wight Wildlife Trust will help inform our conservation strategy for the indigenous species and help protect it from the threat of signal crayfish and crayfish plague.

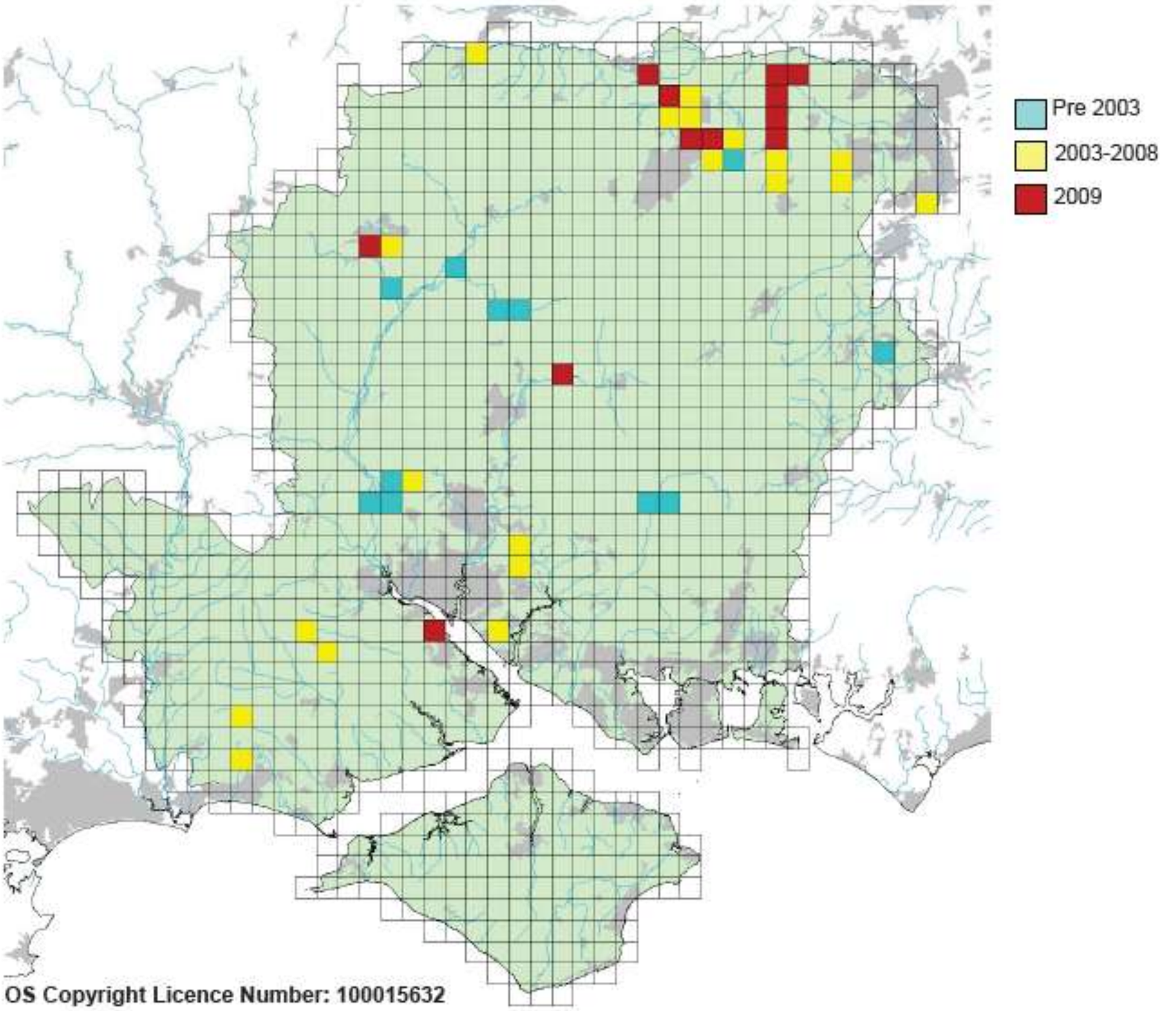

Figure 6. Map showing the recorded distribution (by 2 km grid squares) of signal crayfish (*Pacifastacus leniusculus*) in Hampshire.

CRAYFISH AND THE LAW

White-clawed Crayfish

The indigenous crayfish is **protected** under European (**EU Habitats Directive**) and UK (**Wildlife and Countryside Act 1981, as amended**) legislation (see Holdich et al. this volume).

As a consequence, it is **illegal** to "**take from the wild** or **offer for sale**" white-clawed crayfish without a licence. In England, a **licence to handle** white-clawed crayfish must be obtained from Natural England, and **trapping of any species of crayfish** requires licensing from the Environment Agency.

Non-indigenous crayfish

Signal crayfish were introduced into Britain from Sweden in the early 1970s for farming, to supplement the declining Scandinavian crayfish market. However, since the early 1980s the keeping of any species of non-indigenous crayfish has been subject to strict regulation in England (see Holdich and Sibley this volume).

Under the **Wildife and Countryside Act 1981** (as amended), it is an **offence to release, or allow to escape**, any non-indigenous species into the wild in Britain except under licence.

The **Prohibition of Keeping of Live Fish (Crayfish) Order 1996** (as amended), made under the **Import of Live Fish (England and Wales) Act 1980**, makes it an **offence to keep any crayfish** in England and Wales, except under licence (with specific exemption areas for signal crayfish).

These **laws** are **discussed** in more detail throughout this booklet in the **context** of different **interest groups**.

Anyone undertaking crayfish farming must register their business with The Fish Health Inspectorate, CEFAS*. For an application form or information on the cultivation/importation of crayfish please contact:

The Fish Health Inspectorate,
CEFAS Weymouth Laboratory,
Barrack Road,
The Nothe,
Weymouth,
Dorset, DT4 8UB
Tel: 01305 206673

* Centre for the Environment, Fisheries and Aquaculture Science

PRACTITIONERS

Public and Private Bodies

A number of **commercial** (such as water companies, environmental consultancies) and **public** bodies (such as the Environment Agency) work in and around rivers (Fig. 7). Likewise, many **charitable Trusts** (such as Wildlife Trusts) and local action groups work on aquatic projects.

This can involve regular trips to a number of different rivers or streams within or across catchments, and these groups are therefore at high risk of transferring **crayfish plague**. This risk is minimized by following the **"Golden Rules"** set out on the back of this booklet.

Furthermore, where there is **volunteer**, **out-posted staff** or **contracted staff** involvement, it is essential that these personnel are provided with an **appropriate** level of **training** and **caution** is exercised in the sites they are allocated to.

In addition, any organisation working directly with either indigenous or non-indigenous species must ensure that they have obtained the **relevant approvals** and **licences**.

Figure 7. Surveyor looking for signs of water vole *Arvicola terrestris*.

ANGLING

River Management

In stretches where angling clubs **manage** the river and the river bank, a number of opportunities exist to manage these habitats for the **benefit** of both the **target fish** species and the **white-clawed crayfish**.

Survival from juvenile to adult life stages of both **crayfish** and **brown trout (***Salmo trutta*) can be **enhanced** by the **presence** of a range of **habitat features**. These include bankside features such as areas of overhanging tree root systems, and in-channel features such as gravel and cobble refuges and a combination of open and vegetated areas (Fig. 8).

It is important to note that any in-channel or bankside works will require **consent** from your local **Environment Agency** office, and you should **contact** your local **Natural England** office to check that the site is not subject to special designation. Advice can also be sought from the Wild Trout Trust. Consultation with these organisations from the outset is strongly advised.

Figure 8. Large flint piles provide shelter for crayfish and trout.

ANGLING AND RECREATION

Anglers / Angling Shops

The principal risk anglers pose to the white-clawed crayfish is through the transmission of **crayfish plague** via equipment and footwear (Fig. 9). This risk is minimised by following the **"Golden Rules"** set out on the back of this booklet.

In addition, the use of **crayfish as bait** in any form is **illegal**, as even dead and liquidised signals can continue to carry crayfish plague.

Figure 9. Fishing is very popular on many of Hampshire's rivers.

Walking and Watersports

As has been highlighted throughout this booklet, **crayfish plague** can readily be **transferred between sites** on wet boots, shoes, vehicle tyres and animal fur. You and your pets should **avoid moving between sites** in a watercourse where **crayfish** are present.

The risk of transferring **crayfish plague** is heightened in activities that involve extensive amounts of time on or in the water, such as kayaking and rowing.

Where activities and equipment are being used across different sites (within or between rivers/streams), it is essential that the **"Golden Rules"** set out on the back of this booklet are followed.

AQUACULTURE

Aquariums and Water Gardens

Under the **Crayfish Order**, the **keeping** of any non-indigenous crayfish (with the exception of one tropical species, the Australian redclaw, *Cherax quadricarinatus*) such as the noble crayfish *Astacus astacus* (Fig. 10) **without a licence** is an **offence**.

Since licences to keep non-indigenous crayfish are rarely issued, the keeping of crayfish as ornamental animals is effectively prohibited.

If you have any concerns about the keeping or selling of non-indigenous crayfish please contact The Fish Health Inspectorate on 01305 206673 or email fish.health.inspectorate@cefas.co.uk (in strict confidence)

Figure 10. Adult noble crayfish *Astacus astacus* in an aquarium.

Watercress Farms

Watercress farms pose a risk to the white-clawed crayfish in two ways. Firstly by the transfer of **crayfish plague** from an infected to an uninfected watercourse via equipment and personnel. This risk can be minimised by following the **"Golden Rules"** set out on the back of this booklet.

Secondly, like many other agricultural practices watercress farms may pose risks of organic **pollution** and the resulting reduction in water quality. This risk will be regulated by the Environment Agency as part of the "consent to discharge".

AQUACULTURE

Fish Stocking

Fish stocking can pose risks to white-clawed crayfish since live **non-indigenous crayfish** can be collected within the catch and **crayfish plague** can be carried on the scales of fish and on the equipment used in their transport.

The addition of large adult fish (Fig. 11) into river systems can also have adverse effects on the balance of freshwater life and may lead to an increased level of predation on juvenile white-clawed crayfish.

Under **Section 30** of the **Salmon and Freshwater Fisheries Act 1975**, the Environment Agency regulates the movement of fish within all inland waters in England and Wales.

Although an assessment of the risk to the white-clawed crayfish is included within this process, it is still recommended that the **"Golden Rules"** set out on the back of this booklet are always followed.

Figure 11. Adult brown trout.

LANDOWNERS

Bankside habitat

Riparian (river bank) landowners can provide great benefits for both the indigenous crayfish and other wildlife through **sympathetic management** of the river banks.

Riparian features such as vegetated margins (Fig. 12), areas of overhanging vegetation or tree root systems and undercut banks provide habitat for fish, crayfish and a number of other invertebrate species.

It is strongly recommended that you **contact** an advisory body such as your local **Natural England** office, the Wild Trout Trust or the Wildlife Trust at the outset for **advice** and **support**. In addition, it is possible that your enhancements may qualify for financial assistance under Natural England's **Environmental Stewardship schemes**.

It is important to note that any bankside works will require **consent** from your local **Environment Agency** office, and consultation with the Environment Agency from the outset is also strongly advised.

Figure 12. Bankside and marginal habitat enhancement using temporary fencing to allow the vegetation to establish.

LANDOWNERS

Adjacent land-use

The management of land adjacent to a watercourse can greatly influence **habitat** and **water quality**. This can be particularly true for some farming practices and industrial works, and can adversely affect white-clawed crayfish populations.

The major risk to water quality stems from diffuse (surface run-off, drainage) and point (direct) **pollution** from industrial waste or discharge, the use of fertilisers, pesticides, sheep dip and silage.

Cattle, intensive management and **vehicular access** to the river banks can cause serious damage or destroy habitat features essential to crayfish development (Fig. 13). By avoiding a high stock density and limiting vehicle access to the banks, you can not only minimize bank damage but can improve the diversity of bankside habitat, vegetation and species without the need for fencing.

If you have a **pond or lake** within your land, it is important to note that under the **Crayfish Order** the **keeping** or allowing the **release of** any **non-indigenous** crayfish **without a licence** is an **offence**.

It is recommended that you **contact** an **advisory body** such as your local Natural England or Environment Agency office for **advice** on how to minimize these risks. In addition, it is possible that your enhancements may qualify for financial assistance under Natural England's **Environmental Stewardship schemes**.

Figure 13. Bank failure can occur due to over-stocking.

FOOD AND RETAIL

Suppliers

Only signal crayfish can be **trapped** and **traded commercially**.

Under the **Crayfish Order**, anyone **farming/holding** non-indigenous crayfish must hold a licence and be registered with The Fish Health Inspectorate.

However, the Crayfish Order includes a list of areas where you may keep signal crayfish without a licence (see www.defra .gov.uk/fish/freshwater/pdf/licreq.pdf).

Anyone wishing to **trap** signal crayfish (Fig. 14) from the wild must obtain a trapping **licence** from their local **Environment Agency** office.

If you have any concerns about the keeping or selling of non-indigenous crayfish please contact The Fish Health Inspectorate CEFAS on 01305 206673 or email fish.health.inspectorate@cefas.co.uk (in strict confidence).

Figure 14. A licensed crayfish trap with catch of adult signal crayfish.

Restaurants and Fish Markets

Restaurants, hotels and fish markets are **exempt** from the **licensing** requirements provided they hold crayfish for **direct human consumption** only (Fig. 15).

Releasing crayfish without a licence, or **allowing** them to **escape**, is a **criminal offence**. The signal crayfish remains the major threat to our indigenous species.

Crayfish are master escape artists! Transfer animals quickly and in **secure watertight containers**. If necessary, ensure any re-packaging takes place indoors, away from rivers and ponds.

Never give away surplus stock. Where possible return them to your supplier. If this is not possible, make sure all animals are humanely killed and, to minimize the risk of crayfish plague transmission, seek advice on suitable disposal from the local Environment Agency or Wildlife Trust office.

Ensure that **staff** who handle crayfish are **aware** of these guidelines and the legal requirements associated with crayfish. Treat crayfish with care. Crayfish are subject to the normal provisions of animal welfare.

Figure 15. Crayfish is becoming an increasingly popular dish.

GOLDEN RULES

Avoiding the Transmission of Plague

Remember: Spores of the crayfish plague can remain active without a host for up to about 16 days under humid and cool conditions and are lethal to the white-clawed crayfish.

Disinfect and dry: Wet equipment and mud will harbour spores, so ensure boots / waders and equipment are thoroughly cleaned, disinfected and where possible allowed to dry. For more detailed information on disinfection procedures please visit www.hwt.org.uk.

Plan visits: Be aware of the distribution of crayfish and plan any visits (such as surveys) to minimize the risk of spreading plague. If possible, visit white-clawed crayfish sites first and signal sites afterwards. For information on the location of crayfish populations, contact the Wildlife Trust.

Work downstream: If possible work in a downstream direction, rather than risk infecting upstream white-clawed sites with spores.

Donor site: If undertaking fish stocking or habitat enhancement works (such as planting marginal vegetation), consider the donor site carefully as fish and plant material can harbour plague spores. Plants may even conceal young crayfish.

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Winterburn Reservoir compensation flow reduction trials impact on white-clawed crayfish

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ABSTRACT

Winterburn Reservoir is a supply reservoir for the Leeds and Liverpool Canal located in the Yorkshire Dales National Park, in addition to the canal the reservoir feeds the Winterburn/Eshton Beck which flows into the River Aire. In dry summers there are concerns that there may be insufficient water stored in the reservoir to maintain the compensation flow of 9.35 tcmd and there is a risk of the reservoir running dry. This would give rise to operational issues for British Waterways, the owners of the reservoir and the canal, and it would have major implications for the ecology of Winterburn and Eshton Becks. The becks support a population of white-clawed crayfish *Austropotamobius pallipes* as well as healthy invertebrate and fish communities.

In 2006 British Waterways, working with the Environment Agency, embarked on a study to investigate the impacts of a reduced flow on the ecology of Winterburn/Eshton Beck. Only the impact on the crayfish population is addressed in this paper. The objective of this study was to determine the impact of a flow of 5.30 tcmd with a view to ensuring the sustainable management of this water resource.

A standardized crayfish survey methodology was employed. Crayfish were found to be present in the catchment, numbers caught were generally low but there was an overall increase in the numbers caught during the study.

The compensation flow was reduced between January and September of each year of the survey; crayfish surveys were undertaken in late September. Rainfall events during the period of reduced flow caused the reservoir to overtop at least twice, in each of the four years. As a consequence, it has proved difficult to determine the true impact of a reduced flow on the crayfish.

The study recommends that the compensation flow is reduced to 5.30 tcmd for ten months of the year and this is set out in a compensation flow strategy which includes details of a monitoring programme for the crayfish.

Keywords: white-clawed crayfish, British Waterways, compensation flow, low flow, reservoir.

INTRODUCTION

Changing weather patterns in recent years and, in particular, the unpredictability of rainfall has caused many businesses to seriously reconsider how they use and store water. British Waterways nationally owns and operates over 3 000 km of waterways and this requires a significant water resource. To meet the demand for water, British Waterways uses several sources including river abstractions and reservoirs. British Waterways owns over 95 reservoirs and has the use of water from six more (Holt 2009, pers. comm.), water supply from these reservoirs needs to be sustainably managed and the allowable discharge rate, or the compensation flow, is often set in an act of parliament.

Winterburn Reservoir, in North Yorkshire, is one such supply reservoir. It is critical in its location as it provides water to a summit pound of the Leeds and Liverpool Canal. The reservoir took eight years to construct and was completed in 1893 under an Act of Parliament. The original plans were to build three reservoirs in the valley in order to generate sufficient capacity to supply the busy Leeds and Liverpool Canal, a compensation flow of 9.35 thousand cubic metres per day (tcmd) was set. However, only one reservoir, Winterburn was built and in recent years during dry summers, the level in the reservoir has got very low. In 2005 the Leeds and Liverpool Canal had to be closed due to insufficient water, and significant restrictions have had to be enforced in both 2008 and 2009.

The catchment is upland carboniferous limestone in the Yorkshire Dales National Park, it is a sub-catchment of the River Aire. The land use in the catchment is predominantly pastoral with cattle and sheep grazing; there are small pockets of mixed woodland. Winterburn Beck changes its name to Eshton Beck just downstream of the village of Winterburn, together they are approximately 8 km long. The Winterburn/Eshton Beck system is important in ecological terms with a diverse macro-invertebrate fauna, including white-clawed crayfish, Austropotamobius pallipes (Lereboullet), and a thriving fish community that includes brown trout *Salmo trutta* (Linnaeus), grayling *Thymallus thymallus* (Linnaeus) and bullhead *Cottus gobio* (Linneaus).

In 2006 British Waterways, working closely with the Environment Agency, embarked on a study to investigate the potential impacts of a reduced flow on the ecology of Winterburn/Eshton Beck. The study has just completed its fourth year and comprises an in-depth look at aquatic macro-invertebrates, crayfish and fish under reduced flow conditions. For the purpose of the study the compensation flow has temporarily been reduced to 5.30 tcmd between January and September. Only the crayfish component of this study is addressed in this paper.

There has been very little research carried out on the tolerance of *A. pallipes* to reduced flows. However, there has been a considerable amount of work, which began in earnest in North America in the late 1960s investigating the impact of low flows on the macro-invertebrate fauna in general and how one can establish the "minimum ecologically acceptable flow". The driver behind this work was primarily a perceived link between the loss of valuable fisheries and the development of the reservoir and water management systems in the mid 20th C. In the UK it happened later with researchers studying the relationship between flow velocities and flow regimes on lotic ecosystems. Work was led by the Institute of Freshwater Ecology and the Institute of Hydrology (now merged into the Centre for Ecology and Hydrology), they took the American work forwards and applied it to British rivers, an example would be work done by Bullock et al. (1991). In addition, a research team within the Environment Agency, led by Chris Extence, developed an approach referred to as the Lotic-invertebrate Index for Flow Evaluation (LIFE) (Extence et al. 1999). This analysed the relationship between a wide range of hydrological variables and benthic macro-invertebrates. It identified the critical flow parameters that influenced the invertebrate community structure. It is of relevance to this study that the team determined that in chalk and limestone streams it was the summer flow variables that were most influential in predicting the invertebrate community structure.

It is important to note that the objective of this study is not to determine the minimum ecologically acceptable flow. It is to determine whether a reduced compensation flow would be detrimental to the ecology of Winterburn/Eshton Beck. If it can be demonstrated that a discharge of 5.30 tcmd was not detrimental then this can be implemented in future years giving the benefit of retaining more water within the reservoir and ensuring a more sustainable use of the water resource. Without retaining this water there is an increased risk of the reservoir drying up completely during a long dry summer.

METHODS

Preliminary desk study

In the first survey season a request was made to the Environment Agency for all existing crayfish records for the study area. Records of *A. pallipes* went back to 1986. A comprehensive survey by the University of Durham of the catchment identified *A. pallipes* on Flasby Beck and in the upper reaches of Winterburn Beck.

Project design

Seven sites were selected for survey, then, in years three and four an additional site was added in at the request of the Environment Agency (see Table 1). Two of these sites were on a tributary of Winterburn/Eshton Beck, called Flasby Beck, these were used as control sites.

Table 1. Survey sites and dates

Site	Watercourse	Site Name	km *	Survey dates
1	Winterburn Beck	Horse Holme Wood	0.8	30-08-06, 01-10-07, 24-09-08, 24-09-09
2	Winterburn Beck	Abbey Hill	2.0	30-08-06, 01-10-07, 24-09-08, 24-09-09
3	Eshton Beck	Brockabank	4.7	30-08-06, 20-09-07, 24-09-08, 24-09-09
4	Flasby Beck,	Hetton Bridge	n/a	31-08-06, 20-09-07, 24-09-08, 25-09-09
5	Eshton Beck	d/s Holme Bridge	7.5	31-08-06, 21-09-07, 23-09-08, 24-09-09
6	Flasby Beck	u/s Eshton Beck	n/a	31-08-06, 20-09-07, 23-09-08, 25-09-09
7	Eshton Beck,	d/s Flasby Beck	6.0	31-08-06, 20-09-07, 23-09-08, 24-09-09
8	Eshton Beck,	d/s Eshton Weir	6.9	23-09-08, 25-09-09

*This column refers to distance downstream from the reservoir discharge point, when applicable.

The fieldwork was undertaken in late August or September at the end of the reduced flow period in each survey year. The survey work was carried out by suitably experienced and licenced surveyors.

Survey method

The standard crayfish survey methodology written by Peay (2003) was used. This study adhered closely to the standard methodology summarized above with the exception of the site selection. Sites were not randomly selected but were strategically chosen to investigate the impact of varying flow regimes in the channel.

The carapace length of all crayfish caught was recorded as was gender, damaged or missing claws and limbs and any evidence of porcelain disease *Thelohania contejeani* (Henneguy) (see Imhoff et al. this volume)

The control sites are not a true control as the number of variables that could affect the crayfish populations is large. Consequently, one cannot draw firm conclusions over differences between the experimental sites and the control and firmly attribute them to the reservoir. However, there is still some value in monitoring a crayfish population that will remain unaffected by the regulated flows from the reservoir.

It is important to note that crayfish surveying is prone to errors. There are differences between surveyors and how they operate; visibility can vary enormously depending on depth, turbidity and weather conditions. The lack of a quantifiable and random methodology makes it difficult to compare data and to apply meaningful statistics. In cases such as this the long-term data set becomes valuable allowing trends to be seen and some conclusions to be drawn with a greater degree of confidence.

RESULTS

Results have been summarised on Figure 1, a map which also shows the site locations.

In Year 1 crayfish were found at two sites out of seven surveyed and in Year 2 they were found at three sites out of seven. In years 3 and 4 an additional site was surveyed and crayfish were found at five of the eight sites in both years. At Site 1, no crayfish were found in 2006, this rose to 15 in 2008 and then 14 were recorded in 2009. A similar pattern was seen at Site 2, where the highest number of crayfish was found; there was an increase from five in 2006 to 33 in 2008 and then 32 in 2009. At Site 3 no crayfish were found until 2008 when five were recorded and three in 2009. Crayfish were only found at one other site on Winterburn/Eshton Beck; at Site 8 one crayfish was caught in 2008 and two in 2009, this site was not surveyed in the first two years of the study.

In this paper the actual population structure using carapace length and size classes is not investigated, but general observation shows that when crayfish were found there was both male and females present and a good range of carapace lengths, including very small juveniles. The numbers of crayfish caught was generally considered to be low but did increase during the course of the study. At the upstream control site (Site 4) the numbers varied little during the four year period, numbers recorded were six, four, seven and ten in chronological order No crayfish were found at the downstream control site (Site 6).

Porcelain disease was found in several animals including one large dead male. In Year 4 the incidence of porcelain disease was 8.2%. Unfortunately this was not accurately recorded in previous years.

The beck is a typical riffle-pool system, with faster flowing riffles, 10-20 cm deep with a stony substrate and also deeper (40+ cm), siltier, slower flowing stretches. Consequently there was a good range of substrate sizes and available refuges. At certain sites, notably Site 5, the cobbles and boulders were covered in filamentous algae and impacted in the sediment, making them less suitable as a habitat. In places the beck was tree-lined and there were submerged tree roots, there were no submerged or emergent macrophytes only aquatic moss at some sites. Bullheads were found at all sites.

The discharge from the reservoir has been maintained at 5.30 tcmd between January and September 2009. However, during periods of heavy rainfall the reservoir may “overtop” and extra water flows over the spillway. This additional water in the system cannot be controlled and results in higher flows in the system during the reduced flow period.

DISCUSSION

The presence of crayfish and the increase in numbers of crayfish at Sites 1 and 2 in particular, but also at other sites on Winterburn/Eshton Beck is encouraging. Crayfish were found at two out of seven sites in 2006, three out of seven sites in 2007 and five out of eight sites in 2008 and 2009. In addition, when several crayfish were found at one site there was usually a range of carapace lengths including some very small juveniles. As there was no corresponding increase at the control, Site 4, over the first two years, the results appear to indicate that the population is recovering. Exactly what it is recovering from and when any such incident took place is difficult to determine. Work on the recolonisation of crayfish of a 3 km stretch of river that had previously been densely populated with *A. pallipes* showed that it took four years for the density to reach a similar density to those seen upstream (Ream et al. this volume). In cases where there is no upstream "reserve" from which recolonisation can occur one would expect it to take considerably longer for populations to recolonize and recover. It is known that in recent years, despite several dry summers, Winterburn Beck has not dried up completely, there has always been some water released from Winterburn Reservoir. In dry summers, however, there will be a reduced wetted area and therefore less available habitat.

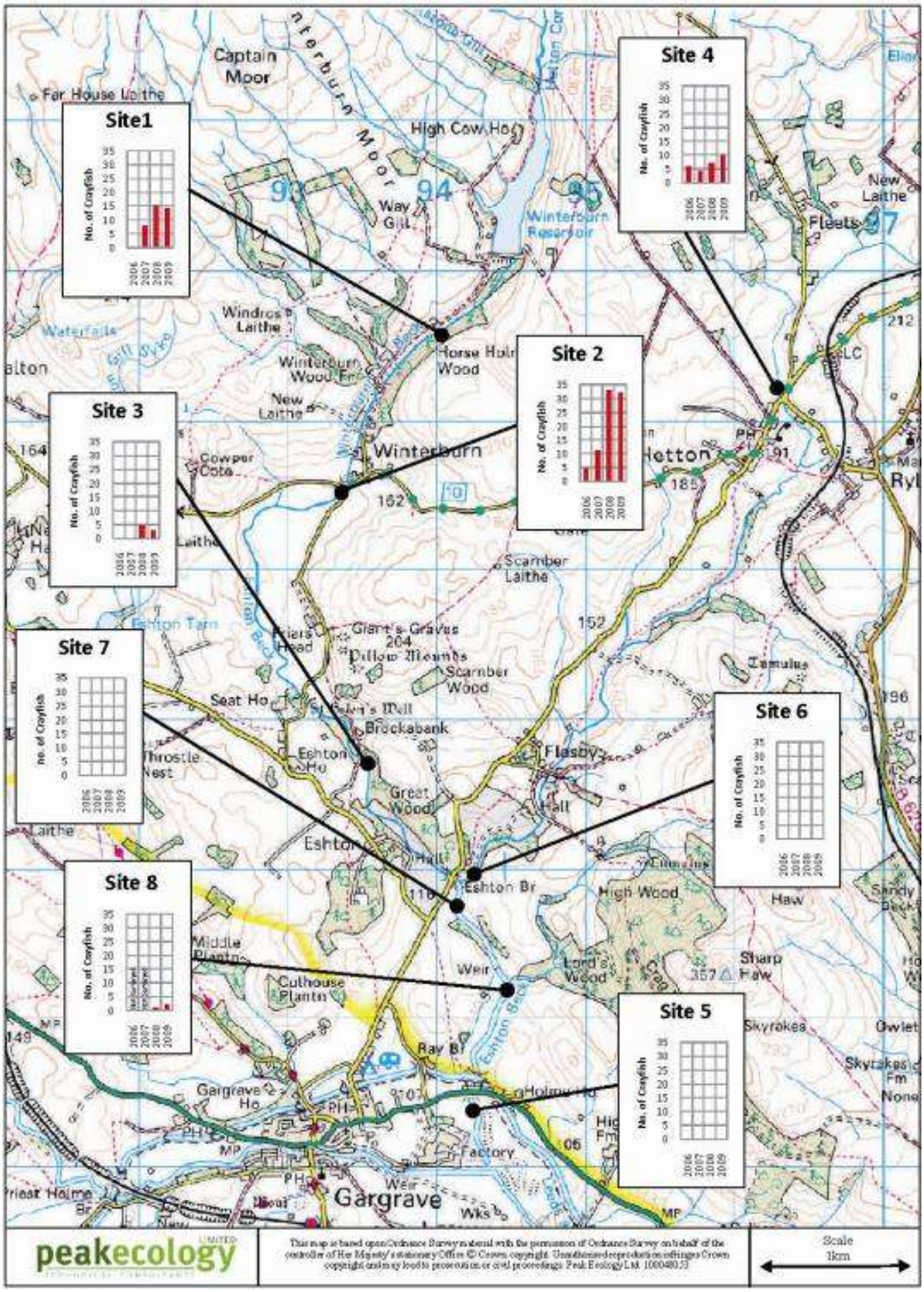

Figure 1. A map show the location of sites and the numbers of crayfish caught, 2006 to 2009.

The lack of water in the system would have resulted in greater dissolved oxygen fluctuations and a reduced capacity to dilute any pollutants such as agricultural run-off. The Environment Agency has confirmed that there have been no known pollution incidents on the system. One would expect reduced flows to have other impacts on an *A. pallipes* population; there would be fewer available refuges, less foraging area for food and an increase in the density of crayfish. The consequence of this would be increased competition between animals and more fighting and the claw and limb damage that comes with it. It may also result in the greater transfer of disease and parasites, thus weakening the population as a whole. The reduced depth and greater density would make some animals more prone to predation, in the Winterburn catchment heron, otter, mink and trout are all present. In cases where an increased density leads to increased mortality, this effect would be self regulating and would not ordinarily lead to an extinction of the crayfish. Nevertheless, a reduced flow clearly makes the *A. pallipes* population more susceptible to certain threats.

The objective of this study was to investigate the impact of a discharge of 5.30 tcmd on the population of *A. pallipes*. However, during the course of the study, rainfall events have caused the reservoir to fill and on occasion overtop, this has caused higher flows than planned. These excessive flows in a regulated system cannot be prevented, the key question is "what impact do these flows have on the crayfish and can the impact of the regulated flow actually be determined?" During periods of high flow velocities, crayfish tend to remain under larger boulders and remain there in relative safety until flow velocity subsides. In an unregulated system with a more natural flow regime, they would be subject to such flows fairly regularly during a wet winter and, normally, less frequently through the drier summer months. In a regulated system the flow attenuation effects of the reservoir would not prevent them but would make them less frequent. It is, therefore, not unreasonable to suggest that the crayfish in Winterburn/Eshton Beck have not been negatively impacted on by the overtopping. It is also a possibility that the over-topping has resulted in a positive effect and in their absence the crayfish population would have declined or remained static. The latter appears to have been the case at one of the control sites (Site 4). Higher flows will have additional effects such as washing away detritus and debris build up, this would be beneficial for cleaning salmonid spawning gravels and for certain macro-invertebrates, there is no evidence to indicate that this is either beneficial or detrimental to the *A. pallipes* population.

There were two control sites used for this study, both on Flasby Beck. At the most upstream site (Site 4) low numbers were found in each year, crayfish were also found here in a survey carried out in 2003. However, no crayfish have been found at the downstream control site (Site 6) in this study or in the 2003 survey. The reasons for this are unclear; it appears unlikely that it is the result of low flow as there are no known significant water abstractions between the two sites. Crayfish plague, *Aphanomyces astaci* Schikora, is a possibility, but there are no known North American crayfish species in the Winterburn/Eshton Beck catchment but they are in the wider catchment. Crayfish are sometimes used, unlawfully, as angling bait and they can spread to new watercourses, however, there is no evidence to indicate the presence of NICS. Crayfish plague could be spread on damp equipment such as an angler's keep net, despite no crayfish mortality ever being reported at this point this remains a possibility. The possibility of a pollution incident cannot be ruled out, macro-invertebrate data does not support this theory, and, again, there has never been a reported crayfish kill. It is understood that the sewage treatment works that discharges to Flasby Beck, between the two control sites, performs well. Had there been a pollution incident, one would have expected to have observed a recovery in the crayfish population over the last four years but this has not been the case. The detailed distribution of *A. pallipes* in Flasby Beck is not known, this would reveal the most downstream point at which crayfish are present and this in turn may help explain their absence at Site 6.

The presence of signal crayfish, *Pacifastacus leniusculus* (Dana), in the wider catchment forms the greatest threat to the *A. pallipes* in the Winterburn/Eshton Beck system. A sustainable flow regime can be implemented and this gives the crayfish population the best chance of survival. It is highly unlikely that a pollution incident, should it occur, would wipe out all of the crayfish. However, in time *P. leniusculus* will most probably spread in the catchment and will, at some point, find their way into the Winterburn/Eshton Beck and it will be a matter of time before *A. pallipes* disappears.

CONCLUSIONS

A constant discharge of 5.30 tcmd cannot be guaranteed by British Waterways between January and September of any given year because of seasonal over-topping of water from the reservoir.

The study has been inconclusive regarding the impact of a constant compensation discharge of 5.30 tcmd.

Over the four years the *A. pallipes* population appears to have expanded, being found at more sites and in greater numbers at each site where they were present.

The absence of *A. pallipes* at certain sites cannot be explained by this study.

A 9.35 tcmd presents a real risk of running out of water completely, which would clearly be disastrous for *A. pallipes* and the ecosystem as a whole.

A discharge of 5.30 tcmd presents a reduced risk to *A. pallipes*.

The greatest threat to the population of *A. pallipes* in the Winterburn/Eshton Beck system is from the presence of *P. leniusculus* in the River Aire catchment.

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Identifying crayfish in British waters

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ABSTRACT

Guidance is given on identifying adult crayfish that might be found in British waters. Photographic and written details are provided of the rostrum, carapace, pereopods and abdomen of the seven species known to occur in the wild as well as of two aquarium species. In addition, the differences in the form of the genitalia between the families are provided. The difficulties in identifying immature crayfish is discussed and some examples given.

Keywords: crayfish, identification, British Isles, adults, juveniles

INTRODUCTION

Even with the various keys that are available, e.g. Gledhill et al. (1993), Environment Agency (1998), Pöckl et al. (2006), and Souty-Grosset et al. (2006), difficulty can be experienced in correctly identifying crayfish in British waters. If possible it is important not to focus on one key character. In Holdich and Sibley (this volume) brief details are given of the key characteristics for crayfish found in British waters and photographs of whole crayfish are provided. In this paper additional photographic guidance is given to avoid identification pitfalls by focussing on the morphology of the rostrum, carapace, pereopods and abdominal structures of the seven species known to occur in the wild as well as of two aquarium species. In addition, the differences in the form of the genitalia between the families Astacidae, Cambaridae and Parastacidae are provided. The problems in identifying immature crayfish are highlighted and some examples given. Further details of crayfish morphology can be found in Hobbs Jr (1989), Holdich and Reeve (1988), Holdich (2002) and Scholtz (2002).

Colour is not usually a good guide to separating crayfish, e.g. the noble crayfish, *Astacus astacus* (L.); the signal crayfish, *Pacifastacus leniusculus* (Dana); and the red swamp crayfish, *Procambarus clarkii* (Girard), all have red undersides to the chelae (see below). Many ICS and NICS in Europe have blue varieties. The underside of the chela in the white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet), is not always white, and may even be pink. Although, the maroon stripes across the abdominal segments of *Orconectes limosus* (Rafinesque) are characteristic, the dorsal abdomen of *P. clarkii* can also have reddish markings. However, the adults of the marbled crayfish (marmorkrebs), *Procambarus* sp., do have a characteristically marbled appearance (see Fig. 9 in Holdich and Sibley this volume).

MATERIAL and METHODS

With the exception of Figs 5b, 6f and g the photographs in Figures 2-6, 8-9 were taken by the author from alcohol preserved or defrosted specimens from a variety of sources in

England using a Nikon Coolpix P3 camera. Figure 5b was supplied by Jason Coughran, and Figs 6c (left inset), 6f and 6g were supplied by Stephanie Peay. The higher power photographs shown in Figs 5, 8 and 9 were taken with specimens submerged in water using a Dino-Eye microscope eye-piece camera (AnMo Electronics Corporation) attached to a dissecting microscope with a phototube and linked to a computer via a USB cable.

CRAYFISH MORPHOLOGY

Before the species are dealt with individually, an account is given below describing the features to be looked out for when trying to identify crayfish.

Carapace

A shield-like, unjointed structure covering the cephalon (head) and thorax dorsally and forming the covering (branchiostegites) of the gill chambers laterally (Fig. 1). The front part of the anterior carapace is extended forwards as the rostrum (see below) on either side of which are the postorbital ridges (see below) (Fig. 1). The carapace is divided into an anterior and posterior half by the cervical groove (Fig. 1). The carapace is relatively smooth except in the case of *Astacus leptodactylus* Eschscholtz where it is rough to the touch, especially in the posterior part. Towards the lower part of the posterior edge of the cervical groove there are usually sharp cervical spines that can be felt by running a finger backwards across the groove (e.g. 6c). The exception to this is in *P. leniusculus* where there are no such spines. In *A. leptodactylus* (Figs 3d, 8e) and *O. limosus* (Fig. 6d) a spinous tubercle is also present behind the lower part of the cervical groove. The lateral margins ("cheeks") of the anterior carapace are usually smooth or only slightly granular, but in *A. leptodactylus* they are rough (Figs 3d, 6e); in *O. limosus* there are a number of sharp spines on the cheek (hence its common name) (Fig. 6d); in *A. pallipes* and *O. virilis* there are a few scattered low tubercles. The posterior half of the carapace has a pair of dorsal branchiocardiac grooves, the space between them being known as the areola (Fig. 1). Usually the areola is distinct (Figs 2, 3i), but in *P. clarkii* the two grooves are very close together and virtually occlude the areola (Fig. 3j).

Rostrum

This consists of a main basal unit projecting from the front of the carapace, with parallel or inwardly sloping raised margins that lead to lateral shoulders each usually capped by a sharp spine, and a sharp terminal acumen (e.g. Fig. 3e). The rostrum is usually well pronounced, although in *Orconectes virilis* (Hagen) it is relatively short and wide with a short acumen (Fig. 3f). The borders of the acumen in *Cherax quadricarinatus* (von Martens) have a number of spines and the raised margins of the basal unit extend well down into the anterior carapace (Fig. 3k), features not found in the other species in British waters. A low median carina may run from the acumen to the basal part of the rostrum as in *P. leniusculus* (Fig. 3b) and *A. leptodactylus* (Fig. 3d). The anterior part of this carina has a number of nodules in *A. astacus* (Fig. 3c), a feature not found in the other species in British waters, and in *A. leptodactylus* a series of spines may be present in this position giving it a comb-like appearance (Fig. 6a). The rostra of *A. pallipes* (Fig. 3a), *P. clarkii* (Fig. 3g) and *Procambarus* sp. (Fig. 3h) are triangular in shaped, with long tapering margins leading to small shoulders and a short acumen; sometimes a mat of fine hairs is visible on the surface between the raised rostral margins in *A. pallipes*.

Postorbital ridges

Members of the Cambaridae and Parastacidae have pronounced ridges on the anterior carapace, one on either side of the posterior part of the rostrum and behind the eyes; the tip of each ridge being capped by a sharp spine (e.g. Figs 3e-h, k). In *C. quadricarinatus* each ridge forms a long keel down the sides of the anterior carapace (Fig. 3k), and in some *Cherax* species there may also be a third keel in the centre. In the Cambaridae the ridges are shorter (Fig. 3e, f, g, h). In *P. clarkii* (Fig. 3j) and *Procambarus* sp. (Fig. 3h) a pair of tubercles occurs towards the posterior margin of the anterior carapace.

Members of the Astacidae in British waters have two postorbital ridges, although the second pair may be indistinct, especially in *A. pallipes* where they may merge (Fig. 3a), although they can sometimes be separated (Fig. 6c inset). In *P. leniusculus* (Fig. 3b) and *A. astacus* (Fig. 3c), two ridges are apparent on either side of the rostrum, but the second pair may be no more than a tubercle, both pairs are capped by a sharp spine. Two pairs of ridges are present in *A. leptodactylus* (Fig. 8e), the second ridge may almost merge into the first (Figs 3d, 6a), but the tip of the second can be felt with the finger.

Pereopods

The five pairs of pereopods arise from a basal two-part protopod (coxa plus basis), followed by an endopod comprising an ischium, merus, carpus and propodus (hand, the apical part being referred to as the fixed finger); the propodus has a moveable finger, the dactylus, either arising from its side to form a claw or chela as in pereopods 1-3 or from its apex as in pereopods 4-5 (Fig. 1). The tips of the dactylus and propodus of the cheliped each have a curved hook; in astacid and cambarid stage 1 juveniles these are recurved to help with attachment to the mother (see below). From an identification point of view it is the first pereopod or cheliped that is important.

As a result of allometric growth (Reynolds 2002) the chelae tend to be more developed in adult males (e.g. Figs 2, 4b, h) than females, especially where cyclic dimorphism occurs (see below). However, it should be noted that the size of the cheliped may not reflect the age of the crayfish, i.e. older specimens may have smaller chelipeds than younger ones, as they have been lost or damaged in encounters and are in the process of being regenerated at each moult. Occasionally deformed chelae may also occur (e.g. Fig. 6g). The chelae are usually larger and more robust in males and are used in territorial behaviour as well to grasp the chelipeds of the female during mating;

In adult males, the inner margins of the fixed and moveable fingers show a variety of forms from being relatively straight in *A. leptodactylus* (Fig. 4e), *A. astacus* (Fig. 4d), *O. limosus* (Fig. 4g) and *C. quadricarinatus* (Fig. 4c) to a more elaborate form in *A. pallipes* (Fig. 4a, 6f), *P. leniusculus* (Fig. 4b), *P. clarkii* (Fig. 4f), *Procambarus* sp. (Fig. 4i) and *O. virilis* (Fig. 4h). The edges of the inner margins may be lined by tubercles some of which are more pronounced than others, as in *A. pallipes* (Figs 6f, g) and *O. virilis* (Fig. 4h). Conspicuous incisions (depressions) often occur between the tubercles (e.g. Figs 4a, b, f and h) and assist the male in holding onto the female during mating, although they are not present in some species (e.g. Figs 4c, e and g). The chelae also help in securing prey whilst the mouthparts shred it, whereas the other pereopods are used during walking and food location, as well as functions such as grooming (Holdich 2002). During mating in astacids and cambarids one of the 5^{th} pair of pereopods is crossed over the body in order to support the gonopods (see below).

The dorsal surface of the chelae of *P. leniusculus* is smooth (Fig. 4b), but pitted (Fig. 9i); that of *C. quadricarinatus* (Fig. 4c) is smooth, whilst in the other species it ranges from weakly granular as in *Procambarus* sp. (Fig. 4i), to rough in *A. pallipes* (Figs 4a, 6c) and *A. leptodactylus* (Fig. 4e), and extremely granular in *P. clarkii* (Fig. 4f). Of all the species that may be found in British waters the chelae of *O. virilis* and *P. clarkii* males and females are the most ornate. Those of *O. virilis* have rows of tubercles along the margins (Fig. 4h), which are yellow in life; those of *P. clarkii* have a tuberculate and spinous dorsal surface (Fig. 4f); and some specimens of *A. pallipes* may also have rows of yellow tubercles along the inner margins of the fingers of the chelae (Figs 6f, g).

In parastacids such as *C. quadricarinatus* the inner edge of the propodus is longer than the length of the dactylus (Fig. 4c), and in *Procambarus* sp. it is about the same length (Fig. 4i), whilst in the other species found in British waters it is shorter (e.g. Figs 4a, b, d-h). A very characteristic feature of *C. quadricarinatus* is the presence in the male of a soft, red-coloured patch on the outer margin of the fixed finger (Fig. 4c). In both adult male and female *P. leniusculus*, the white-turquoise patch at the base of the junction of the dactylus with the propodus is very characteristic (Figs 2, 4b, 9i).

A strong, sharp spur projects from the centre of the inner edge of the carpus of the cheliped in species of the Cambaridae (Figs 4f, g, h). Astacid species such as *A. leptodactylus* (Fig. 6b), *A. pallipes* (Fig. 6c) and *P. leniusculus* (Fig. 9i) sometimes have one or more spines towards the top part of the inner edge of the carpus even in juveniles, but these are not as robust as the spurs of the Cambaridae and may be broken off or worn away with age. A strong spine may also occur on the underside of the carpus. Strong spines may also be present on the next segment, the merus (Fig. 9b). Two distinct spines occur on the upper inner edge of the coxa of the cheliped of *C. quadricarinatus* (Fig. 3c inset). Although the spur in cambarid crayfish has been used as a key character in keys to distinguish between the crayfish families (Pöckl et al. 2006, Souty-Grosset et al. 2006) it should not be used as the only character to separate the families.

Abdomen

This is composed of six tubular segments, each with a broad dorsal tergum and a narrower ventral sternum that are connected on either side by a lateral pleuron. The ends of the pleura are rounded (e.g. Figs 2, 6d) and have marginal setae, except for those in *A. leptodactylus* that are more pointed and have a spine at the apex (Fig. 6e and inset). The first segment articulates with the last segment of the thorax (which is covered dorsally by the carapace) and has reduced pleura, those of the second segment being the largest (Fig. 6d, e). Abdominal segments 2-5 in females each bears of pair of pleopods (swimmerets) (Fig. 5a) comprised of a basal protopod and a terminal, feathery exopod and endopod to which the eggs are attached after laying. The pleopods on segment 1 of females are reduced to thread-like structures (Fig. 5a arrow) and are absent or vestigial in both sexes in the Parastacidae (Fig. 5b). As a result of allometric growth the abdomen of sexually mature females becomes wider (Fig. 2) than that of males so as to house the brood of eggs. The abdomen ends in a tail fan comprised of a terminal telson and the lateral uropods – the appendages of segment 6 (Figs 1, 2). In male astacids and cambarids the first two pairs of pleopods (gonopods) are modified for sperm transfer (see below).

External reproductive structures

The female gonopore is on the coxa of pereopod 3 and that of the male on the coxa of pereopod 5. In the Astacidae and Cambaridae, the first pair of pleopods in males is modified for sperm transfer; those on the second abdominal segment possess a spiral appendix on the endopod – both pairs are known as gonopods.

In the Parastacidae, pleopods are absent from the first abdominal segment in both sexes (Fig. 5b); the pleopods on the second segment in males lack a spiral appendix. Parastacids do not have pleopodal gonopods as such; in *C. quadricarinatus*, at least, the male structures take the form of fleshy outgrowths from the base of the 5th pair of pereopods (Fig. 5b), which deposit a spermatophore on the sternum between the pereopods of the female (Coughran 2009, pers. comm.). There are no ischial hooks in males and there is no sperm storage organ (spermatheca or annulus ventralis) in females.

In the Cambaridae there is form alternation (cyclic dimorphism) between sexually active (FI) and non-active quasi-juvenile (FII) individuals, mainly involving a change in the form of the chelae and sexual apparatus. In addition, the ischia of some pereopods of FI males bear hook-like outgrowths, which are used to connect the male and female during copulation; in *O. limosus*, they occur on the 2nd pair of pereopods (Fig. 5g arrows), and in *P. clarkii* on the 2nd and 3rd pairs of pereopods (Fig. 5f, arrows). In cambarids a sperm storage organ called the annulus ventralis is present between the last two pairs of pereopods in females (Fig. 5a). The 1st pair of gonopods become hard and ivory-like in *O. limosus* FI males and is equipped with a brown, cornified apex and a long sperm groove (Fig. 5c). The 2nd pair of gonopods is also highly modified and each bears an apical structure (spiral appendix) (Fig. 5d) that is pushed into the sperm groove of the first pair of gonopods to assist in sperm transfer. As can be seen by comparing Figs 5c, e and f the form of the gonopods differs between genera and species and this fact is used extensively for identification purposes (Hobbs Jr 1989).

In the Astacidae, there is change in the form of reproductive adults as they attain sexual maturity, notably in the size of male chelae and width of the female abdomen (Fig. 2), but there is no cyclic dimorphism as the features are irreversible and are retained between adult moults. There are no ischial hooks in the adult astacid and there is no annulus ventralis in females. There are two pairs of gonopods in males (Figs 2, 6f) but they do not become hardened as those in cambarids. The 1st pair of gonopods is modified into subtubular (Fig. 5g, upper) copulatory organs for transferring the spermatophore to the female, and part of the 2nd pair is modified into an apical structure (spiral appendix) that is pushed into the tube formed by the 1st gonopod like a plunger (Fig. 5g, lower).

Juveniles and immature crayfish

Once crayfish have hatched from the egg they are known as hatchlings, summerlings or juveniles (Holdich 1992, 2002; Reynolds 2002). It should be noted that spines and setae on the juvenile appendages can be well developed.

In the Astacidae the 1st stage juvenile (Figs 7a, b) is initially attached by a telsonic thread to its egg membrane, which in turn is attached to the mother's pleopods. When it breaks free it attaches itself to the mother's pleopods by recurred hooks at the end of the chelae (Holdich and Reeve, 1988). It has no uropods and the broad telson is without setae (Fig. 7c). The carapace is distended by a supply of yolk and as this becomes depleted the 1st stage juvenile moults to the 2nd stage (Fig. 7d) in which the body elongates, the chelae loose their attachment hooks, the telsonic margins become setose (Fig. 7e), but the uropods are still absent (Fig. 7e). The 2nd stage juveniles remain with the mother for a time but gradually become more independent. At the moult to the 3rd stage they gain uropods (Fig. 7g) and become fully independent (Fig. 7f). The behaviour of the semi-independent juveniles is outlined in Gherardi (2002). At the moult to the 4th stage the first signs of primary male sexual characters can be distinguished in the form of small tubercles on the 1st abdominal segment, which represent the precursors of the 1st pair of gonopods, which then become distinguishable at the 5th stage.

In the Cambaridae the 1st and 2nd stage juveniles are similar to those in the Astacidae, although the 1st stage is less well developed and the 2nd stage does not have a setose telson. Unlike the Astacidae the 3rd stage juvenile remains on the mother and it is this stage that gradually becomes independent. Also, unlike the astacids, the development of primary sexual characters (genital openings, annulus ventralis, 1st pleopod tubercles) become apparent at stage 3, although the appendages associated with the 1st abdominal segment do not become released until stage 4 in the male.

In the Parastacidae, the 1st stage juvenile hangs onto its mother by terminal, recurved spines on the 4th and 5th pereopods, not the 1st and 2nd as in the other families. In most parastacids there are three stages associated with the mother, the third being the stage that becomes independent.

Identifying juveniles is a difficult task as they tend to be similar between species. Viewing the rostra of juvenile *O. limosus* (17 mm CL)) (Fig. 8a), *O. virilis* (28 mm CL) (Fig. 8b), and *P. leniusculus* (9 mm CL) (Fig. 8d) under a microscope reveals few differences, although that of *A. pallipes* (11 mm CL) (Fig. 8c) can be distinguished by the shallow shoulders and small acumen, and *Procambarus* sp. (12 mm CL) by broad base and very shallow shoulders (Fig. 8f). Young adults of *A. leptodactylus* (30 mm CL) can be distinguished by their mottled nature and the form of the rostrum (Fig. 8e) and chelipeds (Figs 6b).

The presence of the post-orbital spines may help in the identification process, although the second pair in astacids may be difficult to see except under high magnification. The juvenile shown in Fig. 8d could only be identified as *P. leniusculus* by the author by the presence of a second spine behind the first post-orbital ridge (Fig. 8d inset), and this was visible even in a 2nd stage juvenile.

The cheliped and chela can also be useful in helping to identify juvenile crayfish. Those of *A. pallipes* have a serrated inner margin to the propodus, incisions and tubercles on the inner margins of the fixed and moveable fingers, and a spine on the upper, inner margin of the coxa (Fig. 9a). The cheliped of *P. leniusculus* is longer and narrower than that of *A. pallipes* and a coxal spine is also apparent (Fig. 9i), a large spine also occurs on the underside of the merus (Fig. 9b inset). The chelae of *A. leptodactylus* are quite compact compared with those of the adult and exhibit mottling (Fig. 9c); as with *A. pallipes* and *P. leniusculus* carpal spines are apparent (Fig. 9d). The carpal spines in both *A. pallipes*, *A. leptodactylus* and *P. leniusculus* are situated further towards the apex of the carpus than the characteristic spur in cambarid crayfish, which is more central in both juveniles (e.g. Fig. 9e) and adults (Fig. 4f-h). The inner margins of the fixed and moveable fingers of the chela of *O. virilis* (Fig. 9f) are relatively straight and similar to those of *O. limosus* (Fig. 9h) and *Procambarus* sp. (Fig. 9g).

The author has in his possession two juveniles from a Yorkshire river that have so far defied attempts to identify them! However, he is keen to receive juveniles for identification so that a more complete picture can be built up.

IDENTIFICATION OF CRAYFISH

Currently, there is one indigenous crayfish (ICS) and six non-indigenous crayfish species (NICS) in British waters (Holdich and Sibley this volume). In addition, the only species from outside Europe that can be kept legally in aquaria, the redclaw, *C. quadricarinatus*, has been found in the wild, but has not, as far as is known, become established (Holdich and Sibley this volume). The unique parthenogenetic crayfish, *Procambarus* sp., is becoming increasing popular as an aquarium pet in continental Europe and is easy to obtain on the internet. It is known from the wild in the Netherlands, Germany and Italy. It is possible that it could be released into British waters by aquarists trying to offload stock of this prolific crayfish. The photographs of whole crayfish in Holdich and Sibley (this volume) are referred to “H and S” below. Figure 1 is provided to illustrate diagrammatically the main body parts in dorsal view and Figure 2 to show these in both dorsal and ventral view in a male and female astacid crayfish.

Austropotamobius pallipes (Lereboullet 1858) (white-clawed crayfish) (Astacidae) (Fig. 1 in H and S).

Characterized by off-white (Fig. 4a), occasionally pinkish (Fig. 6f) undersides to chelae; rough dorsal surface to cheliped (Figs 4a, 6c); chelae more robust in males; inner margins of fixed and moveable fingers may have yellow tubercles, with two larger than the others on both the moveable and fixed fingers, with an incision between them both (Figs 4a, 6f, g); broad-based rostrum with mat of fine hairs on surface, and a short acumen (Figs 3a, 6c); an apparent single pair of post-orbital ridges on anterior carapace (Figs 3a, 6c), but it is sometimes possible to discern a second one (Fig. 6c inset); a number of very sharp spines behind the lower part of the cervical groove (Fig. 6c insets) that can be felt by rubbing a finger backwards over the surface; and rounded abdominal pleura; the sides of the anterior carapace may have a few small tubercles, whilst the posterior carapace is finely granular. Usually, there are no prominent spines on the inner margin of the chelar carpus (Fig. 4a); however, sometimes one or two spines may be apparent (Fig. 6c) similar to those found in *C. quadricarinatus* (Fig. 4c inset) and some *A. leptodactylus* (Fig. 6b). This could cause confusion when trying to separate specimens from members of the Cambaridae. Body colour variable, but usually brown to olive green, occasionally blue specimens are found.

Astacus astacus (Linnaeus 1758) (noble crayfish) (Astacidae) (Fig. 2 in H and S).

Characterized by red underside to chelae (Fig. 4d); chelae are robust and large in the male with two widely-spaced tubercles on inner margin of fixed finger with a shallow incision between them (Fig. 4d); rostrum well–developed with a nodular profile to acumen (Fig. 3c); absence of prominent spur on inner medial margin of chelar carpus (Fig. 4d); two pairs of post-orbital ridges on carapace (Fig. 3c); spines behind lower part of cervical groove; and rounded abdominal pleura. Body colour varies from shades of brown, beige, brilliant red, occasionally blue.

Astacus leptodactylus Eschscholtz 1823 (narrow-clawed crayfish) (Astacidae) (Fig. 3 in H and S).

Characterized by long, narrow chelae in adults (Fig. 4e), which can be straight or sickle-shaped with no obvious incision; chelae larger in males and more compact in young specimens (Fig. 6b, 9c); a granular carapace (Fig. 6e) with two pairs of post-orbital ridges (Fig. 6a), although the anterior pair may merge with the posterior pair (Fig. 3d); a prominent spinous tubercle is present behind the lower part of the cervical groove (Fig. 3d); and pointed abdominal pleura (Fig. 6e) (compare with Fig. 6d) with apical spines (Fig. 6e inset). The median ridge of the rostrum is characteristic in being comb-like (Fig. 6a), and the lateral margins are strongly raised (Figs 3d, 8e). Usually there is no prominent spur on the inner margin of the chela carpus, but one or more spines may occur, even in juveniles (Fig. 6b), and this could cause confusion when trying to separate specimens from members of the Cambaridae. Body colour varies from sandy yellow to dark green, usually with mottled background in paler specimens, occasionally blue; leg joints and tip of chelae often orange.

Note that the name Eschscholtz above does not have brackets around it as the original generic and specific names given by that authority have not changed. When another authority changes the generic name, e.g. *Astacus* to *Pontastacus*, then the original authority and date go in brackets.

Pacifastacus leniusculus (Dana 1852) (signal crayfish) (Astacidae) (Fig. 4 in H and S).

Characterized by a smooth body surface (Fig. 2); absence of spines behind the cervical groove; two post-orbital ridges, although the posterior pair may be no more than tubercles (Fig. 3b); smooth, but pitted (Fig. 9i), robust chelae with bright red underside (Figs 2, 4b), white-turquoise patch at the junction of the fixed and moveable finger (Figs 2, 4b, 9i), two widely-spaced tubercles on inner margin of fixed finger, with shallow incision between them, proximal tubercle the larger of the two (Fig. 4b); chelae more robust in males (Fig. 2); and rounded abdominal pleura (Fig. 2). Body colour reddish-brown (Fig. 2), or light to dark brown.

Procambarus clarkii (Girard 1852) (red swamp crayfish) (Cambaridae) (Fig. 5 in H and S).

Characterized by red, sinuous chelae, which are covered dorsally in tubercles (Fig. 4f); a prominent carpal spur on the cheliped (Fig. 4f); triangular rostrum with wide base, acumen relatively long (Fig. 3g); pair of tubercles on posterior part of anterior carapace (Fig. 3j); and a virtually occluded areola between the branchiocardiac grooves (Fig. 3j) (compare with Fig. 3i). FI males with ischial hooks on 2^{nd} and 3^{rd} pairs of pereopods (Fig. 5f), and two tubercles on inner margin of fixed finger of chela with a conspicuous incision between them. Female with annulus ventralis. Body colour dark red, orange or reddish-brown, but olive-green to brown when young; when out of water the exoskeleton gives off a shiny appearance in adults (Fig. 3i).

Procambarus sp. (marbled crayfish) (Cambaridae) (Fig. 9 in H and S)

Characterized by small chelipeds (Fig. 4i) and a marbled appearance on a brownish, dark-brown, green or blue background; carpal spur present in adults, but not apparent in juveniles; rostrum triangular-shaped with broad base, shoulders shallow and acumen short (Fig. 3h); one pair of post-orbital ridges (Fig. 3h). Only females are known and consequently all specimens will have an annulus ventralis, even juveniles. This unique, parthenogenetic crayfish has yet to be given a specific name. It is not known where it originated from and was first noticed in the aquarium trade.

Orconectes limosus (Rafinesque 1817) (spiny-cheek crayfish) (Cambaridae) (Fig. 6 in H and S).

Characterized by spiny sides to anterior carapace (Figs 6d) and horizontal reddish-brown stripes across abdominal segments (Fig. 6d), surface of body and chelae pitted rather than granular (Figs 4g, 6d); well-developed, straight-sided rostrum with long acumen (Fig. 3e); prominent carpal spur on the cheliped (Figs 4g); chelae with rows of pale tubercles along inner margins; one of more prominent spines behind lateral cardiac groove (Fig. 3i); wide areola (Fig. 3i). Tips of chelae may be orange with a black band below (Fig. 4g inset); however, tips of *A. leptodactylus* claws may also be orange. Female with annulus ventralis. Little difference between chelae of FI and FII individuals. Body colour pale or dark brown to olive-green; may appear black from sites with anoxic sediments (see Holdich and Black 2007).

Orconectes virilis (Hagen 1870) (virile crayfish) (Cambaridae) (Fig. 7 in H and S).

Characterized by broad, flattened, tuberculate chelae, which are bordered by rows of pale-coloured, prominent tubercles both on the outer and inner margins (Fig. 4h); prominent carpal spur on the cheliped (Fig. 4h); chelae larger in Form I than Form II males; rostrum broad with slightly curved margins up to broad shoulders (Fig. 3f) and a short acumen (Fig. 3f); Female with annulus ventralis (Fig. 5a). Body colour usually brown.

Cherax quadricarinatus (von Martens 1868) (redclaw) (Parastacidae) (Fig. 8 in H and S).

Characterized by red patch on outer margin of claw in males (Fig. 4c); rostrum long and well-developed, margins extending well back onto anterior carapace, acumen long and bordered by spines (Fig. 3k); post-orbital ridges forming a long keels down either side of anterior carapace (Fig. 3k); inner margin of propodus longer than dactylus (Fig. 4c); pleopods absent on first abdominal segment in both sexes (Fig. 5b). Male "gonopods" in the form of soft fleshy structures arising from the base of the 5th pereopods (Fig. 5b). Body smooth**.** Antennae and chelipeds very long in adults. Body colour usually blue, mottled with beige and red.

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The author would like to thank Adam Ellis for providing specimens of *O. virilis* and *P. clarkii*; David Baldry for *O. limosus* gonopods, Jason Coughran for the photograph used in Fig. 5b, Tom Moorhouse for specimens of young *P. leniusculus*, Manfred Pöckl for *Procambarus* sp. specimens, and Stephanie Peay for the photographs used in Figs 6c (left inset) and 6f and g. Thanks are also due to Julian Reynolds and Jonathan Brickland for their comments on the manuscript.

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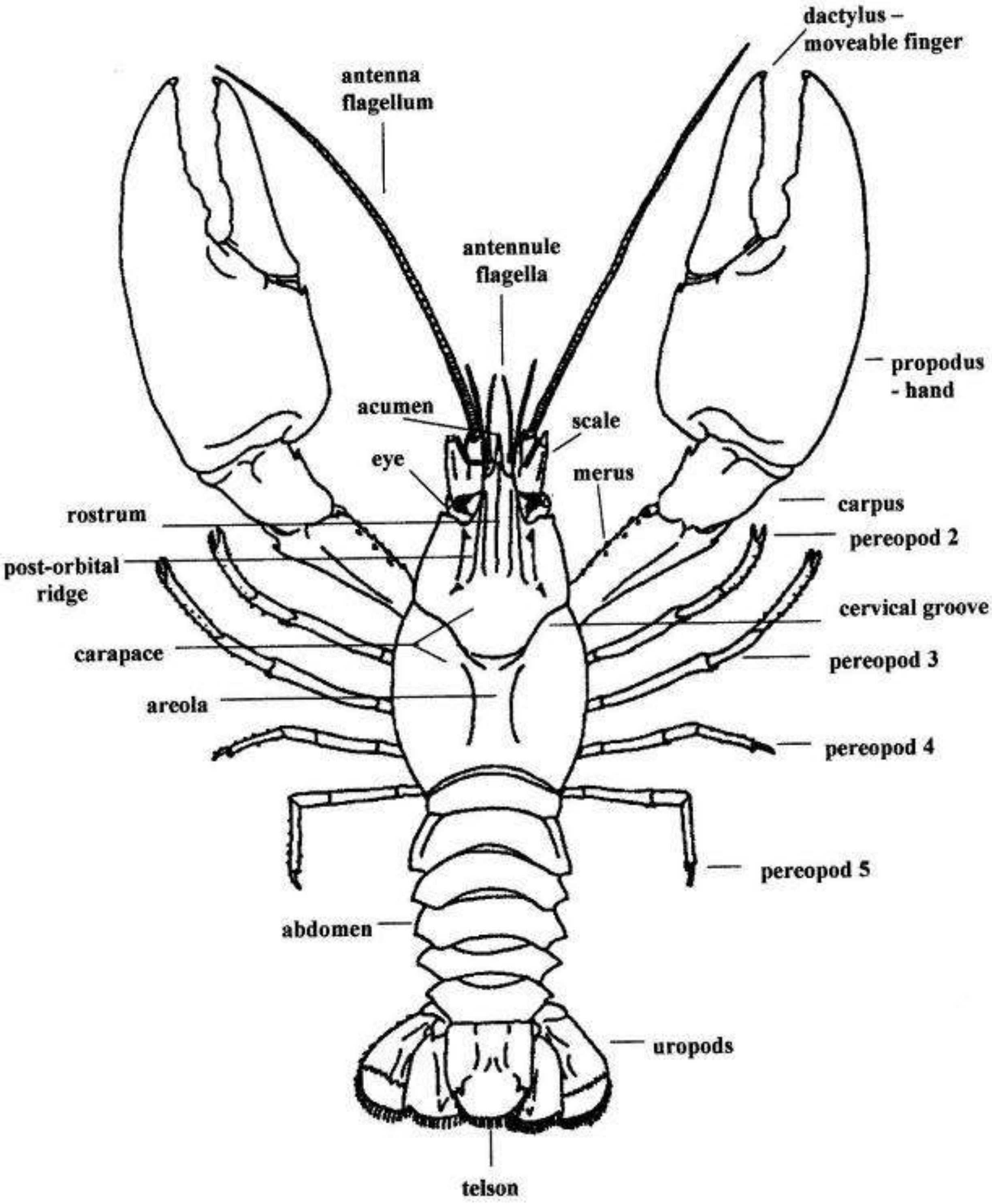


Figure 1. Generalized diagram of a crayfish illustrating the main body parts in dorsal view.

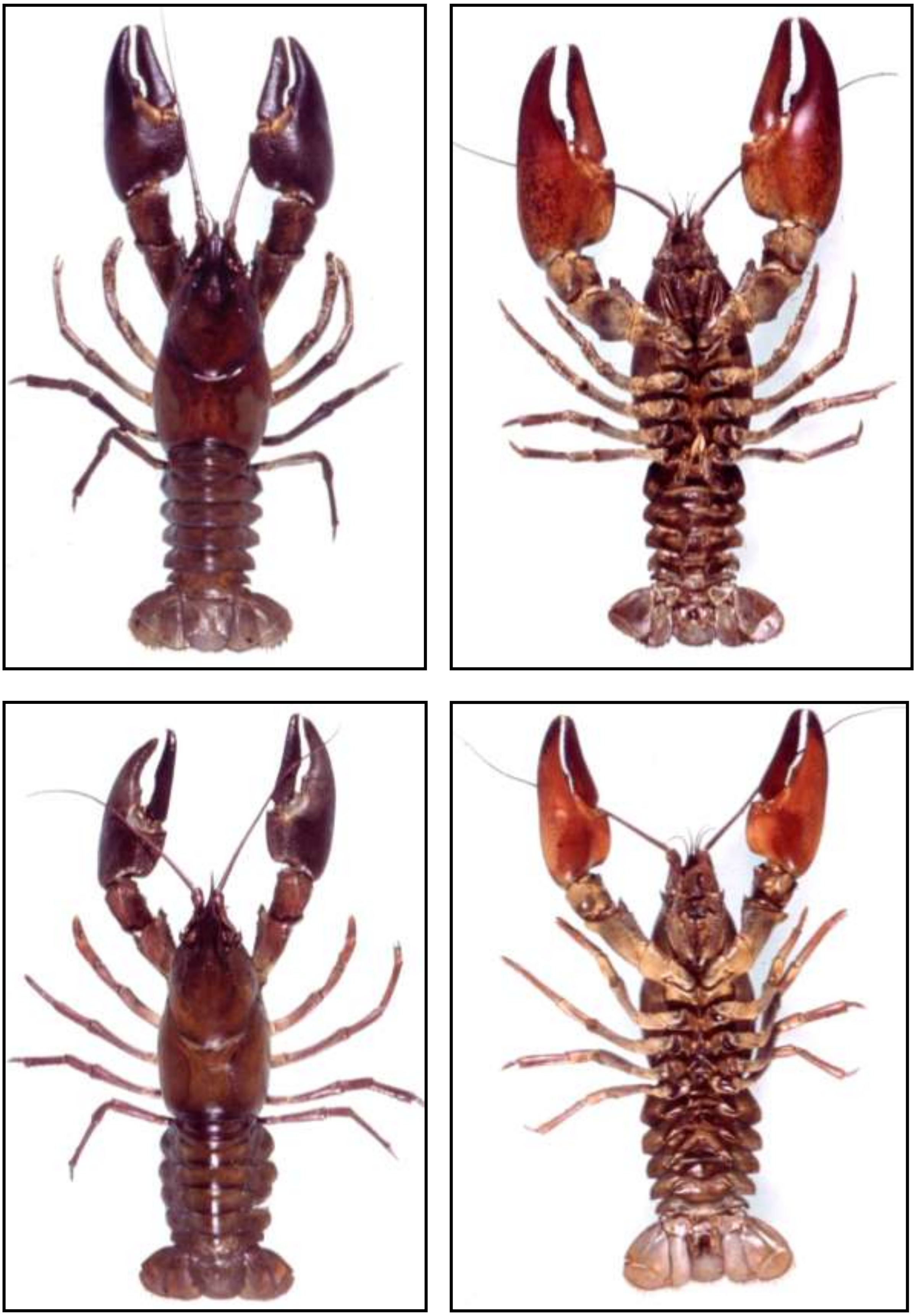
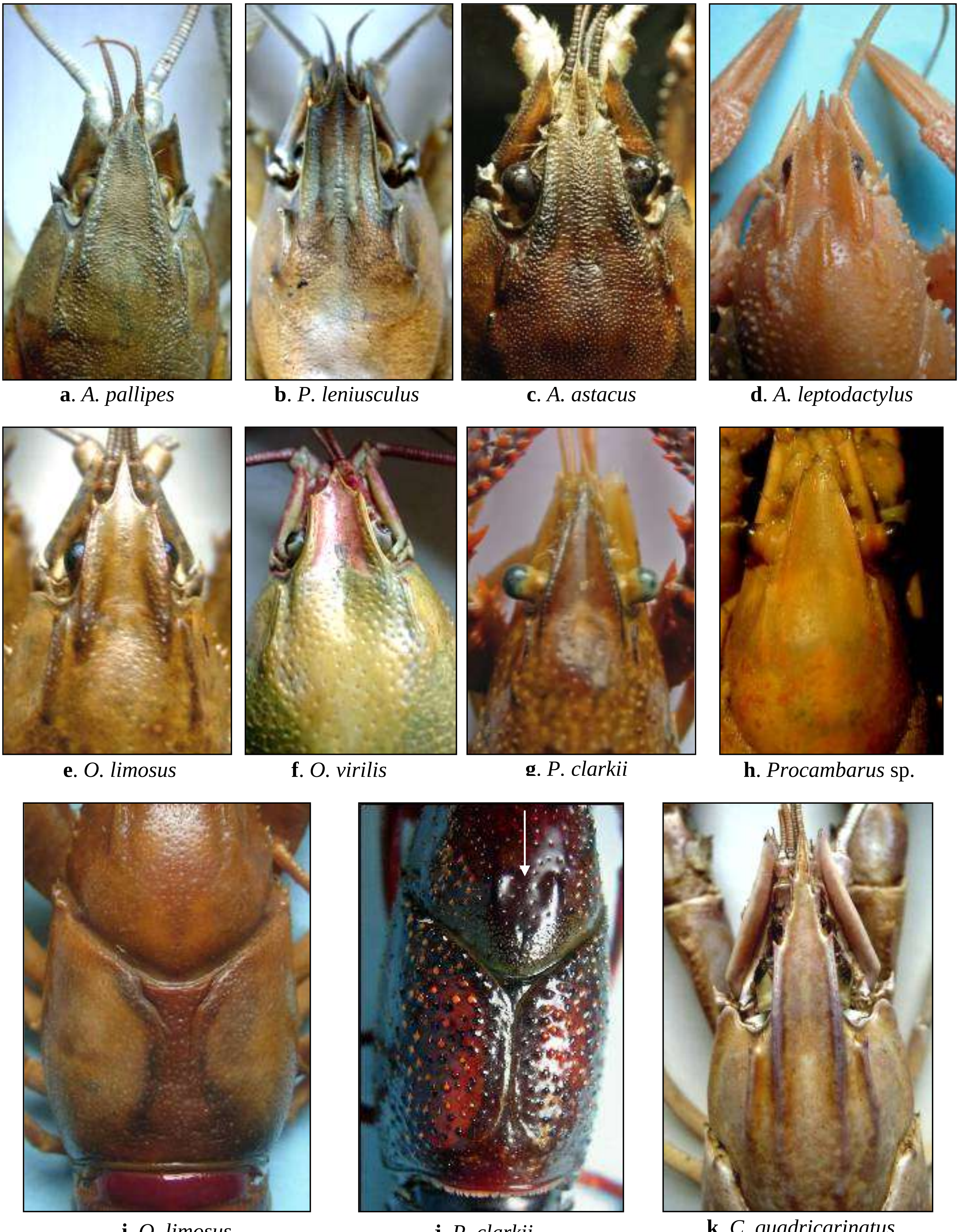


Figure 2. Dorsal and ventral views of a male (top) and female (bottom) signal crayfish, *P. leniusculus*. Note the broader chelae of the male and the wider abdomen of the female.

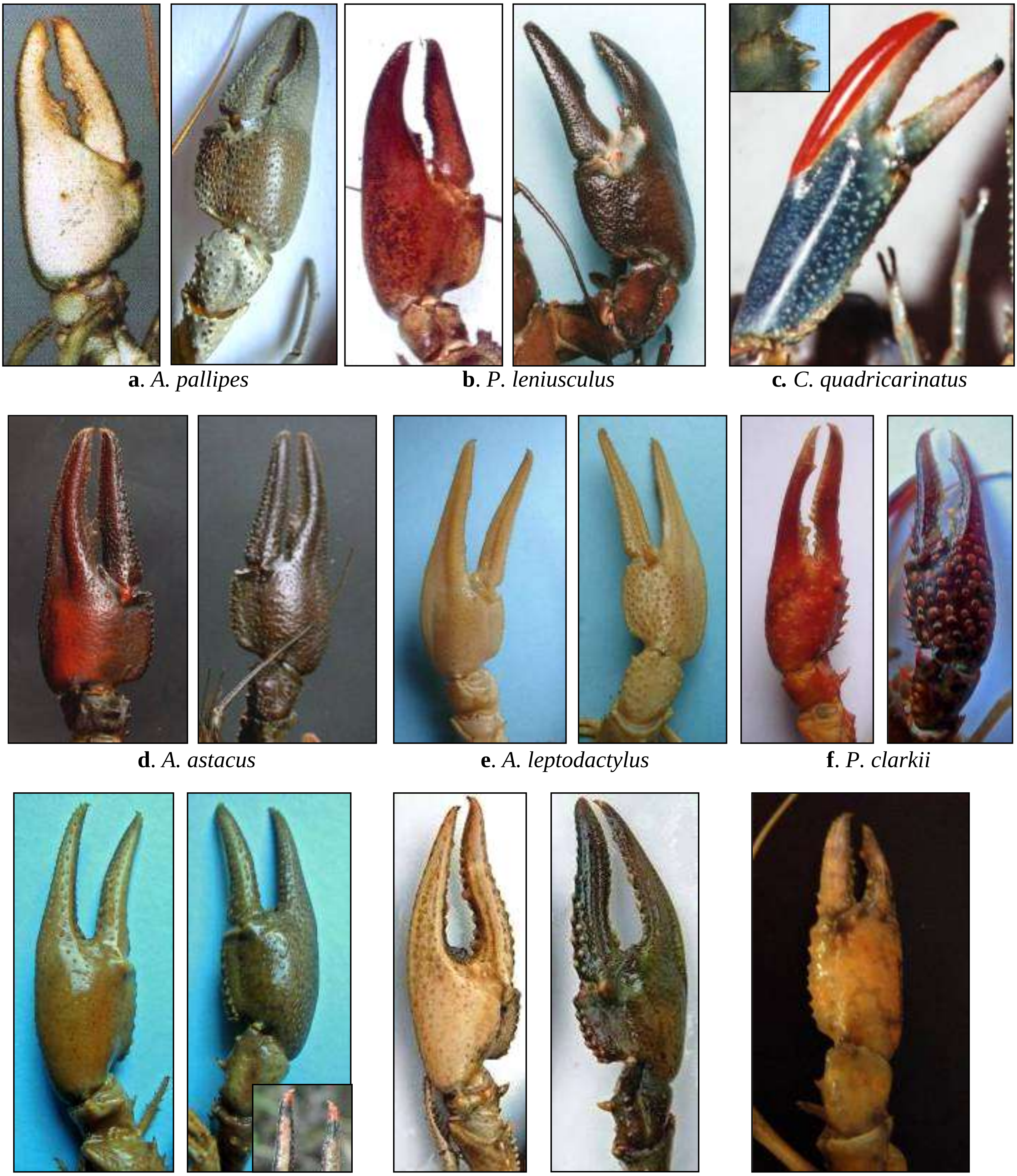


a. *A. pallipes* **b**. *P. leniusculus* **c**. *A. astacus* **d**. *A. leptodactylus*

e. *O. limosus* **f**. *O. virilis* **g**. *P. clarkii* **h**. *Procambarus* sp.

i. *O. limosus* **j**. *P. clarkii* **k**. *C. quadricarinatus*

Figure 3a-k. Series of photographs showing the shape of the rostra in crayfish that may be found in British waters, plus details of the areola in *O. limosus* (i) and *P. clarkii* (j). Note the pair of tubercles on the anterior carapace of *P. clarkii* (j – arrow).

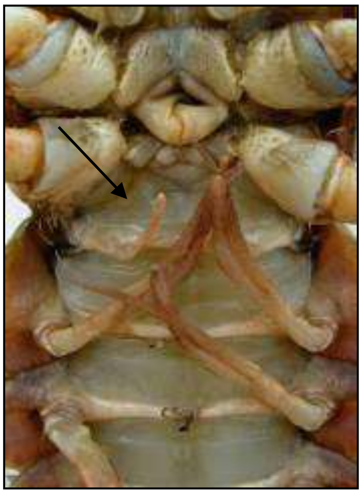


a. *A. pallipes* **b**. *P. leniusculus* **c.** *C. quadricarinatus*

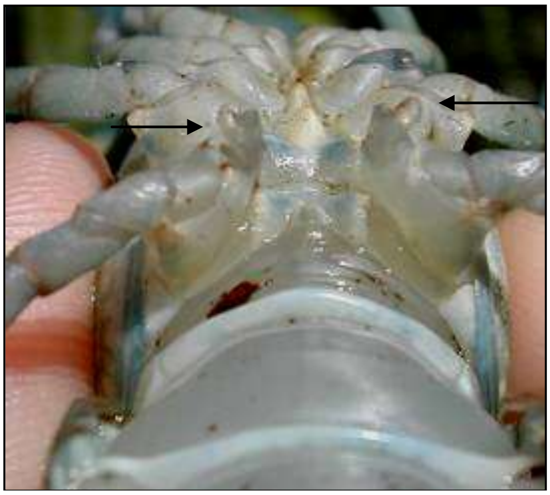
d. *A. astacus* **e**. *A. leptodactylus* **f**. *P. clarkii*

g. *O. limosus* **h**. *O. virilis* **i**. *Procambarus* sp.

Figure 4a-i. Series of photographs showing the shape of the chelae in crayfish that may be found in British waters. The dorsal surface is shown on the right and the ventral surface on the left, the exception being *C. quadricarinatus* and *Procambarus* sp. where both surfaces are similar. The inset on 3c shows the two coxal spines. The inset on 3g shows the tip of the chela.



a. Female *O. virilis* showing annulus ventralis and pleopods, note thread-like nature of first pair (arrow).



b. Male *C. quadricarinatus* with fleshy outgrowths from base of 5^{th} pereopods (arrows). Note absence of 1^{st} pair of pleopods. **(**Jason Coughran).

e. 1^{st} gonopods of FI male *P. clarkii*.

c. 1^{st} gonopods of FI male *O. limosus*, note melanized tips and sperm groove (arrow).

d. Tip of 2^{nd} gonopod of *O. limosus*.

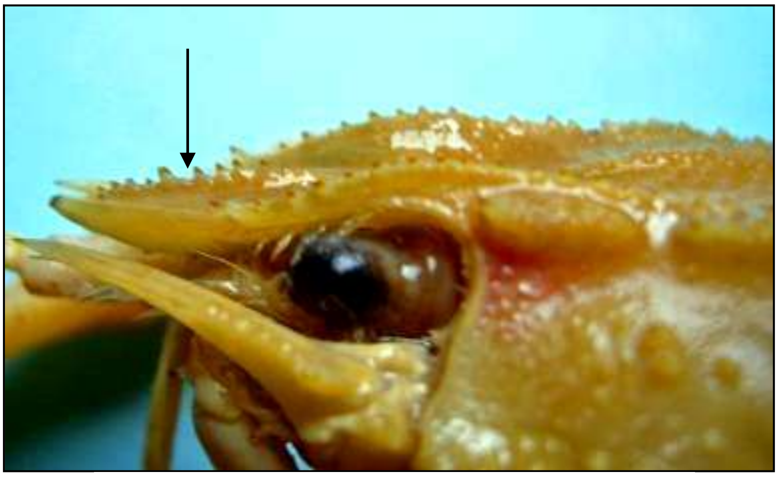
f. Gonopods of FI male *O. virilis*.

g. Gonopods of *A. leptodactylus*: upper - tip of 1^{st} gonopod, lower- tip of 2^{nd} gonopod.

f. 2^{nd} and 3^{rd} pereopods of *P. clarkii* showing ischial hooks (arrows).

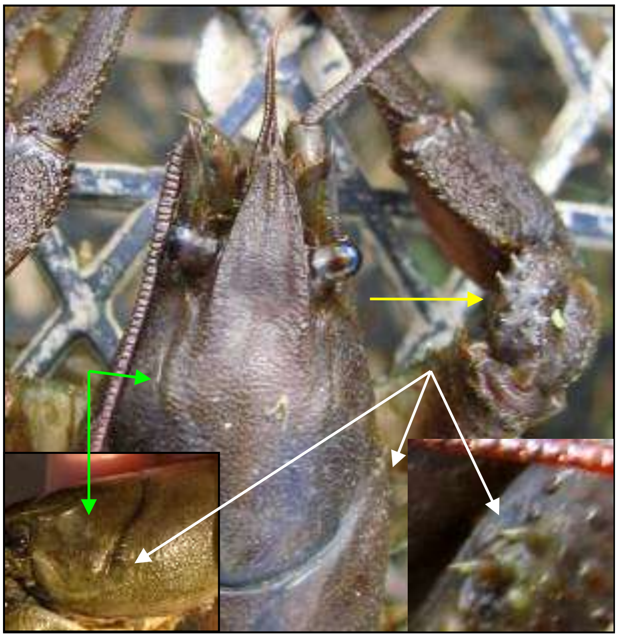
g. 2^{nd} pereopods of *O. limosus* showing ischial hooks (arrows).

Figure 5a-g. Series of photographs showing various external reproductive features exhibited by crayfish that may be found in British waters.



a. Comb-like rostrum of *A. leptodactylus*.

b. Cheliped of young *A. leptodactylus* showing coxal spine (arrow).



c. Anterior carapace of *A. pallipes* showing triangular-shaped rostrum, coxal spines (yellow arrow), cervical spines (white arrows) and post-orbital ridges (green arrows).

d. *O. limosus* showing "spiny-cheek", pitted carapace and rounded abdominal pleura.

e. *A. leptodactylus* showing granular carapace and pointed abdominal pleura with apical spine (inset).

f. Left. Chelipeds and gonopods of male *A. pallipes*. (S Peay).

g. Right. Deformed chela of male *A. pallipes*. (S Peay).

Figure 6a-g. Miscellaneous morphological features.

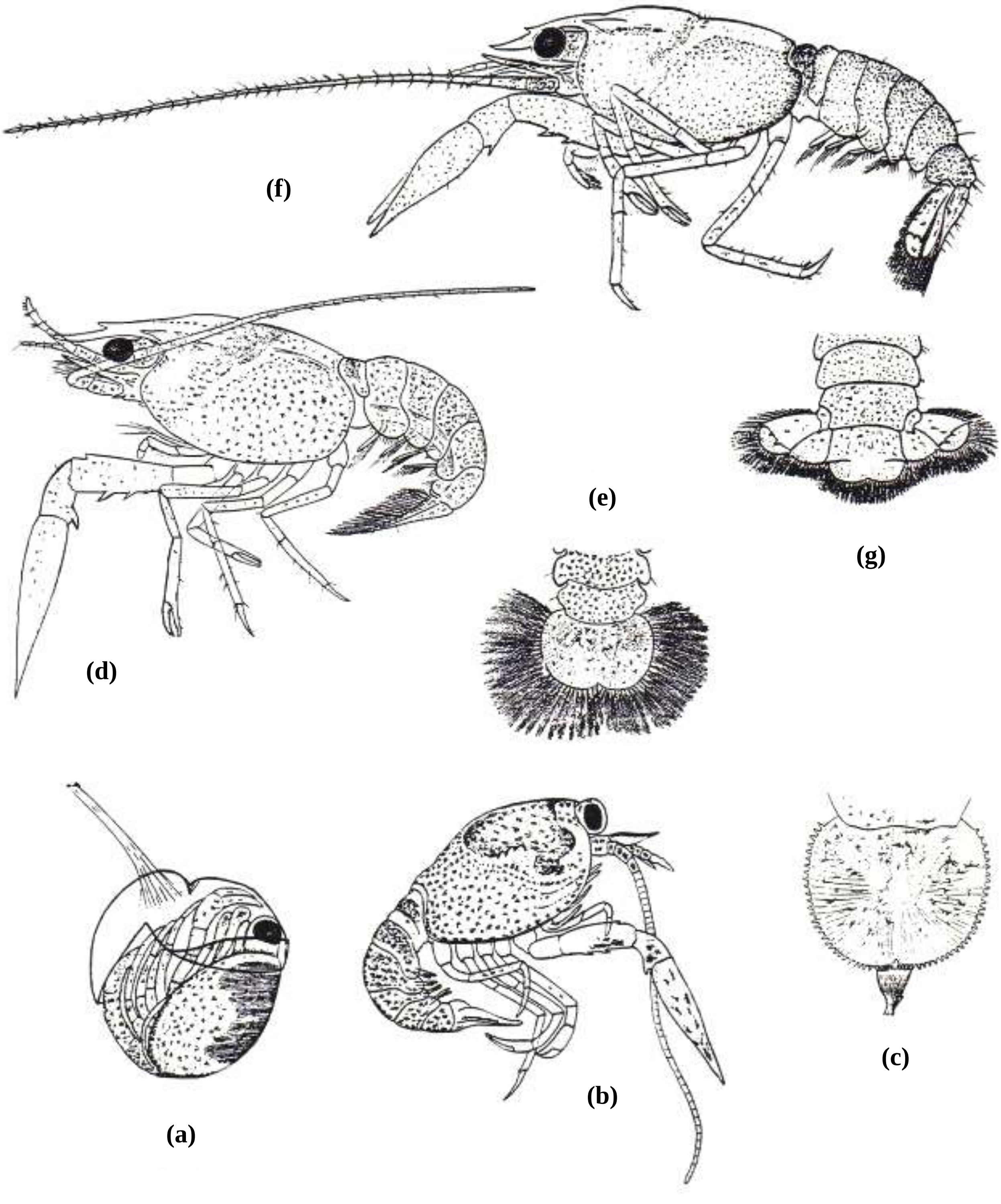
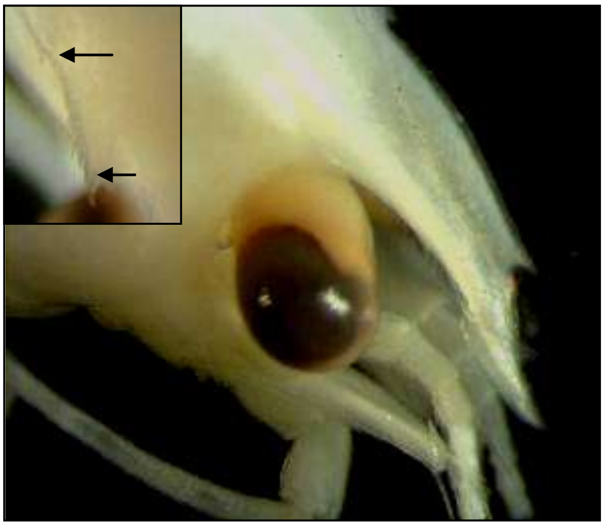


Figure 7. Juvenile stages of *P. leniusculus*.
(a) 1st stage juvenile hatching from egg; **(b)** 1st stage juvenile; **(c)** telson of the 1st stage juvenile; **(d)** 2nd stage juvenile; **(e)** telson of 2nd stage juvenile; **(f)** 3rd stage juvenile, (g) telson of 3rd stage juvenile. Modified from Andrews (1904).

a. Rostrum of juvenile *O. limosus*.

b. Rostrum of juvenile *O. virilis*.

c. Rostrum of juvenile *A. pallipes*.

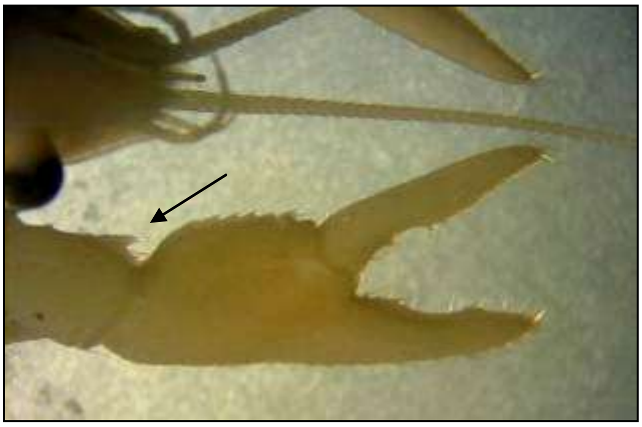


d. Rostrum of juvenile *P. leniusculus*, note presence of two post-orbital spines (arrows).

e. Rostrum of young male *A. leptodactylus*. Note the prominent spinous tubercle behind the cervical groove, the raised margins of the rostrum, and the two pairs of post-orbital ridges.

f. Rostrum of juvenile *Procambarus* sp.

Figure 8a-f. Rostra of selected juvenile crayfish.

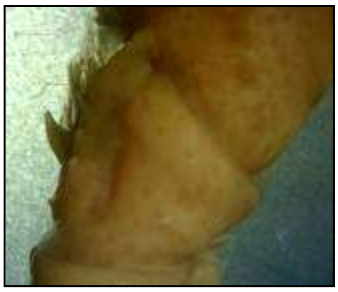


a. Cheliped of juvenile *A. pallipes* – note spine on carpus (arrow).

b. Cheliped of *P. leniusculus* – note large spine on underside of merus (inset arrow).

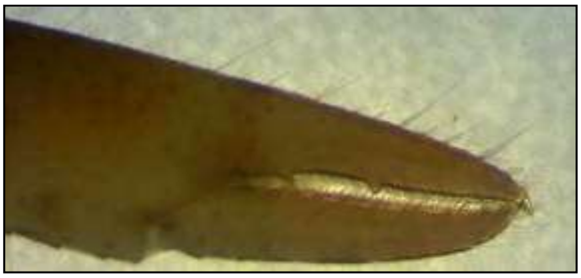
c. Chelae of young male *A. leptodactylus*.

d. Carpal spines of juvenile *A. leptodactylus*.



e. Carpal spines of juvenile *O. virilis*.

f. Chela of juvenile *O. virilis*.



g. Chela of juvenile *Procambarus* sp.

h. Chela of juvenile *O. limosus*.

i. Cheliped of young male *P. leniusculus*, note presence of carpal spine (arrow) (compare to 9b).

Figure 9a-i. Chelipeds and chelae of selected juvenile or young adult crayfish.

A bibliography of studies relevant to crayfish conservation and management in the British Isles in the 2000s

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ABSTRACT

A list is given by topic of literature relating to crayfish conservation and management in the British Isles that has been published this decade. In addition, papers that have been published on European crayfish in general that are considered relevant to the British situation are included, as well as some general studies relating to crayfish biology.

Keywords: British Isles, Europe, white-clawed crayfish, non-indigenous crayfish, legislation, behaviour disease, genetics

INTRODUCTION

Since the last bibliography concerning British crayfish by Holdich (2003) there have been many new publications relating to all aspects of crayfish biology in the British Isles. In addition, there have been several papers published on European crayfish in general that are considered relevant to the British situation. As there is such an interest in the indigenous and non-indigenous crayfish species (ICS and NICS) it was thought worthwhile to list these by topic (excluding biochemical and physiological studies) for the use of researchers. Obviously, in addition to these references there are very many contract reports that could be listed, but only a few have been included. References below may occur under more than one topic heading.

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