MANAGING AN ABUNDANT CRAYFISH RESOURCE FOR CONSERVATION - *A. PALLIPES* IN IRELAND.

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ABSTRACT

Irish white-clawed crayfish stocks show high genetic uniformity between systems, although individual populations usually show good heterozygosity. The inference is that they were derived from a single immigrating stock, related to those in Western France. Irish crayfish stocks occur widely and often in good numbers in lakes and streams; they are protected and rarely fished, and there are no alien species. Their use for reintroduction into depleted areas within Ireland, including Special Areas of Conservation, is examined. Irish crayfish also have potential value for restocking depleted continental locations, under stringent conditions of environmental suitability and genetic conformity.

Key-words : *Austropotamobius pallipes*, conservation, genetics, endangered species, restocking.

UNE GESTION POUR LA PRÉSERVATION D'UNE RESSOURCE ABONDANTE : L'ÉCREVISSE *AUSTROPOTAMOBIUS PALLIPES* EN IRLANDE.

RÉSUMÉ

Les populations irlandaises d'écrevisses à pattes blanches présentent une forte uniformité génétique à travers les bassins hydrographiques, tandis que individuellement, chaque population possède un bon nombre d'hétérozygotes. On peut donc émettre l'hypothèse que la population irlandaise est descendante d'un seul groupe d'immigrant, proche des écrevisses de l'ouest de la France. En Irlande, on retrouve l'écrevisses à pattes blanches dans maints lacs et rivières et souvent en grand nombre. Elles sont une espèce protégée et ne sont que très rarement pêchées pour être consommées. De plus, aucune écrevisse exotique n'a été introduite sur l'île.

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La possibilité d'utiliser des populations abondantes pour réintroduire *A. pallipes* dans des cours d'eau en Irlande où l'espèce est désormais rare ou disparue, en particulier les sites Natura 2000, est sous examen. Les populations d'écrevisses irlandaises possèdent également un potentiel pour le repeuplement des rivières européennes, en prenant compte de critères stricts en matière de conformité génétique et de la qualité de l'environnement.

Mots-clés : *Austropotamobius pallipes*, génétique, espèce en voie de disparition, réintroduction, sauvegarde.

INTRODUCTION

The white-clawed crayfish *Austropotamobius pallipes* (Lereboullet) is well-established and widespread in lowland, lime-rich areas of Ireland (REYNOLDS, 1982; LUCEY and MC GARRIGLE, 1986; REYNOLDS, 1997, 1998). However, the presumed native status of Irish crayfish has been under some doubt. The suggestion that Irish stocks may have been of Lusitanian origin in the early Pleistocene (REYNOLDS, 1979) is now considered unlikely because all populations so far examined are of the subspecies *pallipes*, whereas Spanish crayfish are of the subspecies *italicus* and appear moreover to have been introduced to the Iberian region relatively recently (GRANDJEAN *et al.*, 2001). Many authors have suggested that Irish crayfish stocks may have originated in introductions from England, including THOMPSON (1843) and, most recently, LUCEY (1999) who deduced from unpublished manuscript records that crayfish had been in Ireland since the seventeenth century, and suggested that they may have been introduced from England into southern Ireland, probably around the sixteenth century.

Studies of mitochondrial DNA by RFLP show a single haplotype across all Irish stocks so far investigated (GOUIN *et al.*, 2001). This particular genetic configuration also occurs in Western France where it is restricted to a few populations, but is not represented in Britain or elsewhere in western Europe (GRANDJEAN and SOUTY-GROSSET, 2000). There is also a decline in genetic diversity from south-east to north-west Ireland. We conclude from studies of allele frequencies that Irish crayfish are closest to stocks in western France (SOUTY-GROSSET *et al.*, 1999), from where they were most probably introduced and subsequently translocated and / or spread naturally across the island.

Whatever their origins, estimated crayfish numbers are generally high in favourable sites – around 0.2 adults per square metre in studied calcareous lakes such as White Lake, County Westmeath, where optimal sites also held subyearlings and yearlings estimated at up to 77 and 26 individuals per square metre respectively (O'KEEFFE, 1986). Over 1 million adults were estimated in the 430 ha Lough Lene (MATTHEWS *et al.*, 1993). Summer CPUEs ranged up to 2.8 per trap night in Lough Lene (REYNOLDS and MATTHEWS, 1993). Stocks may also be dense in streams. While mark-recapture estimates for the second order Lisheens stream, Co. Wicklow (22-36 per square metre) were considered unrealistically high (O'KEEFFE, 1986), up to 4.2 adults per square metre were recorded in a second order tributary of the Nore (BYRNE *et al.*, 1999). In some catchments numbers increased downstream, away from the headwaters, and in 3rd-order stretches of the R. Barrow, CPUE was up to 6.5 (DEMERS, unpublished data).

Water requirements, such as pH, temperature and calcium content, are well known for *A. pallipes* (HOLDICH *et al.*, 1999). Other habitat characteristics have been studied in the UK (*e.g.* BROWN and BOWLER, 1977; SMITH *et al.*, 1996; HOLDICH and ROGERS, 2000) and France (*e.g.* DAGUERRE DE HEUREAUX and ROQUEPLO, 1981; NEVEU, 2000; GRANDJEAN *et al.*, 2002). FOSTER (1995) and NAURA and ROBINSON (1998)

both found that overhanging branches and tree shade are related to presence of crayfish, and sandy or poached banks and eroding cliffs with their absence. Crayfish occur in a variety of Irish freshwater habitats, provided that shelter for refuges is adequate, in the form of rocks, tree roots, leaf litter or vegetation. In Ireland, personal observations by one of us show crayfish often to be relatively numerous in wide, sandy stretches, with no trees or stones but plenty of aquatic vegetation.

Irish stocks of *A. pallipes* have benefited from prohibitions on the importation into Ireland of exotic crayfish species, for the reason that these may carry salmonid diseases such as IPN and IHN (UNESTAM, 1974; GIBSON, 1979). Nevertheless, an outbreak of crayfish plague caused by the fungus *Aphanomyces astaci*, generally carried by American crayfish species, occurred in Ireland from 1985 and was corroborated in Lough Lene in 1987 (MATTHEWS and REYNOLDS, 1990). It is believed that its zoospores were carried into Ireland on damp fishing gear (REYNOLDS, 1988). Plague has been implicated in the disappearance of crayfish from most of the Boyne catchment in Eastern Ireland (DEMERS and REYNOLDS, 2002) but it appears to have had limited effects on Irish stocks as a whole (REYNOLDS, 1997; MATTHEWS and REYNOLDS, 1992), compared to the severe impact this disease had on *A. pallipes* throughout Spain (CARRAL *et al.*, 1993), France (LAURENT, 1988) and Britain (HOLDICH *et al.*, 1999) where carrier crayfish species are now resident. Irish crayfish suffer from a low incidence of porcelain disease (*Thelohania contejeani*) (O'KEEFFE and REYNOLDS, 1983), and neither *Psorospermum* nor branchiobdellid parasites have been reported from these apparently introduced stocks.

Perhaps because of the absence of crayfish plague and of competitors, *A. pallipes* in Ireland is found in a range of water types, but generally in areas of moderate to high water quality (REYNOLDS *et al.*, 2002). Disease and direct pollution may account for absence of crayfish from some river stretches (DEMERS and REYNOLDS, 2002). The quality of many Irish rivers has remained relatively high up to now, although declining over the past decade (LUCEY *et al.*, 1999). Eutrophication is becoming a more widespread problem. Habitat degradation by stream dredging and siltation has had some localised effect on populations (*e.g.* on the Tremblestown, MC CARTHY, 1977) although habitat enhancement has followed some drainage operations (LYNCH and MURRAY, 1992). Nonetheless, for all these reasons and because crayfish were never fished commercially in Ireland, the Irish stocks of the white-clawed crayfish are considered to be the strongest remaining in Europe.

CURRENT CONSERVATION SITUATION IN IRELAND

White-clawed crayfish were added to the list of species protected under the Irish Wildlife Act 1976, by Statutory Instrument 112 of 1990. *A. pallipes* is thus protected in Ireland, both under the Irish Wildlife Acts and under international conventions such as the Bern Convention and European Union Habitats Directive, where the habitat of an Annex II listed species is also protected. Licenses may be issued for scientific study of such species, but there is no commercial exploitation of this species in Ireland.

Conservation strategies for the white-clawed crayfish in Ireland have been outlined by REYNOLDS and MATTHEWS (1995) and REYNOLDS (1998). These must be viewed against the unusual background of an obligation to manage a resource which is relatively widespread and abundant in Ireland, but which is considered endangered in Europe and therefore protected under European and National legislation. A number of other species in Ireland also fall into this category, such as otter, salmon and the common frog. In addition, crayfish, like frogs, are doubtfully native by most definitions, although both have become intrinsic elements in Irish freshwaters and wetlands.

Under the EU Habitats Directive [93/43/EEC] member states are obliged to designate Special Areas of Conservation (SACs) for the protection of certain threatened habitats and species. *Austropotamobius pallipes* is one such species and to date the Irish Government have selected 14 sites as SACs for this animal, on the basis of the best available published and unpublished information. Together with well documented sites such as White Lake and Lough Lene in the midlands of the country, less studied locations were also included to provide a geographical spread of crayfish SACs around the island. Of the selected sites, nine are lakes or lake complexes (White Lake, L. Bane, L. Lene and Kilroosky in the midlands; Loughs Corrib, Talt, Gill, Glenade and Nageage in the west and north-west). The remaining five sites, concentrated in the south, are riverine. Rivers include the Aherlow and Multeen (Suir), lower stretches of the Barrow and Nore, and the Awbeg (Munster Blackwater).

MANAGEMENT OF IRISH CRAYFISH STOCKS: POTENTIAL FOR RESTOCKING

Since Irish crayfish stocks are considered the strongest in Europe (REYNOLDS, 1997), owing to relatively high water quality, absence of American crayfish and no tradition of commercial fishing, their potential for use in restocking is high. The genetic close similarity of geographically widely spread crayfish stocks in all Irish lakes and streams so far examined (REYNOLDS *et al.*, 2002) makes the choice of crayfish material for Irish restocking projects relatively simple.

Population surveys (numbers, size, age and gender balance) in relation to determinations of preferred habitats and water quality are needed in order to preserve the Irish stock as a resource for Ireland and the rest of Europe. Only the strongest stocks can safely be used as donor populations.

Since population sizes of most Irish stocks are unknown at present, the availability of « surplus » crayfish for restocking must remain conjectural. If certain crayfish populations are to become « donor » populations, management of the total Irish stock will have to occur. Primary management responsibilities are, first, to establish the current status of Irish crayfish.

Secondly, management measures will have to be put in place to ensure that Irish stocks remain abundant, or that their decline is halted. Such measures include:

- preventative measures against the spores of *A. astaci* entering Irish waterways - mostly through information campaigns for anglers visiting Ireland from places where plague is endemic, and facilities for sterilising recreational fishing gear,

- maintenance of the prohibition on importation of American crayfish. This was established for sanitary reasons, as crayfish outside Ireland have been shown to carry IPN, and it is maintained by EC Trade regulations,

- maintenance and enhancement of habitat for crayfish,

- monitoring of water quality and control of eutrophication in both rivers and lakes.

If stocks are identified which are considered adequate to use as donor, a conservative principle is that crayfish should not be introduced to Irish sites not known to have had crayfish. Although difficult to justify from genetic findings and the knowledge of

widespread human movements of crayfish around Ireland in the past (REYNOLDS, 1979), the principle can be supported by our knowledge of ecosystem impacts of crayfish, particularly in Irish lakes (MATTHEWS *et al.*, 1993).

Management plans are being prepared for every Special Area of Conservation by the National Parks and Wildlife Division of Dúchas, The Heritage Service. Each plan contains a series of conservation objectives and management strategies which strive to maintain and enhance the favourable conservation value of the important habitats and species within the site. Such strategies may have a direct impact on the status of crayfish stocks (*e.g.* restocking) or may act indirectly to improve crayfish habitat (*e.g.* active liaison with local authorities and landowners to reduce water pollution). The plans are drawn up for a five year period and are then subject to review. Annual monitoring programmes are built in to each plan to provide feedback on an ongoing basis for local managers.

Some SACs for crayfish were designated on the basis of old data but recent surveys of the Boyne and Multeen (DEMERS, unpublished) show that these data are no longer reliable. A number of the crayfish SACs lost their stocks during the mid-1980s as a result of crayfish plague (MATTHEWS and REYNOLDS, 1992). In one of these sites, Lough Owel, crayfish have recolonised from feeder streams (P. O'DONNELL, pers. comm.). Where natural re-colonisation of *A. pallipes* has not occurred, reintroduction projects are proposed as part of the management plans for these SACs.

Restocking of Irish SACs from which crayfish have disappeared is thus a management priority. A reintroduction protocol, based on the recommendations of the White Lake Reintroduction Project, will be utilised. This protocol will provide the fundamental information necessary for a successful crayfish reintroduction such as stock numbers, sizes, and male-female ratios, and the selection of appropriate donor populations.

REINTRODUCTION PROTOCOL FOR IRISH LAKES

On the basis of information so far gathered, we have formulated the following protocol for reintroduction of crayfish to Irish lakes. The best strategy for Irish streams is still under review. Other European protocols also involve a check of the proposed reintroduction site for other crayfish species, and holding crayfish in traps or cages on site to check for evidence of plague.

- Examine the host environment,

- check water quality status by biotic indices (BMWP, ASPT and Q indices are widely used in Ireland),

- ascertain physico-chemical suitability, *e.g.* water temperatures, pH and conductivity measurements, availability of cover,

- carry out pre-introduction survey of benthic plants and invertebrates,

- carry out pre-introduction trapping, using 6-10 baited traps set over 2-7 nights, depending on season, to confirm that no crayfish are present. Where appropriate, searches for crayfish exoskeletal remains on the shoreline or in otter or mink spraints, lamp surveys etc. may also be used.

Examining the donor source

When restocking, managers must consider heterozygosity, and hence use adequately large populations to initiate the process. Around 500 are suggested by REYNOLDS *et al.* (2000). A donor population should therefore have the following qualities:

- the population should be strong enough to provide ca. 500 adult crayfish over 3 years,

- crayfish should be healthy, with a low incidence (< 2%) of porcelain disease (*Thelohania* and no other diseases apparent),

- a stream site is likely to have higher heterozygosity than a lake site (REYNOLDS *et al.*, 2002),

- if desired, the genetics of the donor population may be assessed by RAPD analysis without sacrificing animals, by removing one leg from a sample of about 20 crayfish.

The restocking procedure

- Collect 100-200 crayfish in summer, preferably after they have completed the early summer moult. August is best for both females and males,

- measure (carapace length), sex and batch mark with a hot wire for later monitoring,

- introduce crayfish to a selected site with favourable bottom cover, at a water depth of 1-2 m,

- hold introduced crayfish in traps or corrals for a period of 1-4 weeks before release, to assess survival.

Surveillance

While it is not expected that introduced crayfish will be seen in any numbers during the first few years after introduction, the following are recommended:

- the introduced crayfish should be monitored at regular intervals, by diving, trapping or shoreline searches,

- artificial substrates such as bundles of old cans may be useful to attract individuals,

- annual surveillance of the littoral environment should be carried out, paying particular attention to changes in vegetation cover or periphyton film on hard surfaces.

RECENT CRAYFISH INTRODUCTIONS WITHIN IRELAND

There is much circumstantial and anecdotal evidence of humans moving crayfish around the country. Three crayfish introductions are known to the authors, two of which have been documented. In the 1980s, before the species was protected, crayfish were transported from a stream at Borrisokane, Co. Tipperary, to an enclosure in a Co. Clare lake in the Fergus system. Crayfish were previously not known in this catchment (REYNOLDS, 1982), and there is no current information on their survival or success.

Following the outbreak of aphanomycosis plague, introduced probably as spores by visiting anglers around 1985 (REYNOLDS, 1988), there was an almost total loss of crayfish populations from the Boyne catchment (DEMERS and REYNOLDS, 2002) and from some adjacent parts of the lower Shannon catchment. In particular, the well-known lake populations of White Lake, L. Lene and L. Glore were extinguished (MATTHEWS and REYNOLDS, 1992). Lough Lene lake lies in the headwaters of both Boyne and Shannon catchments. Its crayfish became extinct in 1987 and stocks were reintroduced in two phases. In 1989 crayfish were reintroduced by a landowner from unverified local sources. An additional experimental reintroduction took place in 1991 using stocks from an adjacent catchment, the Liffey. Good stocks of crayfish were seen within five years of the second introduction (REYNOLDS and MATTHEWS, 1997).

Following these preliminary experiments, a detailed reintroduction programme was devised for White Lake. This involved genetic examination and selection of stocks from neighbouring systems (Liffey stocks at Blessington Reservoir and at Grand Canal were eventually selected), and a three-year programme of introduction, involving in total 450-500 mature individuals, started in 1999.

In each year, around 150 adult crayfish were introduced. In July of 1999, crayfish were placed into 6 enclosures within the lake, and released three months later, when preliminary estimates of survival, growth and benthic community impacts were made (REYNOLDS *et al.*, 2000). The following summer, monitoring by trapping discovered no crayfish. A second implantation of crayfish was made in August 2000 from the same donor populations, this time directly into the lake. In the summer of 2000, 20 traps deployed for 2 nights again failed to reveal crayfish, and a snorkelling survey at the site of earlier introductions also proved negative. However, a third introduction of mature adults was made in September 2000 and, around the same time, the first evidence of crayfish survival was seen when 20 traps, set about 100 m from the site of reintroduction, captured three large, recently moulted males (C. O'KEEFFE, pers. comm.). If these were from the current year's introduction, their rapid dispersal may explain why introduced crayfish were not previously taken in traps set near the introduction site. The progress of the planted population will be monitored annually.

POTENTIAL FOR USING IRISH STOCKS IN CONTINENTAL EUROPE

Restocking has in the past used crayfish from widely distant areas, as is now evident from the use of genetic markers (SOUTY-GROSSET *et al.*, 1999; GRANDJEAN and SOUTY-GROSSET, 2000). In Portugal, where *A. pallipes* has become extinct, stocks from neighbouring Spain were used in a reintroduction programme (S. BUXELAS, unpublished).

We have noted that the Irish strain of *A. pallipes* is close to those in Great Britain and north-western France, but most similar to certain stocks in Western France (GOUIN *et al.*, 2001). We can therefore hypothesise that Irish stocks might be useful in two continental situations. First, they could be used to restock systems in Western France where the same haplotype is relatively frequent but crayfish are not abundant. Methods using local stocks, such as captive breeding and ranching, should be examined first. If these fail, a pilot project might be developed to test the feasibility of introductions and to examine risks and benefits in detail. This would require finding a site from which populations have been lost, but whose genetic identity is known; evaluating and comparing genotypes of a suitable Irish donor population, and carrying out health studies of Irish donor populations and of the host habitat, including presence of introduced or any residual native crayfish therein, before any reintroduction could begin.

Secondly, their use for restocking elsewhere in the European range of *A. pallipes pallipes* might also be considered, but would need to be treated with extra caution because of their genetic divergence. This could, however, be considered as a last resort for catchments from which native stocks have vanished, and where neighbouring stocks, even if genetically distinct, are too small or sparse to allow adequate volunteers for ranching or restocking. Where crayfish populations have dwindled into extinction, they had probably previously become isolated from one another, limiting gene flow. In addition, genes tested are not « active » and thus do not indicate survival quality. Arguably, then, the genetics of reintroduced stocks may be considered as not of prime importance.

Even if all other conditions are met, restocking of rivers in much of Europe is useless as long as the plague is present. Isolated lakes with no alien species might be possible targets. To keep the plague out of river systems, the identification and development of no-go areas for alien crayfish - as in Britain (HOLDICH and ROGERS, 1997) - would be a first requirement. If restocking of Irish crayfish into France is to be considered, a lot needs to be done in management of alien species and waterways before any reintroduction is attempted. In the meantime, Ireland may be viewed as an offshore reservoir of this species, available should *A. pallipes* continue to decline in Britain and the continent.

CONCLUSIONS

Ongoing studies and experiments with zones of rivers lacking crayfish have shown that *A. pallipes* will tolerate a wider range of freshwater quality situations than currently seen over most of its continental range, where disease and competitors are widespread.

Aphanomycosis has not been detected for some 15 years in Ireland, and several reintroductions of crayfish into their former range have been initially successful.

The white-clawed crayfish is widespread over much of Ireland and some sites may have sufficiently high densities to allow careful harvesting for restocking elsewhere, under certain conditions even outside Ireland.

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REFERENCES

BROWN D.J., BOWLER K., 1977. A population study of the British freshwater crayfish *Austropotamobius pallipes* (Lereboullet). *Freshwater Crayfish*, 3, 33-49.

BYRNE C.F., LYNCH J.M., BRACKEN J.J., 1999. A sampling strategy for stream populations of white clawed crayfish *Austropotamobius pallipes* (Lereboullet) (Crustacea, Astacidae). *Biology and Environment*, *99B (2)*, 89-94.

CARRAL J.M., CALADA J.D., GONZALEZ J., SAEZ-ROYUELA M., GAUDIOSO V.R., FERNANDEZ R., LOPEZ-BAISSON C., 1993. Wild freshwater crayfish populations in Spain: current status and perspectives. *Freshwater Crayfish*, *9*, 158-162.

DAGUERRE DE HEUREAUX N., ROQUEPLO C., 1981. Définition du biotope préférentiel dans l'écrevisse a pattes blanches *Austropotamobius pallipes* dans un ruisseau landais. *Bull. Fr. Pêche Piscic.*, *281*, 211-222.

DEMERS A., REYNOLDS J.D., 2002. A survey of the white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet), and of water quality in two catchments of eastern Ireland. *Bull. Fr. Pêche Piscic.*, *367*, 729-740.

FOSTER J., 1995. Factors affecting the distribution and abundance of the crayfish *Austropotamobius pallipes* (Lereboullet) in Wales and the Marches, UK. *Freshwater Crayfish*, *8*, 78-93.

GIBSON F.A., 1979. An international code of practice and the Irish regulations relating to certain aquatic organisms. *In* : KERNAN R.P., MOONEY O.V., WENT A.E.J. (Eds.), The introduction of exotic species, advantages and problems, 69-72. Royal Irish Academy, Dublin.

GOUIN N., GRANDJEAN F., BOUCHON D., REYNOLDS J.D., SOUTY-GROSSET C., 2001. Population genetic structure of the endangered freshwater crayfish *Austropotamobius pallipes*, assessed using RAPD markers. *Heredity*, *87*, 80-87.

GRANDJEAN F., SOUTY-GROSSET C., 2000. Mitochondrial DNA variation and population genetic structure of the white-clawed crayfish *Austropotamobius pallipes pallipes. Conservation Genetics*, *1*, 309-319.

GRANDJEAN F., GOUIN N., SOUTY-GROSSET C., DIEGUEZ-URIBEONDO J., 2001. Drastic bottlenecks in the endangered crayfish species *Austropotamobius pallipes* in Spain and implications for its colonization history. *Heredity*, *86*, 431-438.

GRANDJEAN F., JOUTEUX R., ROPIQUET A., BACHELIER E., BRAMARD M., 2002. Biological water quality assessment in running waters sites harbouring the endangered crayfish, *Austropotamobius pallipes*, based on macroinvertebrates and its potential in habitat selection for restocking. *Freshwater Crayfish*, *13*, 338-348.

HOLDICH D.M., ROGERS W.D., 1997. The white-clawed crayfish, *Austropotamobius pallipes*, in Great Britain and Ireland with particular reference to its conservation in Great Britain. *Bull. Fr. Pêche Piscic.*, *347*, 597-616.

HOLDICH D.M., ROGERS W.D., 2000. Habitat requirements of the white-clawed crayfish, *Austropotamobius pallipes*. Crayfish Conference Leeds, 109-119.

HOLDICH D.M., ROGERS W.D., REYNOLDS J.D., 1999. Native and alien crayfish in the British Isles, 221-235. *In* : GHERARDI F., HOLDICH D.M. (Eds.), Crayfish in Europe as Alien Species. Balkema, Rotterdam.

LAURENT P.J., 1988. *Austropotamobius pallipes* and *A. torrentium*, with observations on interactions with other species in Europe, 341-364. *In* : HOLDICH D.M. and LOWERY R.S. (Eds.), Freshwater Crayfish: biology, management and exploitation. Croom Helm, London.

LUCEY J., 1999. A chronological account of the crayfish in Ireland. *Bulletin of the Irish Biogeographical Society*, *23*, 143-161.

LUCEY J., MC GARRIGLE M.L., 1986. The distribution of the freshwater crayfish in Ireland. *Irish Fisheries Investigations*, *29A*, 1-13.

LUCEY J., NOWMAN J.J., CLABBY K.J., CUNNINGHAM P., LEHANE M., MAC CARTHAIGH M., MC GARRIGLE M.L., TONER P.F., 1999. Water quality in Ireland 1995-1997. EPA, Ireland.

LYNCH J.M., MURRAY D.A., 1992. Fishery rehabilitation and habitat enhancement following arterial drainage in Ireland. *Verh. Internat. Verein. Limnol.*, *25*, 1502-1503.

MATTHEWS M., REYNOLDS J.D., 1990. Laboratory investigations of the pathogenicity of *Aphanomyces astaci* for Irish freshwater crayfish. *Hydrobiologia*, *203*, 121-126.

MATTHEWS M., REYNOLDS J.D., 1992. Ecological impact of crayfish plague in Ireland. *Hydrobiologia*, *234*, 1-6.

MATTHEWS M.A., REYNOLDS J.D., KEATINGE M.J., 1993. Macrophyte reduction and benthic community alteration by the crayfish *Austropotamobius pallipes* (Lereboullet). *Freshwater Crayfish*, *9*, 289-299.

MC CARTHY D.T., 1977. The effects of drainage in the Tremblestown River. 1. Benthic invertebrates and flora. *Irish Fisheries Investigations*, *A16*, 1-17.

NAURA M., ROBINSON M., 1998. Principles of using River Habitat Survey to predict the distribution of aquatic species: an example applied to the white-clawed crayfish, *Austropotamobius pallipes*. *Aquatic Conservation; Marine and Freshwater Ecosystems*, *8*, 515-527.

NEVEU A., 2000. Etude des populations *d'Austropotamobius pallipes* (Crustacea, Astacidae) dans un ruisseau forestier de Normandie. II. Répartition en fonction de la structure des habitats : stabilité et variabilité au cours de cinq années. *Bull. Fr. Pêche Piscic.*, *356*, 99-122.

O'KEEFFE C., 1986. The ecology of two populations of the freshwater crayfish, *Austropotamobius pallipes* (Lereboullet), in Ireland. PhD Thesis, University of Dublin.

O'KEEFFE C., REYNOLDS J.D., 1983. The occurrence of crayfish diseases and their significance in Ireland. *Freshwater Crayfish*, *5*, 299-307.

REYNOLDS J.D., 1979. Crayfish ecology in Ireland. *Freshwater Crayfish*, *4*, 215-220.

REYNOLDS J.D., 1982. Notes on the Irish distribution of the freshwater crayfish. *Bulletin of the Irish Biogeographical Society*, *6*, 18-24.

REYNOLDS J.D., 1988. Crayfish extinctions and crayfish plague in Ireland. *Biological Conservation*, *45*, 279-285.

REYNOLDS J.D., 1997. The present status of the freshwater crayfish in Ireland. *Bull. Fr. Pêche Piscic.*, *347*, 693-700.

REYNOLDS J.D., 1998. Conservation management of the white-clawed crayfish *Austropotamobius pallipes* Part 1. Irish Wildlife Manuals, No. 1. Dúchas The Heritage Service, Dublin.

REYNOLDS J.D., MATTHEWS M.A., 1993. Experimental fishing of *Austropotamobius pallipes* in an Irish midlands lake. *Freshwater Crayfish*, *9*, 147-153.

REYNOLDS J.D., MATTHEWS M.A., 1995. Conservation strategies for the Irish freshwater crayfish. *In* : REYNOLDS J.D. (ed.), The conservation of Aquatic Systems, Dublin, Royal Irish Academy, 151-155.

REYNOLDS J.D., MATTHEWS M.M., 1997. Successful reintroduction of crayfish to Irish lake. *Crayfish News: IAA Newsletter*, *19 (2)*, 4-5.

REYNOLDS J.D., SOUTY-GROSSET C., GOUIN N., DEVANEY S., GRANDJEAN F., 2000. Experimental restocking of native crayfish in White Lake, Co. Westmeath, Ireland. Crayfish Conference Leeds, ROGERS D., BRICKLAND J. (Eds.), 123-130.

REYNOLDS J.D., GOUIN N., PAIN S., GRANDJEAN F., DEMERS A., SOUTY-GROSSET C., 2002. Irish crayfish populations: ecological survey and preliminary genetic findings. *Freshwater Crayfish*, *13*, 551-561.

SMITH G.R.T., LEARNER M.A., SLATER F.M., FOSTER J., 1996. Habitat features important for the conservation of the native crayfish, *Austropotamobius pallipes* in Britain. *Biological Conservation*, *75*, 239-246.

SOUTY-GROSSET C., GRANDJEAN F., GOUIN N., 1999. Molecular genetic contributions to conservation biology of the European Native Crayfish *Austropotamobius pallipes*. *Freshwater Crayfish*, *12*, 371-386.

THOMPSON W., 1843. On the Crustacea of Ireland – *Astacus fluviatilis*. *Annals and Magazine of Natural History*, *11*, 106-108.

UNESTAM T., 1974. The dangers of introducing new crayfish species. *Freshwater Crayfish*, *2*, 557-561.