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CONSERVATION MANAGEMENT
OF THE WHITE-CLAWED CRAYFISH
Austropotamobius pallipes
Part 1

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1 Introduction

The White-clawed Crayfish *Austropotamobius pallipes* (Lereboullet) is one of four crayfish species indigenous to Europe; others are the rare Stone Crayfish *Austropotamobius torrentium* of the Alps and Balkans; the Noble Crayfish *Astacus astacus* centred in Germany and Poland and the Thin-clawed or Turkish Crayfish *Astacus leptodactylus* of south-eastern Europe (Table 1). In European countries containing more than one indigenous crayfish species, these tend to be segregated by habitat. *Astacus* species are mainly lowland and grow faster and reach a larger final size than those of *Austropotamobius* which often occur in upland brooks, but both are esteemed as food and have been widely moved around by man.

In the past century a number of exotic crayfish have been introduced into Europe, principally from North America (Table 1). Today only three European countries retain a single indigenous crayfish species; these are Norway and Estonia with Noble Crayfish and Ireland with White-clawed Crayfish. In all other countries the situation is more complex; e.g. France and Germany each having 2-3 indigenous species and several exotics. Useful identification features of native and exotic crayfish are given in Roqueplo (1992); these are summarised for White-clawed Crayfish in Figure 1.

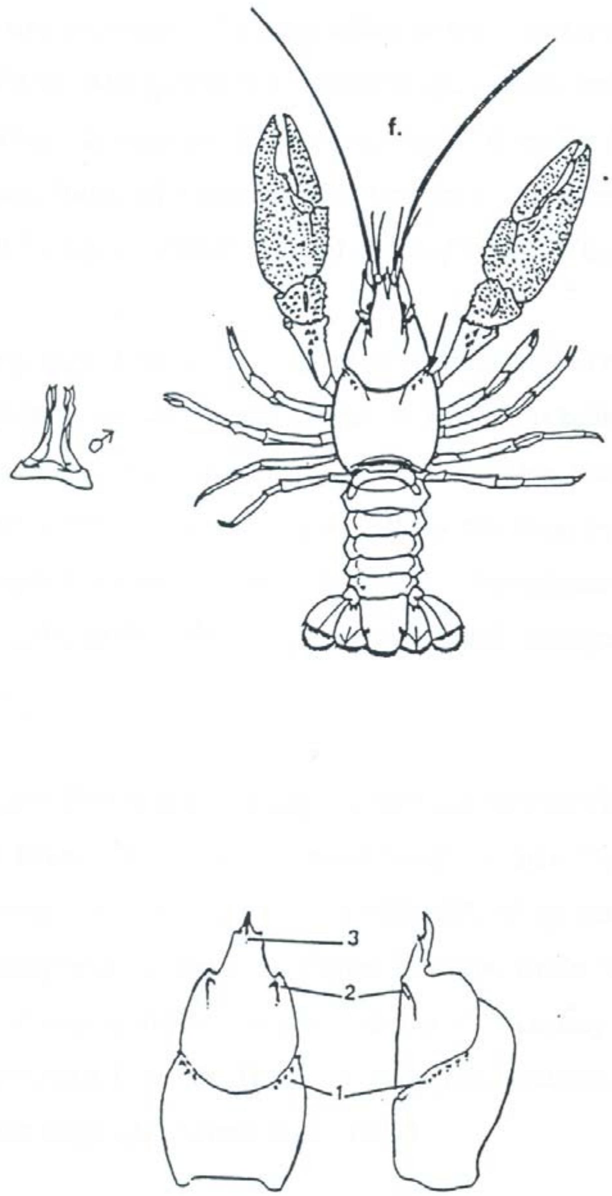
The White-clawed Crayfish is the only crayfish species found in Ireland, where it is protected under the Wildlife Act. It is classified as vulnerable and rare in the IUCN Red List of threatened animals and listed under Annex II of the EU Habitats Directive. Ireland is now thought to hold some of the best European stocks of this species, under least threat from external factors. Irish stocks are thus believed to be of substantial conservation importance. This handbook describes what is currently known of the distribution and biology of this species in Ireland, before recommending appropriate conservation management.

Figure 1. Identification features of White-clawed crayfish. Male gonopods shown separately.

Notes: 1 - a single row of spines behind the cervical groove (absent in Signal crayfish; many spines on cephalothorax in Thin-clawed, American and Louisiana crayfish);

2 - one pair of spines behind the eye (2 in Noble, Signal and Thin-clawed);

3 - rostrum simple and triangular.



2 History

All freshwater crayfish are rather closely related. The present global distribution of species has come about through various geological processes and shorter-term diffusion, aided accidentally or knowingly by man. There are two major family groups in the Northern and Southern Hemisphere respectively. The Cambaridae family of eastern North America and Eastern Asia has radiated widely, with almost 500 American species and many genera (including *Orconectes* and *Procambarus*). In contrast, there are less than 10 species in the Astacidae of Europe (*Astacus, Austropotamobius*) and western North America (*Pacifastacus). Austropotamobius* is probably the original European crayfish, pushed westwards by the larger *Astacus* species.

As a consequence of the last Ice Age many species showed repeated contractions and expansions, becoming fragmented into separate races. *A. pallipes* is believed to have been pushed southwards into three refuges, in the Balkans, Iberia and southern France, from where it radiated again in warmer conditions. As a result, today there are three recognisable sub-species: *A. pallipes italicus* ranges from Italy to the Balkans; *A. p. lusitanicus* is confined to the Iberian Peninsula, while *A. p. pallipes* the Atlantic subspecies is found throughout France and also occurs in Britain and Ireland.

Many workers believe that *A. pallipes* could not have survived permafrost conditions of the last Ice Age in Britain, but may have recolonised southern England either naturally through post-glacial connections with France up to 6000 BP, or by human reintroductions. Crayfish were already widespread in southern England in the 1600s when earliest British records were published. It was common practice from the 17th century to stock English streams and pools with White-clawed Crayfish. There is now genetic evidence that British stocks have a relatively recent French origin (Grandjean *et al.*, 1997).

White-clawed Crayfish are widespread and have been presumed native in Ireland, but without definitive evidence (Reynolds, 1979, 1988). Thompson (1843) and other writers suggested that they may have been introduced into Ireland at the start of the 19th century. However, in 1772 Rutty published earlier records of crayfish in the Dublin area. Historical reports suggest humanmediated movement of crayfish stocks between catchments within Ireland (Reynolds, 1982) but there is today no tradition of crayfish fishing.

Few freshwater forms can have survived the glaciation in refugia, or have recolonised from the continent because Ireland was cut off by rising seas early after the last glaciation. Most Irish freshwater fishes are either migratory or tolerate salt water (sticklebacks, salmonids and eels) or are recognised to have been introduced, some in the middle ages perhaps by continental religious orders with their centralised economies; others were more recent introductions. The White-clawed Crayfish, intolerant of salt water, may have been one such introduction and there is notable genetic similarity between Irish, Belgian, French and Corsican stocks. However, although morphometric examination of some Irish crayfish places them in the Atlantic subspecies, the possibility of some Lusitanian relict populations should not be discounted without investigation.

3 Present status and distribution

3.1 Present status in Europe

The White-clawed Crayfish occurs today in western and southern Europe, from the Balkans, Italy and Spain through western France to Britain and Ireland (Figure 3). Further east it is replaced by the larger Noble Crayfish and east again by the Turkish or Thin-clawed Crayfish. All these species have been moved around by man, the practice intensifying in the Middle Ages and again in more recent times when the Thin-clawed Crayfish was spread north and westwards from Turkey in this century.

Throughout its natural range across western Europe the distribution and abundance of White-clawed Crayfish has been dramatically reduced in the last 150 years due to human disturbance - overfishing, habitat destruction, pollution, the introduction of foreign crayfish species and the resultant spread of the lethal plague fungus (Holdich and Lowery, 1988). While this may not have greatly altered overall distribution, stocks which once flourished and supported local fisheries in France, Spain and Italy are now represented by small relict populations in inaccessible waters, although national surveys in France in 1990, 1995 and 1997 show that these persist in almost all Départements (Figure 3).

Spanish and Italian stocks were used extensively to reconstruct French stocks following waves of crayfish diseases in the 19th century. The Italian and Atlantic subspecies were stocked on at least two occasions into the volcanic Lake Pavin in France in the 1870s (Souty-Grosset *et al.,* 1997). Genetic studies in France show little relationship with catchment boundaries, indicating much transfer of crayfish between basins by humans. It is important to estimate how much genetic variation is partitioned between remaining populations as the species is currently threatened throughout its European range.

3.2 Present status in Britain

Stocking White-clawed Crayfish where they were not previously recorded was frequent in Britain, and partly accounts for the present distribution. Crayfish were introduced into western Wales and northern Scotland in this century and viable populations have resulted. There have also been some successful reintroductions after plague outbreaks, to the Bristol Avon. The current distribution in Britain (up to 1996) is shown in Figure 4.

In Britain, the White-clawed Crayfish is one of the animals identified as of key importance in the UK Biodiversity Action Plan Steering group report. Research has been funded into the distribution of native and non-native crayfish, so that overall status is now well known, and future trends can be monitored. All river catchments in England and Wales are now categorised on the basis of their crayfish status for management purposes. While stocks in southern Britain have been badly affected following the introduction of signal crayfish for farming, there are now statutory no-go areas for exotic crayfish, covering many catchments in northern England and Wales, so the future may be more secure. Education on these species is carried out by dissemination of leaflets.

Figure 2. Length distribution patterns (histograms) of White-clawed crayfish from Blessington Lake (Matthews & Reynolds, 1995).

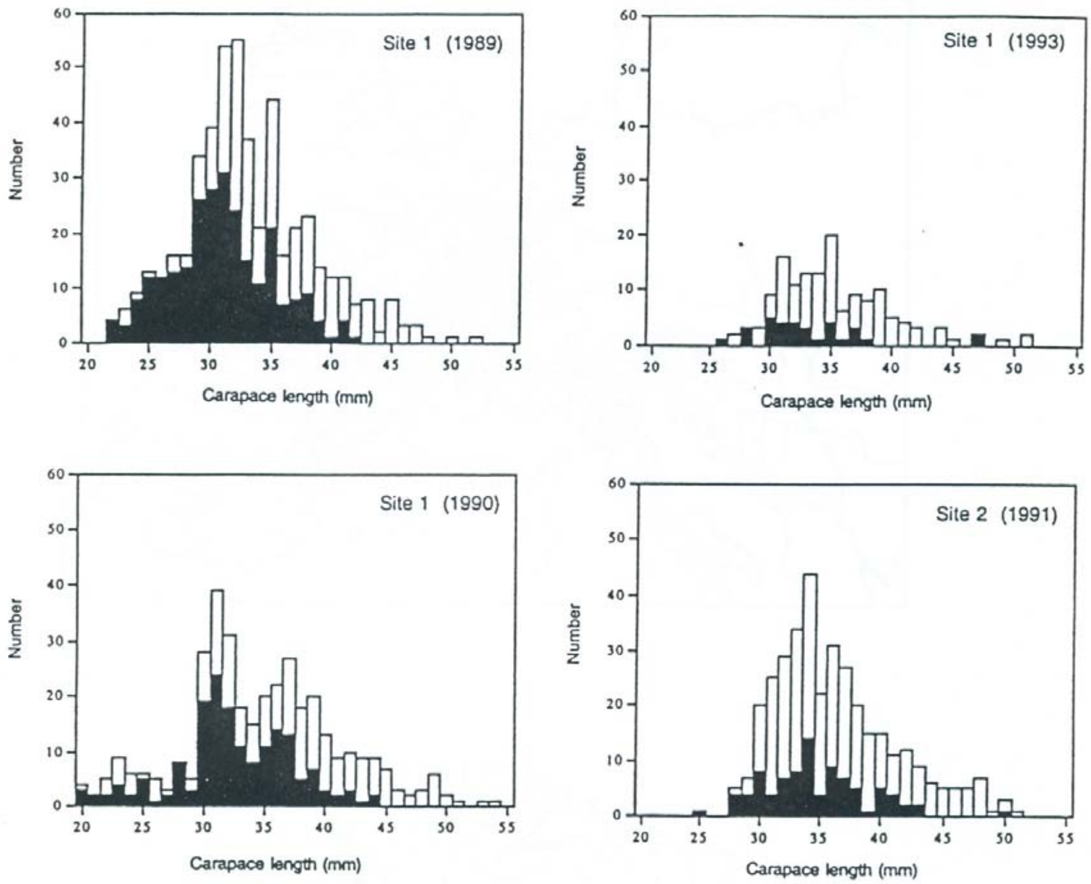


Figure 3. Distribution map of White-clawed crayfish in Europe (after Holdich & Lowery, 1988) and in France (from Vigneux, E., 1997, Bull. Fr. Peche Piscic., 344/345, 357-370)

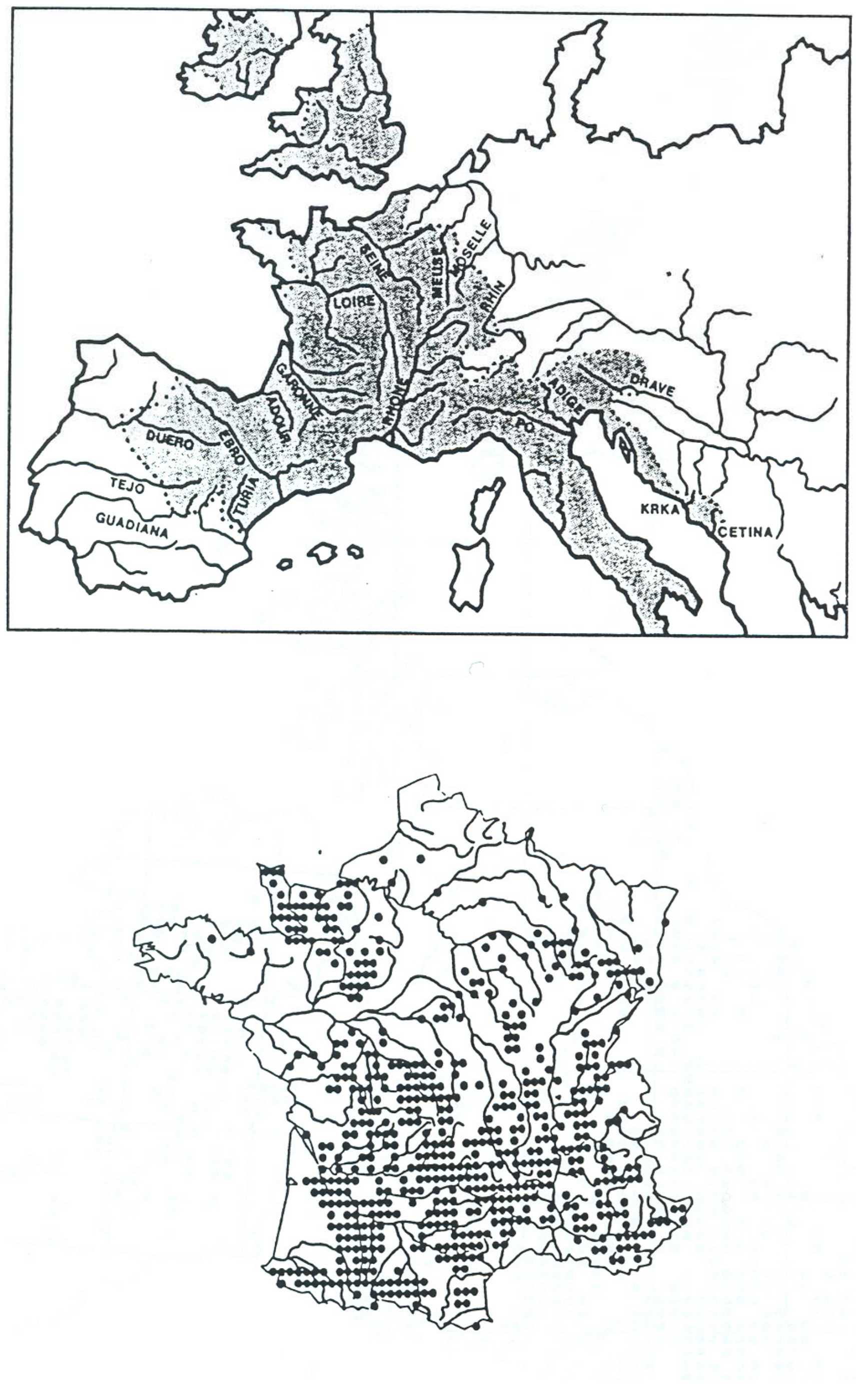
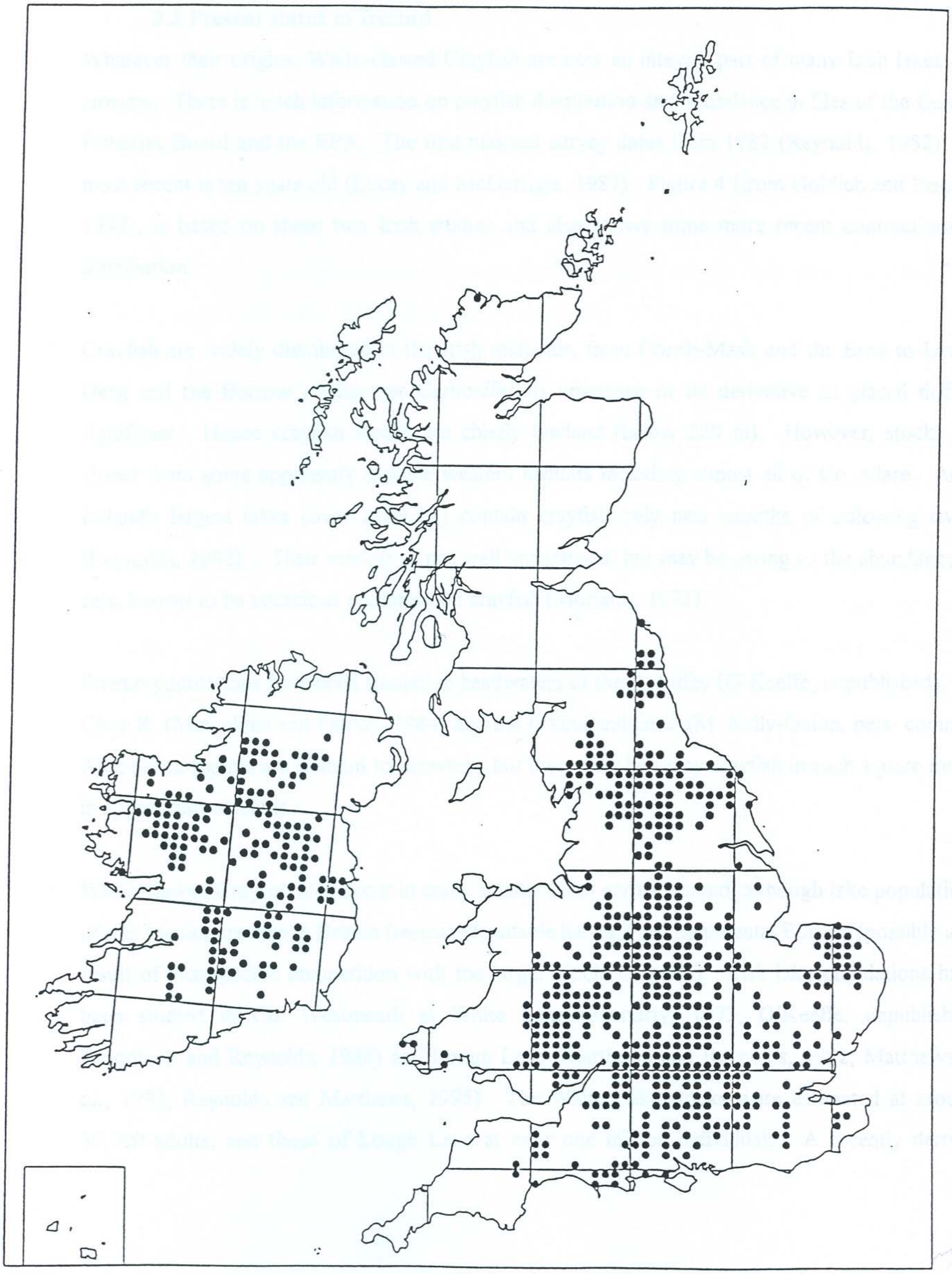


Figure 4. Current distribution of crayfish in Britain (Holdich & Rogers, 1997).



3.3 Present status in Ireland

Whatever their origins, White-clawed Crayfish are now an integral part of many Irish lakes and streams. There is much information on crayfish distribution and abundance in files of the Central Fisheries Board and the EPA. The first national survey dates from 1982 (Reynolds, 1982); the most recent is ten years old (Lucey and McGarrigle, 1987). Figure 4 (from Holdich and Rogers, 1997), is based on these two Irish studies and also shows some more recent contractions in distribution.

Crayfish are widely distributed in the Irish midlands, from Corrib-Mask and the Erne to Lough Derg and the Barrow - wherever Carboniferous limestone or its derivative as glacial drift is significant. Hence crayfish stocks are chiefly lowland (below 220 m). However, stocks are absent from some apparently suitable western habitats including almost all of Co. Clare. Also, Ireland's largest lakes (over 2000 ha) contain crayfish only near mouths of inflowing rivers (Reynolds, 1982). Their scarcity is not well understood, but may be owing to the abundance of eels, known to be voracious predators on crayfish (Moriarty, 1973).

Stream populations have been studied in headwaters of the R. Liffey (O'Keeffe, unpublished), the Clare R. (McFadden and Fairley, 1984) and the Erkina and Goul (M. Kelly-Quinn, pers. comm.). Abundance figures are difficult to ascertain; but there may be many crayfish in each square metre in appropriate streams.

White-clawed Crayfish also occur in many smaller lakes across Ireland, although lake populations of this species are rare in Britain (restricted suitable habitat) and continental Europe (possibly as a result of interspecific competition with the larger Noble Crayfish). Irish lake populations have been studied in Co. Westmeath at White Lake (Moriarty, 1973; O'Keeffe, unpublished; Woodlock and Reynolds, 1988) and Lough Lene (Matthews and Reynolds, 1992; Matthews *et al.*, 1993; Reynolds and Matthews, 1995). The White Lake stocks were estimated at around 37,000 adults, and those of Lough Lene at over one million individuals. A recently derived lacustrine stock was also studied in Blessington Reservoir, Co. Wicklow (Matthews and Reynolds, 1995).

The Irish ecological situation is thus unique in Europe in the occurrence of prolific crayfish populations in the lime-rich waters of lakes; the species can express its maximum habitat range free from competition, from exploitation, and from disease problems associated with introduced species. However, since the first confirmed outbreak of the plague fungus in Lough Lene, Co. Westmeath in 1987 and its suspected recurrence elsewhere (Reynolds, 1988; Matthews and Reynolds, 1990), repeated surveys have indicated the loss of stocks from several midland lakes (Matthews and Reynolds, 1992; Matthews *et al.* , 1993).

3.4 Most recent Irish sightings

Although crayfish are believed to be generally frequent and widespread in suitable locations, there have been no published surveys since the outbreaks of plague were noted in the late 1980s. Sightings in the past two years have been made in Monaghan lakes and on the western shores of Lough Derg (Marnell, pers. comm.), in R. Nore headwaters at Galmoy (Kelly Quinn, pers. comm.), in tributaries of L. Ramor, Co. Cavan (Reynolds unpublished), at R. Termon and Lough Nageage, Co. Donegal (Matthews and O'Keeffe, pers. comm.), and in tributaries of the Inny (Matthews, pers. comm.). These locations represent extensions to the known range of the crayfish in Ireland, but have not yet appeared on distribution maps.

4 Species biology and ecology

4.1 Abiotic relationships

Freshwater crayfish require relatively hard water with a pH of 7 or above and calcium concentrations of at least 5 mg/l. They thrive where there is a firm substrate and moderate productivity levels. White-clawed Crayfish occur in both streams and lakes in Ireland, but chiefly in streams elsewhere in Europe. Typical stream habitat features are described in Smith *et al*. (1996). Their living requirements are rather similar to those of brown trout - good water quality (above 50% oxygen saturation, BOD below 3 ppm) and moderate summer water temperatures (below 20°C) although they only feed actively and moult above 10°C. They are sensitive to acidity and heavy metals, but may tolerate disturbance or recolonise affected areas. Highest populations in Ireland are found in the Liffey headwaters (220 m), altitude being limited by temperature and availability of alkaline water; in Britain they are found at 400 m in Malham Tarn.

4.2 Growth and maturity in Irish crayfish

White-clawed Crayfish are rather slow growing compared to other astacids; they reach 9 cm total length and 40 g in 5 or more years, and an ultimate length of perhaps 12 cm (Table 2). Crayfish grow by moulting their shell and increasing by about 10% in length before the new one hardens. Immatures may moult several times each year, but mature males usually moult twice (early and late summer) and reproductive females only once, in late summer. In favourable Irish conditions growth rates for this species may exceed those recorded elsewhere. Figure 2 shows a typical population structure of Irish crayfish.

4.3 Breeding biology

White-clawed Crayfish breed first at a smaller size, and often when older, than do *Astacus* and *Pacifastacus* species, normally maturing at 22-25 mm carapace length (about 5 cm total length) when 3-4 years old (Reynolds *et al.,* 1992). Secondary sexual characters such as the male gonopods on the first and second abdominal segments (Figure 1) are visible in small juveniles.

Sexual dimorphism in body proportions is already discernible before maturity and increases progressively with each moult, males having a narrower abdomen and larger claws than females.

In late summer ripening females display whitened glands on the under edge of each abdominal segment, while male gonopods may also become whitish in autumn. Mating occurs in October or November at a water temperature of around 10°C. Females become less cryptic and males more active. Males may mate with several females; they immobilise the female with their claws and deposit a white limy spermatophore at the base of her walking legs. The female then takes shelter and a few days later, secretes a sticky 'glair' from her shell glands, which attaches the eggs to the abdominal limbs as they are laid. The reproductive rate is relatively low (an average of 60-80 eggs per year). Fecundity increases with size, but very large females may have few eggs and egg sizes may be variable (Woodlock and Reynolds, 1988; Reynolds *et al.,* 1992).

For the next 8 to 10 months the female remains relatively quiet and incubates the eggs. This inhibition of feeding and activity leads to slower growth in female crayfish than in males. Around 50% of the eggs survive to hatch in June or July. The hatchlings remain attached to the mother until their second moult, when they become independent; she can then resume feeding actively, and moult.

4.4 Community relationships - feeding, predation

Crayfish of all species seem to prefer animal to plant food and obtain most of their carbon from invertebrates, although the bulk of their food may be plants. Details of their diet will depend on whether they are living in streams or in lakes. In Wicklow streams, juvenile White-clawed Crayfish feed chiefly on small insect larvae and amphipods, while adults have a more varied diet including worms, fish and vegetation. The ratio of animal to plant matter in stomachs of crayfish from the Liffey headwaters fell from over 5:1 by volume in subyearlings to 1:1 in mature crayfish (O'Keeffe, unpublished).

In lakes, freshwater crayfish are recognised as 'keystone' species which have measurable impacts on benthic fauna and macrophytes; this has particularly been studied in North America. The American crayfish *Orconectes limosus* feeds readily on small zebra mussels (Holdich and

Lowery 1988). In Irish lakes adult White-clawed Crayfish prey on a wide variety of benthic invertebrates including snails, crustaceans and insect larvae, controlling the abundance of some species (Matthews and Reynolds, 1992; Matthews *et al.,* 1993). In White Lake, Co. Westmeath, subyearlings fed chiefly on small entomostracan crustacea and insect larvae while larger crayfish fed predominantly on charophytes (stoneworts), and the largest ate a significant proportion of both dead terrestrial vegetation (deciduous leaves) and juvenile crayfish. Animal to plant volume ratios fell even more markedly than in streams, from 6:1 for underyearlings to 0.7:1 for large crayfish.

The grazing impacts of crayfish species on aquatic macrophytes have long been known. The impact of White-clawed Crayfish on plants and animals of Irish charophyte meadow communities has recently been demonstrated (Matthews and Reynolds, 1992; Matthews *et al.,* 1993); their grazing checks primary productivity, while in their absence luxuriant macrophyte growth may occur.

Holdich and Lowery (1988) list 10 fish species, 4 birds and 4 mammals as predators on White-clawed Crayfish. In Ireland dragonfly nymphs and large crayfish may be significant predators on juvenile White-clawed crayfish, as are herons, salmonids, eels, perch and pike. Crayfish are also important in the diet of otter (McFadden and Fairley, 1984).

4.5 Diseases

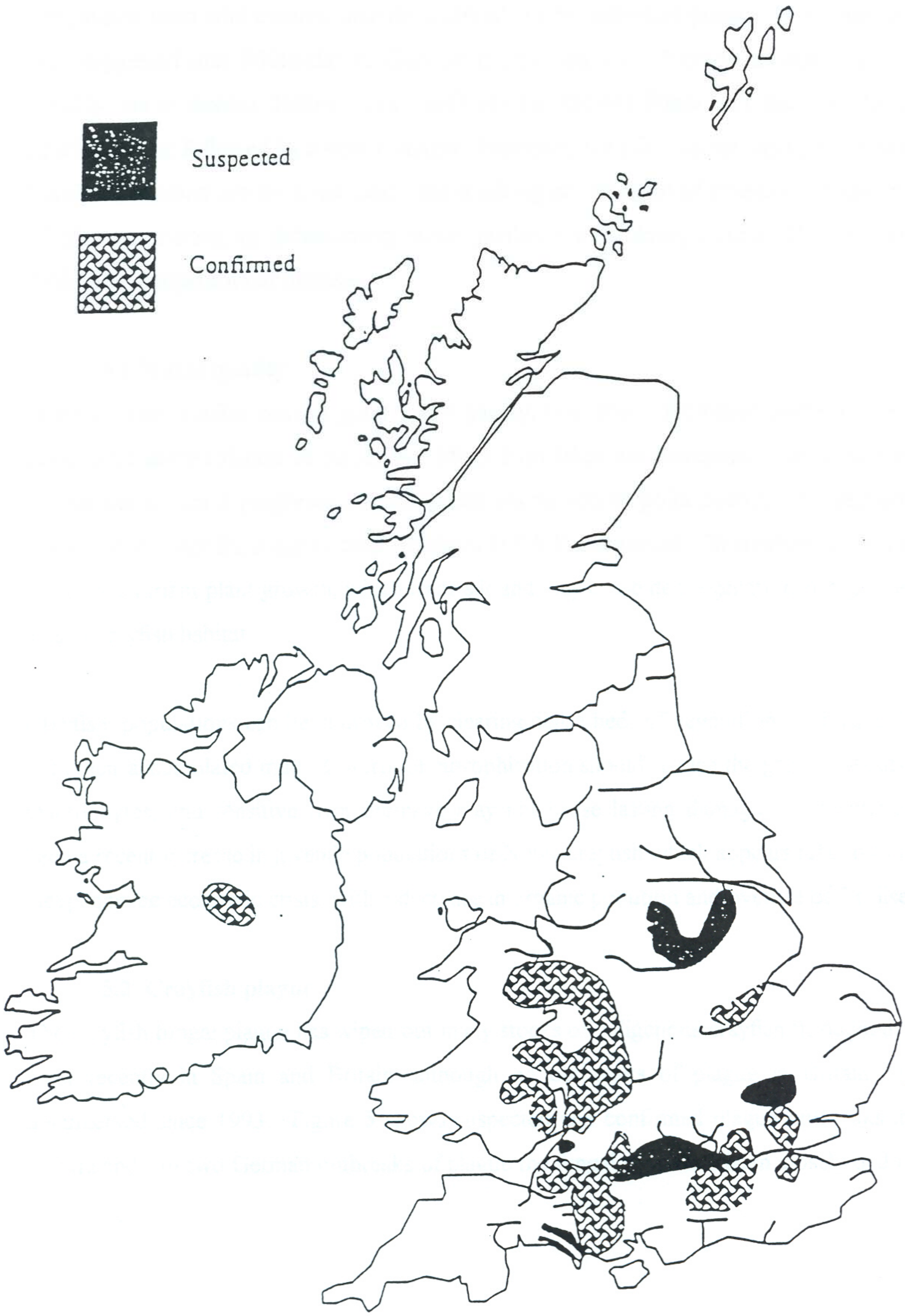
The most virulent pathogens of crayfish are fungi; less serious are bacteria, protozoans and parasitic worms. Viral infections have so far not been detected, but several baculoviruses are known in the gut, hepatopancreas and gills of crayfish. Since viral infections in shrimp culture can lead to heavy mortalities, they may account for some unexplained mortalities of crayfish.

The most serious infection is the crayfish fungal plague caused by the fungus *Aphanomyces astaci* Shikora. This disease originated in North America and one strain was spread to Europe via Italy over 100 years ago, perhaps in ballast water and by the importation of *Orconectes limosus* from eastern North America. Other strains were introduced from California with western American Signal crayfish, and from Louisiana. European crayfish possess no resistance to this fungus, which attaches to thin areas of cuticle as a spore and then grows through the tissues, leading to death in around two weeks. The naked, swimming spores have no resting stage and must be transmitted directly from an infected or recently dead crayfish.

The White-clawed Crayfish has been badly affected by plague in Spain, France and Britain. There has been one diagnosed outbreak of plague in Ireland in 1986 (Matthews and Reynolds, 1992; Figure 5). While there are no American crayfish in Ireland, fungal spores may have been introduced by fishermen on wet gear. However, crayfish reintroduction to Lough Lene some years after their eradication by plague appears to have been successful.

There are a number of other diseases of Irish crayfish, including occasional infections by saprophytic fungi such as *Saprolegnia* and *Fusarium.* Various species of bacteria, depending on the crayfish host species, may attack wounds causing a reddish 'burn spot' which is not usually lethal. Porcelain disease - whitening of the undersides of the abdomen and claws through replacement of the muscles by a parasitic microsporidian protozoan *Thelohania contejeani* - is lethal to individuals but rarely has a serious impact on populations. This infection rarely exceeds 1-2% of a healthy population. The infected crayfish lose their mobility, retreat to deeper waters and eventually die, the disease being passed on by cannibalism most easily in shallow streams supporting dense crayfish stocks. The Irish situation for other diseases is not yet known, but the apparently low level of parasites and disease in Irish crayfish is worthy of note.

Figure 5. Known and suspected plague outbreaks in Britain and Ireland (Holdich & Rogers, 1997).



5 Threats to Irish crayfish

A list of major threats to crayfish would include drought and floods, pollution (industrial, domestic, agricultural), habitat modification (dams, draining, dredging), overfishing and competition from wild exotics, directly, indirectly or as vectors of plague. A number of authors have suggested that White-clawed Crayfish populations are subject to fluctuations in number, possibly due to disease. Natural events such as droughts and floods may have had some impact on Irish stocks; followed by a slow recovery. However, the principal threats to the White-clawed Crayfish in Ireland are environmental - the dredging or alteration of stream channels or addition of effluents leading to deteriorating water quality - and biotic, through the introduction of predators, competitors or diseases.

5.1 Water quality

White-clawed crayfish require good water quality, like trout. However, some authors believe them to be more tolerant of pollution. Many Irish lakes are eutrophied, and Irish river water quality has shown a progressive deterioration owing less to point sources of pollution than to diffuse enrichment from agricultural practices (EPA Publications). In shallow streams this may result in luxuriant plant growth, which traps silt and may cause deoxygenation at night, leading to loss of crayfish habitat.

Crayfish populations can be improved by clearing dense beds of vegetation, such as Yellow Iris, with their accumulated mud. Control of eutrophication should reduce the growth of silt-trapping macrophytes, and sensitive river drainage may not cause lasting damage. In Belarus there has been a recent increase in juvenile populations of Noble crayfish which appears related to the post-independence economic crisis, with a decrease in organic pollution and overuse of fertilisers.

5.2 Crayfish plague

The crayfish fungal plague has wiped out many stocks of indigenous crayfish throughout Europe, most recently in Spain and Britain, although no outbreaks of plague in Britain have been documented since 1993. Figure 5 shows suspected and confirmed plague outbreaks in Britain and Ireland. In two German outbreaks of plague the fungal strain has been closely tied to that in L. Tahoe in North America, corroboration that farmed Signal crayfish from that source were the likely vector.

There are no American crayfish in Ireland, which thus provides a plague-free stronghold for the native species. However, there has been one diagnosed outbreak of plague in Ireland which wiped out stocks from several midland lakes in 1986 (Matthews and Reynolds, 1992). Fungal spores may have been introduced by fishermen, on wet or muddy fishing gear, or on the hulls of pleasure craft brought from Europe, so vigilance is necessary. Other possible vectors include water fowl and fish. Because of its ability to eradicate complete stocks of crayfish in a matter of weeks, this fungus may affect whole lake ecology - once crayfish are removed, the benthos may be changed in nature and in species composition. Natural recolonisation by crayfish is slow and uncertain, as it depends on the persistence of unaffected stocks within the catchment.

Reports of the apparent persistence of the fungus for decades in rivers and lakes, and unresolved questions of the modes of transmission in aquatic ecosystems, are probably owing to the undetected presence of alien crayfish somewhere in a catchment. Some exotic crayfish are currently in private aquaria and repeated warnings are essential of their lethal impact on natural systems. Other control measures include the need for facilities to disinfect fishing gear before use in Irish waters, and constant vigilance for exotic species in the wild, or signs of disease in natives. All plague outbreaks should be controlled as far as feasible, by isolation or by chemical treatment (liming).

5.3 Introduction of exotic species

The epitaph of introductions might be “it seemed like a good idea at the time”. Reasons for introduction may be economic or sentimental, but the risks include degradation of the environment, disruption of the host community, introduction of diseases, genetic degradation of host stocks, reduction of biodiversity, and socio-economic effects. Each of these can be postulated for crayfish. All the North American crayfish successfully introduced to Europe this century carry crayfish plague, use competitive exclusion, damage banks by burrowing, have a differential susceptibility to predation, and practice reproductive interference. Competition with and predation by exotic crayfish is also considered significant. In Britain, no mixed populations of native and exotic (believed plague-free) crayfish have survived more than 5 years (Holdich & Rogers 1997).

Crayfish may be affected by other introduced predators or competitors with a keystone effect in communities. The mink is one such introduced predator in Ireland which, like the native otter, may affect crayfish. The recent introduction and spread of the zebra mussel *Dreissena polymorpha* in midlands catchments may have positive impacts on crayfish, as it provides an additional food source.

6 Management

Several options are open for the conservation of White-clawed crayfish in Ireland - restoration of recently lost lake stocks, range extension through establishment of new lake stocks, and introduction to man-made habitats. It is advisable that such management operations are supported by educational material for the interested public. To provide a satisfactory basis for review of management effectiveness, surveillance of protected stocks requires to be carried out in a standardised way at scheduled intervals. A minimal approach would be to record presence/absence of target populations. This would be desirable on an annual basis. But, to provide the sort of data needed to better understand changes occurring in crayfish stocks, more detailed survey information is required, involving monitoring of site conditions along with survey of the crayfish themselves. This would involve decision in advance as to which target populations would be subject to the more detailed investigation and which site parameters would be recorded. These more detailed investigations would need to be carried out every three years, given the life cycle and longevity characteristics of the species.

6.1 Confirmation of presence / absence; surveillance

Survey of crayfish populations should avoid the colder months (November to April) when crayfish tend to be rather inactive and may move to deeper water or remain in hides.

In lakes, an objective method of crayfish survey is the use of plastic or wire-mesh traps, baited with liver (or pierced tins of pet food) and attached 2-5 m apart to a rope weighted at both ends. Crayfish are active during the night, so the trapline is set parallel to the shore in 1-2 m water in the afternoon and retrieved the following morning. The sampling site should contain some rocks, weed and a firm substrate. The rope can be retrieved with a boat-hook or by wading. Swedish ‘Trapy’ or ‘August’ crayfish traps are designed for the larger Noble Crayfish, so Irish crayfish may escape between the meshes; this may be minimised by hauling all traps on shore and examining them promptly. A mean CPUE (catch per unit of effort) of around one adult crayfish per trap is normal, but large variations in CPUE may be attributable to water temperature, weather conditions and phases of the moon. Therefore 6-10 traps may be necessary to establish crayfish presence, and traps may have to be replaced for a second or third night.

In streams, a shallow riffle with large rocks is the preferred habitat. This may again be examined by turning stones, or more systematically with the use of a pond-net of mesh-size 1mm and strong square metal frame. Sampling should be carried out for at least 15 minutes, moving slowly upstream and checking under banks and among vegetation, to achieve a catch of around 10 crayfish. The net is held downstream of a rock, and as the rock is turned by hand or with a boot, the net is swept quickly forward into the hollow left by the stone. The sampler should avoid undue damage to the habitat, and turn back larger stones.

In both lake and stream habitats the presence of crayfish may also be revealed by more informal methods. Careful stone-turning in 20-50 cm water for 15 minutes should reveal smaller crayfish. The hand may be inserted cautiously into submerged holes or root tangles and any crayfish encountered withdrawn with care. Examination of otter spraints or mink scats will also reveal crayfish presence, as may stomach analysis of caught salmonids. Fisheries operations such as electro-fishing will also disturb crayfish, indicating their presence.

If enough crayfish are encountered simple population data may be collected; e.g. the proportions of males and females, and of adults and juveniles (over and under 5 cm total length). Small samples may not represent the population accurately, and young of the year (less than one cm long) are usually difficult to find.

6.2 Monitoring of water quality and other relevant parameters

The water quality required by crayfish includes high dissolved oxygen, adequate lime in the water and an absence of organic pollution, as described above. Basic water quality data (dissolved oxygen, BOD, alkalinity) should be collected regularly at important crayfish sites if subsequent changes in populations are to be investigated. Many sites may already be monitored. The EPA publishes a summary of water quality every four years, while water quality is regularly monitored by other Irish authorities such as the Fisheries Boards and County Councils. The coordination of such data is to be encouraged.

6.3 Reintroduction

In mainland Europe, restocking of plague-susceptible native crayfish may be hampered by reinfection from exotic species which carry the plague fungus. There are no alien crayfish in Ireland, which enhances the possibilities for stock restoration or introduction to suitable new habitats. Using information on the breeding biology, fecundity and survivorship of this species, it can be calculated that a population in excess of 1 million crayfish could theoretically be produced from a single pair inside 10 years, so tactical reintroductions should help conservation of the species.

In Britain, where there has been much restocking over the centuries, the demonstrated low heterogeneity of White-clawed Crayfish suggests that it may be considered a single stock for management and restocking. In Ireland the situation may be more complex, and so until it is elucidated, restockings should be made from the nearest surviving populations.

Natural stocking has occurred in instances where a stock was eliminated or a new habitat created. For example, Blessington Lake came into existence in 1941 through the construction of a dam on the upper River Liffey. Crayfish were first noted there from fish traps set in 1958 and from stomach samples of resident trout and perch. A recent study indicated about 5 trappable (adult) crayfish per m2 of suitable shoreline (Matthews and Reynolds, 1995). This lake population has developed from pre-existing stream stocks within the 50 years life of this reservoir.

Some of the smaller midland Irish lakes (e.g. L. Owel, L. Lene, White Lake, Pallas Lake) have recently lost their crayfish stocks, through pollution or disease (Reynolds, 1988). Crayfish populations in Lough Lene received brief study in 1987, just before they were eradicated by crayfish plague (Reynolds and Matthews, 1995). Crayfish were reintroduced in 1989 and 1991, and in July 1996, a search by SCUBA and shallow-water netting yielded evidence of crayfish survival and successful reproduction in most years (Reynolds and Matthews, 1997).

Certain lakes, apparently suitable for crayfish, may never have held stocks for geographic reasons such as the absence of outflowing streams. New water-bodies such as those developed on cutaway peatlands may also prove suitable for crayfish.

6.4 Introduction of exotic species - Legislative implications

Appendix II of the Bern Convention for Conservation of European wildlife and Natural Resources lists *Austropotamobius pallipes* as a species for whose protection each contracting party must take appropriate steps, including legislation. This does not preclude the introduction of exotics or completely forbid the capture of natives: EU regulations allow free movement of goods for trade, across frontiers, which has recently led to the introduction of live exotic crayfish to Sweden from Britain and elsewhere. The EU Habitats Directive requires countries to protect listed species in designated Special Areas of Conservation (SAC). The EU Habitats Directive thus has limited effectiveness in protecting a species throughout its natural distribution.

Importation of crayfish to the Irish Republic is prohibited under the Live Fish (restriction of importation) Order 1972 of the Fisheries Acts. Introduction of non-native crayfish to Northern Ireland is an offense under the Wildlife (NI) Order 1955. These measures have so far been successful in preventing the spread of exotic crayfishes to this country. Protected under the Irish Wildlife Act (1975), Irish stocks of White-clawed crayfish remain widespread and abundant. Ireland's crayfish populations are thus today of European importance and are protected under international and national legislation. If Ireland is to retain its favourable status crayfish trade must be regularly monitored, including banning the use of alien crayfish as bait.

In Germany a certificate of health is required when European crayfish are being imported or placed into ponds; other crayfish can only be imported and sold directly to restaurants if these are connected directly to sewage plants. Directive 91/67/EEC provides the basis for establishing no-go areas in Germany. A 1983 law in France forbids alteration or destruction of the habitat of *A. pallipes* and the control of exotic crayfish, which cannot be transported or sold alive. However, the European Court of Justice recently ruled (C-131/93) that a citizen has the right to import live crayfish. It is therefore no longer possible to control their importation, but the member state must control what happens to them thereafter. Vigilance of inspectors e.g. for CITES is thus needed to ensure the protection of native crayfish and of their habitats.

In Britain it is illegal to release non-native crayfish into the wild (Section 14, Wildlife and Countryside Act, 1981) but a license may be obtained from the Ministry of Agriculture, Fisheries and Food (MAFF) to farm Signal crayfish if 'due diligence' is observed to prevent their escape. In May 1996 MAFF and the Welsh Office designated no-go areas in most of northern England, Wales and all Scotland, under the prohibition of keeping live fish (crayfish) order 1996 (Figure 6). In Sweden, sports fishermen are obliged to disinfect nets and gear if moving from one river system to another.

7 Impacts of Other Management

7.1 The legislative background

Crayfish are sensitive to water quality, and management of water quality is the responsibility of a number of different agencies in Ireland, under various pieces of legislation. The 1977 Local Government (Water Pollution) Act is the basis of most water quality management planning today, although slightly modified in 1990. Section 15 provides for Water Quality Management Plans by local authorities. Plans have now been established for the Slaney, Barrow, Nore, Suir, Liffey and Moy; while several more, including the Shannon, Erne, Boyne, Deel, Lee and Blackwater, are in draft. These plans, by their dependence on BOD levels, do not adequately address the implications of non point source pollution, and so agricultural catchments have continued to deteriorate. Further, water quality management plans only cover the principal streams in a catchment, whereas the smaller tributaries may be the richest habitats for crayfish.

Within some Local Authorities there may be insufficient coordination between the sections responsible for the Development Plan and for the Water Quality Management Plan. For example, the Meath County Development Plan does not discuss the draft water quality management plan prepared for the Boyne, and the South-East Tourism Development Action

Plan fails to address the relationship between visual amenity and environmental quality, making no reference to the four existing catchment water quality management plans.

Since the EPA Act (1992) established a national Agency to license polluters some roles of local authorities in management planning have been superseded. A number of bodies including County Councils now have responsibility to plan for water catchment management in Ireland, but the beneficial user may not consider the well-being of crayfish. The Fisheries Acts (1959-1990) empower Regional Fisheries Boards to prosecute polluters, including the local authorities, but the Boards do not have a primary role in water quality management planning. Thus, several authorities may be monitoring the same water bodies but without coordination of strategy or results. It is important that wildlife officers are aware of the variety of other users who might affect crayfish, and that appropriate liaison is established.

7.2 Fisheries management

Fisheries management is chiefly the responsibility of Regional Fisheries Boards, who enhance stocks, control predators and maintain access to selected fishery waters. This may include monitoring water quality and prosecuting point source polluters, as well as bank management, stream channel alteration, and the introduction of predatory game fish. These actions, taken for specific fish management objectives, may have either positive or negative impacts on crayfish populations. For example, increasing stocks of certain fish (trout, pike, perch, eels) may increase predation pressure and bank management may remove crayfish hides, while construction of docks or jetties may conversely improve the rocky cover needed by crayfish.

7.3 Waterway management

Waterway management involves flood control and the maintenance of banks and structures such as bridges, weirs and locks. These engineering operations are carried out by local authorities and by the Office of Public Works (OPW) & Waterways. Efficient maintenance may affect crayfish populations by reducing the incidence of crevices in retaining walls and of riverine tree-roots in which crayfish may hide.

Large scale drainage and flood control measures are controlled by the OPW. While these may enhance crayfish habitat by removing excessive silt and macrophyte beds, they may have a disruptive impact on crayfish populations at least in the short term. Field drainage is usually the responsibility of the farmer or local authority; maintenance of these drains may result in destruction of crayfish refuges.

7.4 Other management

Water abstractions and point source discharges are the responsibility of the Local Authority and the EPA. Abstractions may reduce flows and hence affect invertebrate life; discharges of silt or organic materials may seriously affect water quality and hence crayfish well-being. Monitoring for crayfish presence above and below a discharge or abstraction point may be useful. Local Authorities are also responsible for road construction which may have an indirect impact through pollution or silty runoff.

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Table 1. Native and *introduced species of crayfish in western Europe.

Scientific name	Common name	(Origin)	Status
Austropotamobius pallipes	White-clawed crayfish	(SW Europe)	Strong only in UK, Irl
Austropotamobius torrentium	Stone crayfish	(SE Europe)	Relict status in Alps, Dalmatia
Astacus astacus	Noble crayfish	(N Europe)	Still strong in parts of N and E
Astacus leptodactylus	Thin-clawed crayfish	(Turkey)	Expanding N and W
**Pacifastacus leniusculus*	Signal crayfish	(California)	Farmed throughout Europe
**Orconectes limosus*	American crayfish	(Mississippi)	In large N Europe rivers
**Procambarus clarkii*	Red-clawed crayfish	(Louisiana)	S Europe, expanding

Table 2. Some biological data for Irish crayfish stocks. All measurements in mm. m: male; f: female; CL: carapace length; TL: total length (90mm TL is usual minimum capture size). %MI = per cent moult increment in length, Fec = pleopodal fecundity counts.

Site	modal sizes (CL)	max size	%MI	Ref.
White Lake, Co. Westmeath				
	f:13, 20, 32, 35, 37			
	m:13, 21, 34, 39, 42, 44, 49	max 55.0		(1)
	f:10.8, 23.5, 30.7, 35.5, 40	max 50.0		
	m:10.8, 23.7, 30.7, 38.6, 45	max 58.5 (62.8 g)	%MI 2.6-21.7	(2)
Lough Lene, Co. Westmeath				
	f:14-20, 30-31			
	m:14-20, 39, 50	max 50	%MI 21%	(3)
Blessington Lake, Co. Wicklow				
		max 52	%MI 6-9%	(4)
Lisheens Stream, Co. Wicklow				
	f:7.6, 13.2, 22.0,	max 41		
	m:7.6, 14.2, 20.8, 28,	max 46		(2)

(1) MORIARTY, 1973; (2) O'KEEFFE, 1986 (unpublished PhD Thesis); (3) REYNOLDS & MATTHEWS, 1997; (4) MATTHEWS & REYNOLDS, 1995