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SERIES OF ECOLOGICAL ASSESSMENTS ON ARTERIAL DRAINAGE MAINTENANCE No 10

Ecological Impact Assessment (EcIA) of The Effects of Statutory Arterial Drainage Maintenance Activities on White-clawed Crayfish *(Austropotamobius pallipes)*

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Disclaimer

Foreword

This Ecological Impact Assessment follows on from the strategic approach outlined in "**Series of Ecological Assessment on Arterial Drainage Maintenance No. 1: Screening of NATURA 2000 Sites for Impacts of Arterial Drainage Maintenance Operations.**"

It examines the impacts of statutory arterial drainage maintenance activities on white-clawed crayfish *(Austropotamobius pallipes)*, outlines measures to mitigate any negative impacts, and possible enhancement opportunities.

Environment Section

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1. Remit

In 2005 the Office of Public Works Drainage Division commissioned the Central Fisheries Board to undertake a two-year study to examine impacts of OPW's channel maintenance programme on two Habitats Directive Annex II taxonomic groups, the lamprey species and the white-clawed crayfish.

The study was intended to undertake field studies and collect pre- and post-maintenance data sets on populations of the target organisms with a view to assessing impacts and identifying mitigation measures.

One of the deliverables from this commission involved the compilation of Ecological Impact Assessments (EcIAs) on each of the target groups. The present document deals with the white-clawed crayfish. The document is broadly structured in the same manner as earlier EcIAs submitted to OPW and published in its "Series of Ecological Assessments on Arterial Drainage Maintenance".

2. Executive Summary

- Both immature and adult crayfish co-occur in river and lake habitats. Adults may be found in open-water river locations associated with physical habitat capable of providing cover. Juvenile crayfish may be more commonly associated with basal areas and root wads of plants.
- The crayfish species found in Ireland (*Austropotamobius pallipes* Lereboullet) is recognised as an Annex II species under the Habitats Directive and Special Areas of Conservation (SACs) have been designated for it.
- Some crayfish SACs occur in catchments subject to arterial drainage and ongoing maintenance by the Office of Public Works (OPW).
- Channel maintenance is an ongoing requirement under the1945 Arterial Drainage Act.
- Channel maintenance involves removing features that are or may interfere with the design conveyance of a channel e.g. siltation, instream growth of a range of vegetation types, growth of trees within the channel cross-section.
- Crayfish have been shown to be widely distributed in channels maintained by OPW, both inside and outside SACs with maintenance on many of the arterially drained channels ongoing since the early 1950s.
- Channel maintenance may lead to physical removal of individual crayfish from a channel as well as removal of habitat used by crayfish.
- A series of case histories presented below indicated, generally, a decrease in crayfish numbers 12 months after maintenance.
- One study found a decrease in crayfish numbers after a 12-month period with no maintenance having been carried out on the channel.
- The literature indicates that crayfish populations can fluctuate, particularly due to disease such as crayfish plague.
- Two short-term studies, over a four-month period, did not detect any initial decrease in crayfish numbers or population structure immediately after summer maintenance. Repeat surveys in early autumn showed a sharp decline, suggesting habitat loss, rather than mortality due to works, as a key factor.

- One study below did not identify any change in crayfish populations after maintenance. This may be a consequence of implementation of the OPW's 10-point environmental training programme.
- A range of mitigation measures is proposed.
- Mitigations include more long- and medium-term strategic measures centred on (a) an on-going survey programme to map crayfish presence and status and (b) creating a GIS-based platform of knowledge on locations of significant areas of habitat and population of lampreys in individual OPW channels.
- A series of operational measures are also proposed.
- The bottom line is the potential for maintenance to impact on crayfish populations and habitat in almost any channel of OPW's arterial drainage scheme networks in which crayfish occur.

3. Introduction

3.1. Historical Background and functions of statutory arterial drainage maintenance

This matter was reviewed, in an Irish context, by King (1996). River channelisation programmes are designed primarily to offset flooding of urban and rural areas and to enhance the productive value of agricultural land (Hockin 1985). Channelisation is also used to enhance navigation and for the floating of timber. Schoof (1980) quotes a figure of 300,000 km of channel channelised in the USA over a period of 150 years. Brookes (1987) describes the widespread effects of man on river channels in Denmark, to the extent that few 'natural' or unaltered channel segments now exist. A primary aim of channelisation in Ireland, where it is generally referred to as arterial drainage, is to enhance the incomes of landholders whose lands are affected by drainage or flooding problems. Other objectives include the provision of employment and flood prevention and drainage of urban areas, public roads and bogs (Howard 1980).

Drainage schemes alter the network of streams and rivers in the affected area to enhance their conveyance capacity. The topography of Ireland, with many mountainous areas around the perimeter and a flat central plain, creates a situation where many rivers discharge to the centre of the country with low-gradient flood plains (O'Flynn 1932, Lynn 1980) and extensive areas of flat and low-lying ground. Gardiner and Radford (1980) reported that 21% of agricultural land in Ireland contained wet mineral soils, which required drainage to improve their value and potential. Schemes carried out under the 1945 Act were generally designed to allow protection for a minimum of the three-year flood event in addition to creating an outfall for drainage of the adjoining lands. Where the creation of an outfall dictated the design bed levels, greater protection than the three-year flood event would have been achieved as a consequence. (Gilligan & Dooley 2007).
The Q3 or 3-year flood return design criterion in Irish arterial drainage schemes since 1945 reduces flood incidence in the cropping season to one in *circa* 15 years (Ryan 1986).

The first Act of Parliament relating to drainage in Ireland was passed in 1842 and was followed by a number of other Acts up to 1945. A large number of small drainage schemes were carried out under these Acts, but on a piece-meal basis. Many schemes fell into disrepair due to lack of maintenance and some Acts were passed simply to allow for the refurbishment of derelict schemes (Lynn 1980). Current arterial drainage practice in Ireland is largely regulated by the 1945 Arterial Drainage Act (Eire 1945). The important features of this Act were that (i) schemes were based on a holistic or river catchment basis rather than on the previous segmented approach, (ii) the Office of Public Works became responsible for the design and implementation of schemes, (iii) maintenance was to be carried out by the Office of Public Works and (iv) the cost (of same) to be recouped from the County Councils of the counties containing the benefiting land (Funded directly by OPW since the late Seventies). The first major scheme under this Act was initiated in the Brosna Catchment in 1948. Up to 1980, 34 schemes had been completed, accounting for the improvement of 200,000 ha of lands suffering from water logging and flooding (Lynn *op. cit.*). Ryan (1986) summarised the impacts of the 1945 Act as (i) leading to an end to piecemeal drainage and (ii) the protection of the capital investment by ensuring that maintenance would be carried out on a regular basis to an adequate standard.

Major urban flooding events in the mid 1990's identified limitations in the state's capacity to deal with these issues. The OPW was obligated to carry out channel management on a catchment basis, whereas the flooding events were occurring at particular pinch points. To overcome such legal issues, new legislation was introduced in 1995 permitting OPW to carry out engineering works for flood relief on a localized basis.

3.2 Legal and policy context for this ecological assessment

Since 1990 the Central Fisheries Board (CFB) has been engaged in studies, commissioned by OPW, designed to examine the impact of maintenance processes on fish and the fisheries habitat and to examine the feasibility, conveyance benefit and ecological value of alternative strategies that may be adapted in maintenance. These studies were undertaken under the Environmental Drainage Maintenance (EDM)

programme (King 1996, King et al 2000). These developments have occurred at a time of major change in emphasis in regard to environmental protection and land management practises, with greater awareness of the sensitivity of the environment and need to conserve biodiversity. The Habitats Directive and Water Framework Directive, at EU level, and the National Biodiversity Plan have all served to heighten environmental obligations and have created a framework for organisations to examine the impacts of their work practises on the environment and to comply with guidelines or legal obligations. Conscious of this and of the potential for its (OPW) work practises to impact adversely on the environment of the river corridor, OPW adopted a new suite of channel maintenance practises designed to reduce environmental impact and, where appropriate, to provide habitat enhancement in the course of its river maintenance work. The implementation of this new policy involved training provision to OPW's team of field staff throughout the country based on the experience and findings of the EDM programme. Follow-up involved individual site visits to machine crews (2 persons) and their foreman by CFB. By the end of 2005, *circa* all of the seventy machine crews had been visited by CFB personnel.

Looking forward, OPW was conscious of the requirements of agencies in working within 'conservation areas' designated by the National Parks and Wildlife Service (NPWS). Such areas might include Special Areas of Conservation (SACs) designated under the Habitats Directive and Special Protection Areas (SPAs) under the Birds Directive as well as areas designated under national legislation. Some of the species listed in Annex II of the Habitats Directive, and thus requiring designation of SACs for their conservation, also enjoy protection under national legislation.

The OPW have set out in the report "Screening of Natura 2000 Sites for Impacts of Arterial Drainage Maintenance Operations a strategic approach to managing the requirement for environmental assessments in European Sites. The report selects the conservation aspects that have a realistic potential of being significantly impacted upon by drainage maintenance works. It identifies conservation aspects that warrant further consideration and envisages that the resultant assessments by conservation aspect will be

carried out in the form of a multi annual programme. Thus, a series of national studies was proposed, as outlined in OPW's Screening Report (Gilligan and Dooley 2007).

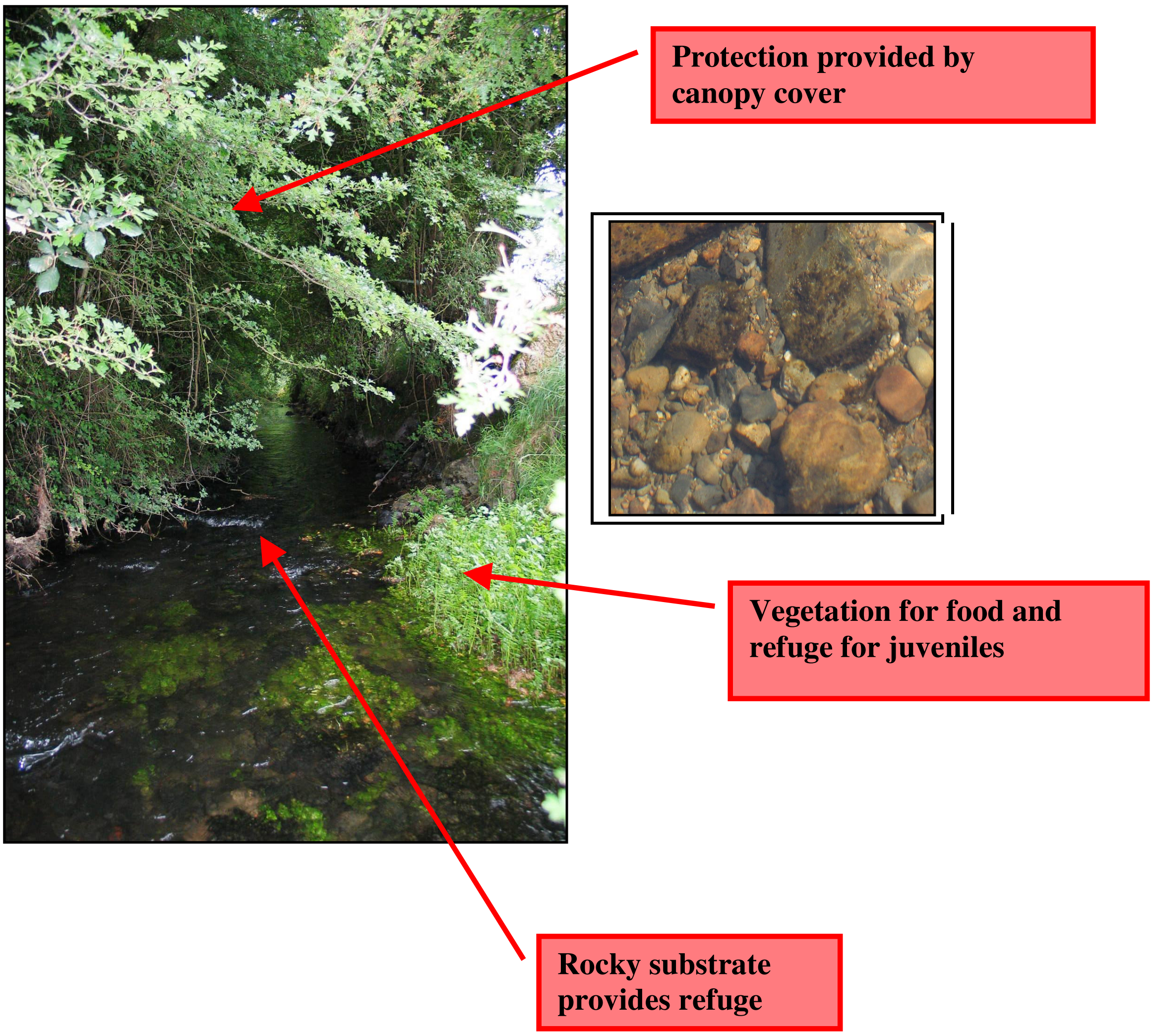
3.3 Crayfish (*Austropotamobius pallipes* Lereboullet) ecology and Irish investigations

There are three indigenous crayfish species reported for Europe; *Austropotamobius pallipes* occupies the Western and Southern areas of Europe; *Astacus astacus* is found in Northern Europe and *Austropotamobius torrentium* is a species from the circum alpine region (Souty-Grosset 2005). Most countries contain a number of crayfish species; only three European countries, including Ireland, retain a single crayfish species. Crayfish in Ireland are represented by *Austropotamobius pallipes*, commonly called the White Clawed Crayfish. Genetic research indicates that *A. pallipes* is derived from an introduced French crayfish stock (Reynolds *et al.* 2002). One of the strongest populations of white-clawed crayfish in Europe is found in Ireland (Reynolds 1997; Souty-Grosset 2005), although the size of the crayfish stocks is widely unknown (Reynolds *et al.* 2002).

Different size classes of *Austropotamobius pallipes*.

On average crayfish live to ten years of age and adults are usually less than 10cm in total length (Brewis & Bowler 1982; Holdich 2003). After 3 or more years they reach sexual

maturity (Hogger & Lowery 1982), at carapace length >22mm and >25mm for males and females respectively (Pratten 1980; Brewis & Bowler 1983; Lowery 1988; Robinson *et al.* 2000). Crayfish grow via moulting, a process by which they shed their hard exoskeleton. During this period they are most vulnerable to predators. Factors affecting growth include water temperature, reproductive activity and food supply. Moulting rates fluctuate throughout their life cycle. As adults mature, females moult less frequently than males due to energy involved in reproduction (Brewis & Bowler 1982).



White clawed crayfish characteristically occur in fast and slow flowing, clean, alkaline channels, strongly linked to carboniferous limestone geology (Hynes 1970; Reynolds

1978; Jay & Holdich 1981; Lucey & McGarrigle 1987). They are considered to favour rocky sections of channel with shelter and food sources, often along river margins. However, studies associated with this EcIA found crayfish populations of substantial size in a number of clay-bed channels with heavy instream growth of *Sparganium erectum* (Lordan et al 2008). Crayfish are opportunistic feeders and eat a 'varied diet including oligochaetes, fish and vegetation' (O'Keeffe 1986).
Crayfish are most active at night, seeking refuge under rocks, in crevices and burrowing into clay banks during the day. The habitat of juvenile crayfish differs from adults and they are often found among the fibrous roots of aquatic plants.

Crayfish are known to occur in streams, rivers and lakes across Carboniferous Limestone areas of Ireland. However, detailed information on the distribution, population structure and density of crayfish in Ireland is limited. While crayfish populations are widespread, Reynolds *et al.* (2002) reported that stocks were absent from most of the south-west, from the acid coastal fringe of hills, and from Northern Ireland outside the Erne system. Where populations are present, crayfish occupy streams and smaller lakes below 220m in altitude (Reynolds 1998; Reynolds *et al.* 2002).

In Ireland research has taken place predominantly on lake populations of crayfish and animals have been recorded in Lough Lene, Co. Westmeath; (Reynolds 1988; Matthews and Reynolds 1992; Matthews *et al.* 1993; Demers & Reynolds 2002); White Lake Co. Monaghan (Moriarty 1973), Loughs Carra, Corrib, Gowna, Carrigaport Lake and Lough Ree (Reynolds 1982) and Blessington Reservoir, Co. Wicklow (Matthews and Reynolds 1995). Moriarty (1963) recorded crayfish presence in the Poulaphouca Reservoir

Lucey *et al.* (1987) provide a comprehensive overview of crayfish distribution in a range of catchments. Stream populations have been identified on the Sinking River, the Abbert, Dalgan, Grange, Robe, R. Suir, Clodiagh, Loobagh and Morningstar (Lucey *et al.* 1987). Sites recorded positive for crayfish were recorded on Brittas R. (O'Keeffe & Reynolds 1982) and the R. Nore (O'Keeffe 1986) including sites on the Castlecomer, Dinin and Muckalee rivers (Lucey *et al.* 1987). Records exist from the R. Clare (Mc Fadden &

Fairley 1984), Westport R. (Lucey *et al.* 1987) and the Erkina and Goul (Byrne 1999). Lucey *et al.* (1987) have also listed a series of major tributaries of the Moy with crayfish. These included the Glore, Owengarve, Sonnagh, Swinford and Yellow in the east of the catchment and the Castlebar, Manulla, and the R. Deel in the western area. Crayfish were identified on the R. Erne and six of its tributaries as well as in the main-stem upper reaches of the Shannon and twenty two of its tributaries (Lucey *et al.* 1987). O'Keeffe (1986) and Demers *et al.* (2002) had studies of crayfish from the R. Liffey and crayfish were also recorded in two of it tributaries, the Morrell and Rye Water. Crayfish presence was recorded as widespread on the Boyne Catchment (Demers *et al.* 2002). Positive sites were identified on the Athboy (Trimblestown), Blackwater, Kells Blackwater, Castlejordan, Deel, Knightsbrook and Moynalty (Reynolds 1982; Lucey *et al.* 1987; Demers et al 2002). Demers (2001) and Lucey *et al.* (1987) recorded crayfish on the R. Barrow. Along the southern belt from Dungarvan to Dingle crayfish records are scare and have only been recorded in the Awbeg (Lucey *et al.* 1987). A comprehensive survey of crayfish distribution in OPW-managed channels of the Inny catchment was undertaken by Lordan et al (2008).

Water quality, nutrient levels, flow regime, riparian habitat, level of disturbance, presence or absence of threats are all attributes that can affect this riverine species (Peay 2004). The greatest threats to populations of *A. pallipes* in Ireland include habitat destruction, pollution and the introduction of crayfish diseases such as crayfish plague (*Aphanomyces astaci*) and porcelain disease.

3.4 Objective and scope of the study

Within the ambit of the EDM Programme, CFB had begun studies to examine the impacts of maintenance on the Annex II Habitats Directive taxa – the lamprey species and the White-clawed crayfish. The importance of this work was further highlighted when OPW commissioned additional studies to focus on these target groups over a two-year period (2005 – 2007). The deliverables from this project were:

- Compilation of Ecological Impact Assessments (EcIAs)
- Identification of locations of populations of the species
- Identification of typical habitats
- Identification of cost-effective and practical mitigation measures
- Identification of enhancement measures where feasible and applicable

The background context to this assessment is as follows:

- OPW continues to have an obligation to maintain channels that now lie within SACs.

- Some of these SACs are designated for species that may be directly impacted by maintenance operations.

- OPW, in carrying out arterial drainage maintenance activities within or adjacent to Natura 2000 sites, must have regard for the objective, under the Habitats Directive and the Wildlife Act, of maintaining the favourable ecological status of Annex II species.

- The assessment examines the extent of potential geographic impact, range of maintenance activities that may impact on the different life-history stages of the species in question, assesses potential impacts and identifies appropriate channel management strategies that are consistent with conserving the ecological status of the target species.

- In the present case, the target species is the White clawed crayfish, *Austropotamobius pallipes* Lereboullet.

4. Special Areas of Conservation

Special Areas of Conservation (SACs) are established by EU member states under the Habitats Directive. These are defined as areas within which the conservation status of the species or habitat, for which the designation is made, is retained at a favourable conservation level. Within the Republic of Ireland, SAC designations are generally made, for an area, in respect of a range of qualifying interests. Thus a geographical area may be delineated as an SAC in respect of a range of habitat types listed in Annex I of the Directive as well as a range of species of plants and animals listed in Annex II.

Those SACs with areal overlaps into OPW arterial drainage schemes are tabulated, with qualifying interests, in the OPW's Screening Report (Gilligan and Dooley 2007). In the case of the white-clawed crayfish, a total of 8 SACs, listed by National Parks and Wildlife Service (NPWS), have a spatial overlap with OPW arterial drainage schemes. Some of these are entirely lacustrine – as in L. Lene, White Lough-Ben Lough-Lough Doo and Lough Bane-Lough Glass – and these waters are not likely to experience any direct mechanical impact of OPW maintenance work. Any maintenance scheduled on channels flowing into these waters lay lead to increased siltation to the lakes. Such siltation is likely to settle out rapidly under lake conditions. Given the upland and headwater locations of many of these waters it is not considered likely that any major maintenance impacts will accrue due to upstream works. In contrast, the remaining five SACs constitute large riverine catchments, including the Moy, Suir, Barrow-Nore and the lake-river systems of Lough Corrib and Lough Gill.

Site Code 0297 Lough Corrib: This SAC includes the entire lake as well as a number of tributary catchments. Many of the latter have been arterially drained as part of the Corrib-Clare or Corrib-Headford schemes. Principal of these are the R. Clare and its large tributary channels in the east of the catchment, all of which form part of the OPW's Corrib-Clare Drainage Scheme. A number of smaller channels discharging directly to the

lake, including the Black River on the east side and the Oughterard River on the western shore, constitute part of the OPW's Corrib-Headford Drainage Scheme.

White-clawed crayfish is considered widespread in L. Corrib and in the inflowing rivers coming off limestone i.e. those rivers discharging along the eastern shore. The majority of these rivers form part of the Corrib Clare drainage scheme undertaken by OPW. Reynolds (1982) reported crayfish in Loughs Carra and Corrib while Lucey *et al.* (1987) provide a comprehensive overview of crayfish distribution in the R.Clare system. These included populations in the Abbert, Dalgan, Grange and Sinking River. Records also exist from the R. Clare (Mc Fadden & Fairley 1984) in the context of otter feeding studies.

Site Code 1810 White Lough, Ben Loughs and Lough Doo: This SAC is designated primarily in terms of the Annex I habitat type – typifying hardwater, calacareous lakes. The lakes have also been designated for white-clawed crayfish.

While the lakes lie within the OPW's Boyne Arterial Drainage Scheme it is not considered that channel maintenance would impact on these waters. Thus no adverse impact on crayfish, arising from channel maintenance, would be anticipated within this SAC.

Site Code 1976 Lough Gill: In addition to the white-clawed crayfish, this SAC has been designated in respect of all three lamprey taxa, Atlantic salmon and otter. As well as L. Gill, the SAC includes the inflowing R. Bonet upstream to its outfall from Glenade Lake. The Bonet has been arterially drained by OPW, with work being completed in the early 1990's. Maintenance is undertaken annually in the channels included in the scheme.

Site Code 2120 Lough Bane and Lough Glass: This SAC is designated primarily in terms of the Annex I habitat type – typifying hard water, calcareous lakes with vegetation of *Chara* species. The lakes have also been designated for white-clawed crayfish. Lough

Bane held a substantial crayfish population but this was eliminated by a fungal plague of *Aphanomyces astacii* in the 1980's. NPWS propose to re-introduce *Austropotamobius* into Lough Bane (NPWS website www.npws.ie/ 29.11.2008)
The lakes lie within the OPW's Boyne Arterial Drainage Scheme and the outflow of Lough Bane forms the source of the R. Deel. It is not considered that channel maintenance would impact on these waters. Thus no adverse impact on crayfish populations in the lakes, arising from channel maintenance, would be anticipated in this lacustrine SAC.

Site Code 2121 Lough Lene: This SAC is designated primarily in terms of the Annex I habitat type – typifying hard water, calcareous lakes with vegetation of *Chara* species. The lake has also been designated for white-clawed crayfish and has been extensively studied for this taxon (Reynolds 1988; Matthews and Reynolds 1992; Matthews *et al.* 1993; Demers & Reynolds 2002). Lough Lene held a substantial crayfish population but this was eliminated by a fungal plague of *Aphanomyces astacii* in the 1980's. It was reintroduced by NPWS and a breeding population was confirmed in 1995. This has since experienced a further infestation of crayfish plague and the white-clawed crayfish has again been eliminated (NPWS website www.npws.ie/ 29.11.2008).
Small tributary channels to the lake undergo maintenance by OPW. However, it is not considered that channel maintenance would impact on these waters. Thus no adverse impact on crayfish populations in the lake, arising from channel maintenance, would be anticipated in this lacustrine SAC.

Site Code 2137 Lower River Suir: This SAC covers the main stem upriver to Thurles and many of the larger tributaries. The sole area of OPW activity is at Carrick-on-Suir at the head of the tide, where a flood relief scheme was completed in the early part of this decade. That programme consisted principally of floodwall and embankment construction, with no instream works in the R. Suir and no maintenance requirement in the main channel. OPW is currently developing a flood relief programme for Clonmel,

on the R. Suir. The current flood relief works and designs for Clonmel involve a similar strategy to that used in Carrick-on-Suir, with no inchannel works.

It is not considered that OPW maintenance works would impact adversely on the status of crayfish within this SAC.

Site Code 2162 River Barrow and Nore: This SAC covers the main stem of the Barrow and Nore as well as major tributaries in both systems. The sole area of OPW activity is at Kilkenny where a major flood relief scheme was completed in the early part of this decade. That programme consisted of floodwall and embankment construction as well as major instream works of widening and deepening. There will be some on-going maintenance requirement. A pre-flood scheme survey of white-clawed crayfish in the R. Nore in the general area to be impacted by the flood relief scheme yielded negative results at most sampling stations (Mary Kelly-Quinn personal communication).

Site Code 2298 River Moy: This SAC encompasses almost all of the main stem and major tributaries of the R. Moy as well as L. Conn and L. Cullin. In addition to the white-clawed crayfish, this SAC is designated for both Sea- and Brook lamprey, Atlantic salmon and otter. The entire catchment was drained as part of the Moy CDS by OPW and ongoing maintenance takes place.

Lucey *et al.* (1987) listed a series of major tributaries of the Moy in which crayfish were recorded. These included the Glore, Owengarve, Sonnagh, Swinford and Yellow in the east of the catchment and the Castlebar, Manulla, and the R. Deel in the western area.

5. Maintenance Activities carried out by OPW

The 1945 Arterial Drainage Act deems that channels within drainage schemes should be retained "..in proper repair and effective condition….". In theory, this could mean that maintenance on channels could revert a recovering or naturalising watercourse back to its immediate post-scheme appearance with perfectly-formed trapezoidal cross-section, removal of any instream features or obstructions, removal of any tree growth within the cross-section and bankslopes devoid of plant cover.

Drained channels have extended segments of uniform character and maintenance is intended to retain the hydraulic capacity of channels by removing depositions and obstructions within the cross-section. Sediment transport and deposition can facilitate vegetation growth, both marginal and instream. This growth can, in turn, facilitate a cycle of further silt accretion and plant growth. Such developments can create an elevated water level for a particular flow discharge, increasing the potential for bank overtopping in summer flood conditions. Removal of such obstructions lowers the water surface level for the same volume discharge and serves to facilitate land drainage outfall works. Tree growth within the cross-section can also serve to impede flood flow or create an elevated flow level for a particular volume discharge. Both instream and marginal vegetation, as well as tree cover, contribute to the biodiversity of the river corridor as an ecological unit.

The scale of the OPW's national remit in respect of channel maintenance has been outlined in its Screening Report (Gilligan and Dooley 2007) and includes maintenance work on channels, structures and embankments. The changed climate of environmental awareness, reflected in the series of environmental Directives from the European Union, and major developments in machinery technology have facilitated significant changes in OPW's channel maintenance activities. Coupled with these have been changes away from whole-catchment arterial drainage and the emergence of a senior corps of engineers empowered to work in a partnership type approach, as one of several river corridor stakeholders, rather than in the older more one-track approach. The requirement for a

greater balance between conveyance requirements and wildlife or river corridor concerns was a key theme in the training course on environmentally-sensitive work practises delivered to OPW staff in 2002-03.

OPW's three Maintenance Regions generate annual programmes detailing proposed lists of channels scheduled for maintenance. These are finalised and circulated to relevant stakeholders in the first weeks of each year. The programmes contain GIS-based maps as well as the lists, showing clearly the channels, or channel segments proposed for works. These documents form a basis for consultation with major stakeholders, particularly the Regional Fisheries Boards and Divisional staff with the National Parks and Wildlife Service. The consultation facilitates specifying of timescales and windows in respect of particular channels, as well as flagging additional environmental opportunities for 'enhancement' e.g. fisheries instream enhancement work, while maintenance may be underway.

Important elements that inform OPW's current maintenance approach include:

- Replacement of dragline machines with long-reach hydraulic machinery

- Deployment of a fleet of hydraulic excavators, giving drivers full control of the machine bucket at all stages of extension and retrieve

- Bringing specialist excavator 'bolt-ons' into use as these come on-stream – including specialist weed-cutting buckets and tree-management jibs

- Dividing long channels into a series of segments, with successive segments done in annual sequences

- Compliance with environmental windows for working – including salmon and trout spawning windows in winter-spring and bird nesting windows in spring-summer

- Implementation of the ten-point environmentally-sensitive training programme as a Standard Operating Procedure (SOP) in channel maintenance

- Circulation of annual maintenance programmes to key stakeholders

- Regular meetings with key stakeholders to preview scheduled maintenance work
- Environmental River Enhancement Programme 2008 – 2012 (EREP
    1. Capital Enhancement and enhanced maintenance of channels targeting 100km annually – focus is on salmonid enhancement. Coupled with pre and post biodiversity and hydromorphological assessments.
    2. Environmental Training for machine operators and outdoor staff (Training provided in 2002/2003. New training programme being developed and being rolled out in late 2009 early 2010)
    3. Ongoing environmental studies - focusing on Lamprey & Crayfish presently.

6. Maintenance impacts on life-history stages of crayfish

This chapter is divided into three parts. The first provides a rapid overview of likely impacts on white-clawed crayfish, given the ecology and life history (Holdich 2003) and involves terminology used to describe the nature and extent of impact in Environmental Impact studies (IEEM 2006). The second part provides a more detailed commentary on potential maintenance interactions with life stages and the final part presents results from case studies in Irish arterially-drained channels undertaken in the context of this study.

6.1 An overview of potential impacts

Terms in italics below are those used in IEEM (2006) to describe potential impacts in Ecological Impact Assessment studies. Maintenance work may involve impacting on a range of features on the river corridor. The nature and magnitude of works may depend on the current habitat status relative to its interaction with conveyance requirements and on the time interval since previous maintenance. The type of maintenance works undertaken by OPW has been outlined in Chapter 5 and may involve such impacts as bankside removal of tree cover; instream removal of heavy blanketing of water celery-type vegetation and of tall emergent plants; removal of instream silt banks and of marginal areas of cover. The outline of crayfish ecology (Section 3.3) points to the capacity of the white-clawed crayfish to occur in a wide range of channel types, given appropriate water chemistry, and to utilize a wide range of niches for cover and foraging. In view of this cosmopolitan capacity there is considerable potential for channel maintenance to impact on habitat types of value to crayfish and, thus, for maintenance to be potentially *negative.*

Maintenance work can, potentially, remove both habitat and crayfish and may be of substantial *magnitude* over an *extensive* area in the channel being maintained. The direct impact will be in the habitat of the wetted channel. However, removal of tree cover will diminish shading and may expose the site to predators such as the heron. The magnitude of maintenance impact may be exacerbated if substantial numbers of juveniles are lost as

a consequence of maintenance operations. The *duration* of impact may also be substantial, as both habitat features and potential occupants are required to redress the initial negative impact. The *duration* of the maintenance work in any channel may be circumscribed – with many large channels divided up into sequential segments and maintenance proceeding in one direction with annual selection of the next or following segment. This approach may reduce or constrain impact.

Timing and *frequency* of maintenance can be managed, for many species, with timing commonly being linked to permissible environmental windows. However, in the case of *Austropotamobius,* breeding occurs in autumn (Holdich 2003) and females overwinter with a clutch of eggs attached to their abdomen. These are released in the June – August period, depending on latitude. Thus mature females may be involved in some stage of the reproductive cycle virtually all year. In such circumstances it may be impossible to arrange *timing* of maintenance to avoid the period when females are carrying young. While *frequency* of maintenance is related to a cycle of multiple years on many channels, some waters may receive annual maintenance. Such frequency may militate adversely against crayfish, as any habitats may be of very temporary or tentative nature. This may be particularly so in water celery channels, some of which can carry substantial crayfish populations actively using the plant cover (see 6.3. below).

Impacts may be considered to be *reversible*. However, a substantial time scale may be involved both to permit the habitat to recover, facilitating crayfish use, and for crayfish populations to build up again following any negative maintenance impact on population size or on specific life stages or age groups. Given that crayfish may require 3 -4 years to reach sexual maturity, any recovery of population in a site may require survival or immigration of mature adult crayfish.

6.2 River engineering works and crayfish life history stages

The OPW arterial drainage maintenance programme can cause disturbances to a range of elements in the river corridors that are significant to stages of the crayfish life cycle. Adult crayfish occupy a wide variety of habitats from fast flowing rocky habitats to slow flowing soft substrates. Water quality, nutrient levels, flow regime, riparian habitat, level of disturbance, presence or absence of threats are all attributes that can affect crayfish (Peay 2004). It is not easy to predict where *A. Pallipes* will be found due to the localised nature of crayfish populations along and between channels. Once a river section has been identified as possessing good crayfish populations efforts should be made to protect this Annex II species.

Juvenile crayfish: The timing and release of crayfish young varies upon the habitat characteristics. Fertilised eggs will hatch in 2 to 20 weeks depending upon water temperature. Once hatched, juveniles remain attached to the underside of the females' abdomen until after their second moult. During this period juveniles are extremely dependant upon the reproductive females for food and protection. If there is any disturbance to the channel or destruction of refuges it could cause the female to loose the eggs/juveniles.

Unsexed juveniles (0+ and 1+) have carapace lengths <13mm (Brewis & Bowler 1982). Free-swimming immature juveniles become sexually identifiable with carapace lengths in the range of 11mm to 25mm. Once removed from the channels, juvenile crayfish are exposed on spoil heaps and die from exposure or predation. Additionally, the removal of instream vegetation will result in a decrease in the habitat available for the juvenile crayfish that remain along this section of channel.

Adult crayfish: Arterial drainage maintenance works can impact on crayfish populations in two main ways – directly or indirectly. Firstly, individuals may be killed or mortally injured while the bucket works along the channel bed, removing and disturbing rock and

substrate. In addition, crayfish may be caught in the machine bucket and deposited on the bankfull area. Here they have little chance of making their way back to the channel and are often buried alive by overlying sediment, rock and vegetation removed from the channel. Individuals that do make it to the surface desiccate once out of water or are eaten by birds or small mammals when they emerge from the spoil.

Secondly, crayfish may be subject to longer term impacts if the works destroy or alter habitats, causing longer-term effects. In heavily vegetated, silt-and-sand substrate channel areas crayfish burrow into the substrate or utilise the cover around the roots and stems of aquatic vegetation. Consequently when maintenance removes this instream vegetation the number of suitable refuges is substantially reduced.

Crayfish were originally thought to prefer rocky/gravel habitat, which provides interstitial spaces between rocks that crayfish utilise as cover habitat. Recent Irish studies undertaken by the Central Fisheries Board (CFB) for the Office of Public Works (OPW) have shown that crayfish also use clay and silt dominated channels (Lordan *et al.* 2008).

Throughout their life stages crayfish shed their exoskeleton as they grow in a process known as moulting. Moulting rates vary throughout their life cycle. For a few days following moulting crayfish have soft exoskeletons and are extremely vulnerable. Without available refuges, which, may have been removed in maintenance, adults are subject to predation from heron, otters and mink.

Berried Female crayfish: Adults are sexually mature at 3 to 4 years old, with carapace lengths of 22mm and 25mm for males and females respectively (Brewis & Bowler 1983; Lowery 1988; Reynolds 1997; Byrne *et al.* 1999). Mating for the white-clawed crayfish occurs from mid September until November. Fertilised eggs are carried on the underside of the female's abdomen. Egg-carrying adult females are found from November until June. During this period females are more vulnerable and less mobile and spend most time sheltering in refuges. Timing and release of the young varies upon the habitat

characteristics. Any disturbance to habitat on identified crayfish channels by machinery during this life stage would result in the potential loss of ovigerous females – with consequences for both the ripe adults and the eggs/juveniles being carried by them.

Barriers: The present study is essentially concerned with *Austropotamobius* in riverine habitats. This species is best known or studied in Ireland in lakes and it is likely that lake populations serve as a reservoir for colonization and recolonization of many river reaches, and whole catchments, downstream of themselves. It is easy to conceive of downstream dispersal for crayfish, with natural flow processes carrying the organism downstream and over or through any hydraulic barriers. However, crayfish are highly mobile creatures and are also capable of upstream movement, using their own powers of locomotion. On their upstream migratory routes there must be no significant obstacles (chemical or physical), if crayfish are to successfully disperse. The colonization of the higher reaches of a catchment allows maximum dispersal of juveniles to find suitable conditions for settling, growing and moulting prior to breeding. This allows for the slow, continuous downstream movement of juveniles.

Of less dramatic appearance, but equal impact, are barriers created by bridge sills and apron structures. These may pass such thin films of water in low flow as to prevent crayfish passage. The design level of bridge floors is not always smoothly aligned with the up- and downsteam channel segments. This can create vertical barriers that may be impassable to crayfish. This facet is also of relevance to OPW in terms of the stability of the structure. Such downcutting frequently leads to an undermining and subsequent collapse of part of these apron structures. Remedial work, if using large quantities of rock armour to fill voids and dissipate the fluid forces, can also facilitate fish passage, including crayfish, in these situations. Bridges provide permanent overhead shading and crayfish have been sampled under bridges in the present study, where upstream and downstream levels are undisturbed by the bridge floor level.

Disturbance of juvenile habitat: Once juveniles emerge from the protection of the females' abdomen they are subject to predation from fish and birds. To maximise survival they require protection from predators and readily-available food sources. The principal habitat requirements for juvenile crayfish have been documented in literature as submerged, aquatic vegetation and tree roots; they are most commonly found situated along channel margins. Open-water stands of low-growing forms such as water celery and *Callitriche* (starwort) and of tall emergents such as *Scirpus* (tall rush) and *Sparganium* ('flaggers') all serve to act as habitat for juvenile crayfish who may use the three-dimensional matrix of underwater stem and rooting material as well as burrowing into the upper layers of sediment around the plants' basal areas.

Spoil sampling and hand grabbing surveys have shown that juveniles are often found tangled in the roots of aquatic plants and among macrophytes (Lordan *et al.* 2008). Marginal vegetation provides juveniles with protection from predators and harbours good food sources. The removal of silt and instream vegetation from the channels also reduces the amount of available habitat for newly-hatched crayfish recruiting to the population.

6.3 Case Histories of OPW channel works/maintenance impacts on *Austropotamobius pallipes*

Overview of studies in OPW drainage schemes 2005 – 2008:

Pre-maintenance studies on population size and structure were undertaken at six locations in 2006. All six locations were examined in 2007, twelve months after maintenance to assess ‘medium-term’ impacts on crayfish. A further two channels were examined for ‘short-term’ impacts in 2007, with pre- and post-maintenance studies in the same season. A further specific study was carried out in 2008, examining direct losses of crayfish from a vegetated habitat.

A comparison of the total numbers captured in the individual channels in the 2006-07 studies (Figures 1 & 2 respectively) indicated a general decrease in numbers in the year following maintenance. This was true both for male and females crayfish. However, a number of points are pertinent:

- The CM4/43 channel was not, apparently, subject to maintenance but still showed a decrease in numbers

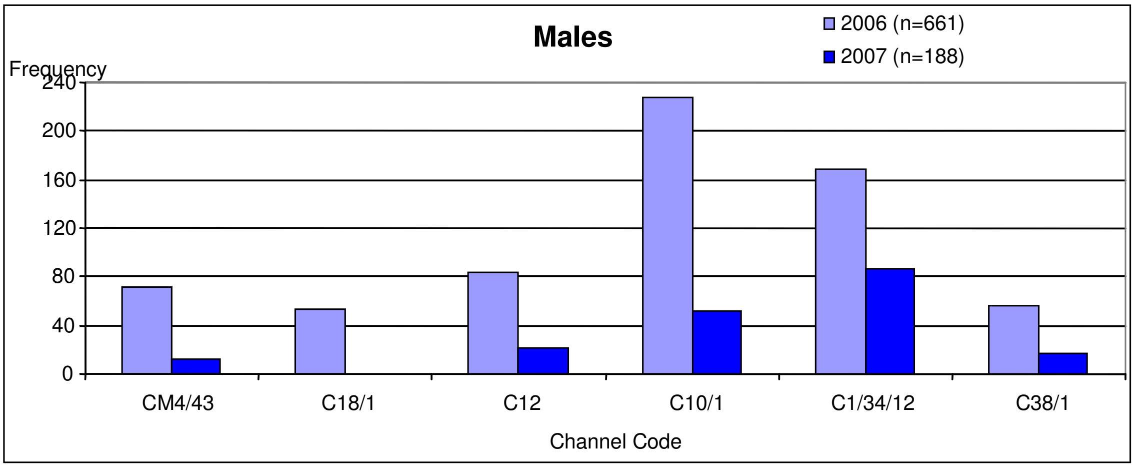


Figure 1. Number of males captured per site in 2006 and 2007.

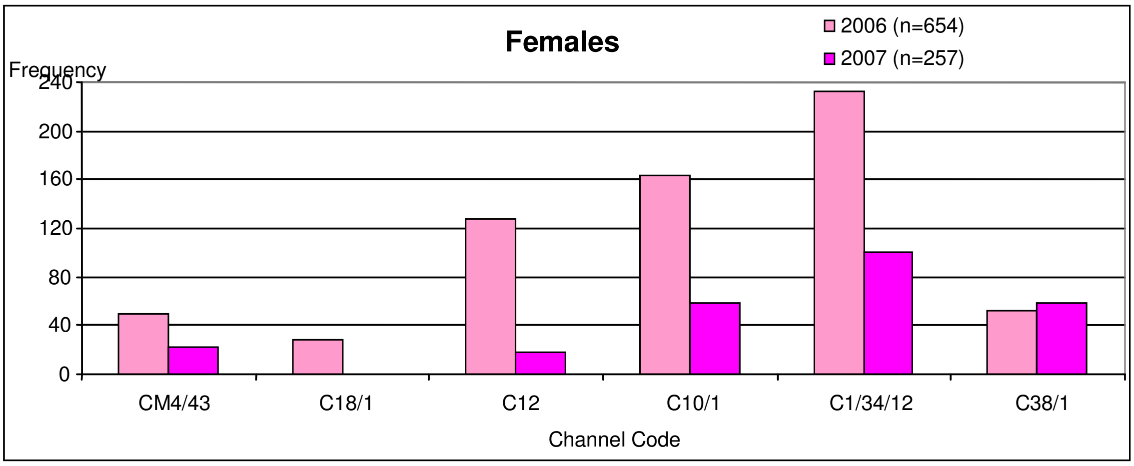


Figure 2. Number of females captured per site in 2006 and 2007.

- The C18/1 (Brosna) channel appeared to experience a pollution/fish kill event between samplings
- The C38/1 (Brosna) channel showed a differential response between numbers of male and number of female crayfish in respect of maintenance works.

The 'short-term' studies in 2007 indicated two important findings:

- No decrease in crayfish numbers in the immediate aftermath of maintenance work
- Substantial decrease in crayfish numbers later in the season

The study in 2008 indicated a substantial degree of loss of crayfish, particularly sub-20 mm individuals, during a weed-removal exercise.

The majority of sampling gears were suited to remove 'larger' crayfish - in excess of 20 mm carapace length. However, any crayfish population is likely to contain a substantial number of smaller (sub 20 mm carapace length) individuals. Details of selected case histories are presented below, based on Lordan et al (2008).

Case History I: R.Glore (C50 Inny CDS) – short-term seasonal impact

R. Glore during channel maintenance.

The R. Glore data showed that there was little or no impact from channel maintenance on the number of crayfish in the immediate aftermath of maintenance. There was no significant difference between the pre and post maintenance numbers. A similar finding was recorded on the larger (10 m wide) R. Brosna main stem, as part of this series of studies. When the Glore site was resurveyed three months later the number of crayfish caught was only 25% of the pre-maintenance population (Figures 3 - 5). There was a significant difference recorded between the pre-maintenance numbers and those of 3 months post-maintenance.

The spoil sampling did not generate large numbers of adult crayfish (> 20 mm) but did yield substantial numbers of smaller or sub-adult crayfish (Figure 6).

It is considered that the physical process of maintenance did not lead to substantial mortalities of crayfish but that these emigrated from the area in the period following maintenance due to loss of necessary habitat features, particularly cover. This cover had been provided by instream 'flaggers', marginal tall grasses and the elevated water level caused by the extent of tall instream plant stems.

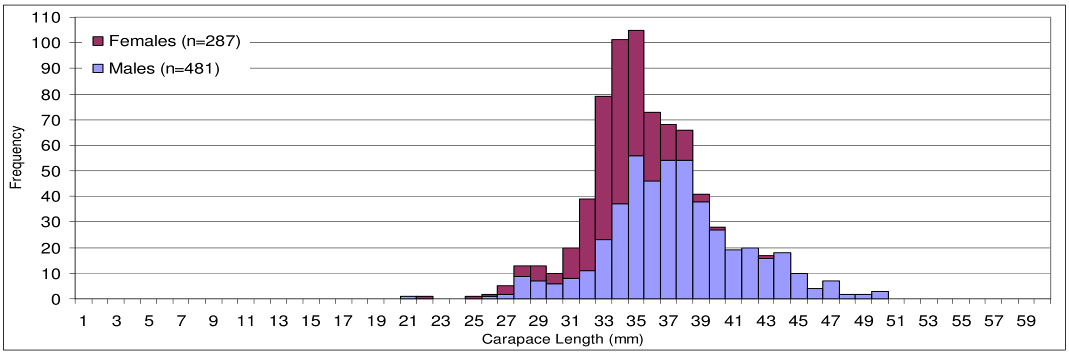


Figure 3. ***Crayfish length frequency pre-maintenance (N = 768) on C50.***

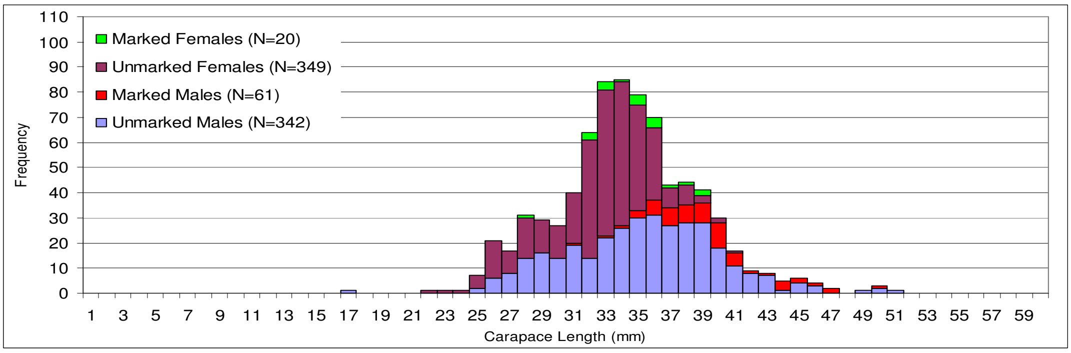


Figure 4. ***Crayfish length frequency post-maintenance (N = 772) on C50.***

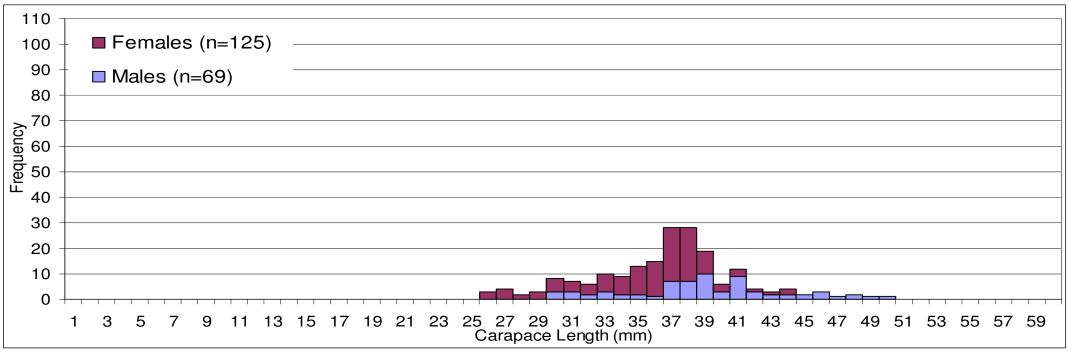


Figure 5. ***Crayfish length frequency 3 months post-maintenance on C50 (N = 194).***

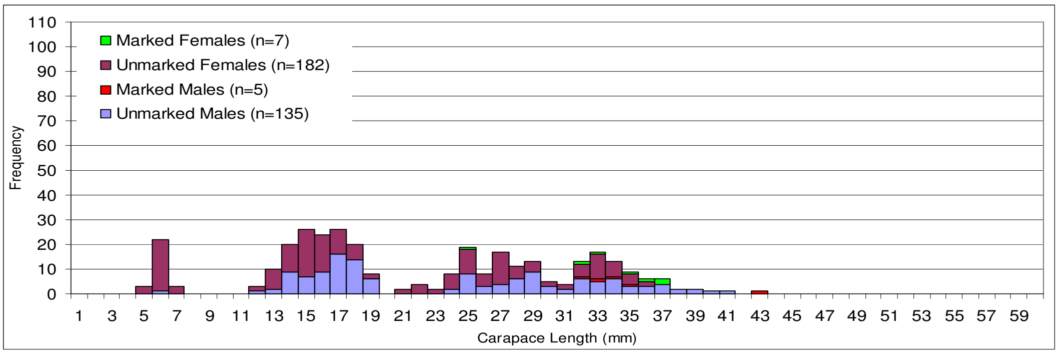


Figure 6. Crayfish length frequency distribution for spoil sampling on C50 channel.

Case History II: R. Rath (C12 Inny CDS) – 12-month study 2006-07

C12, Inny CDS: pre- (LHS 2006) and post maintenance (RHS 2007).

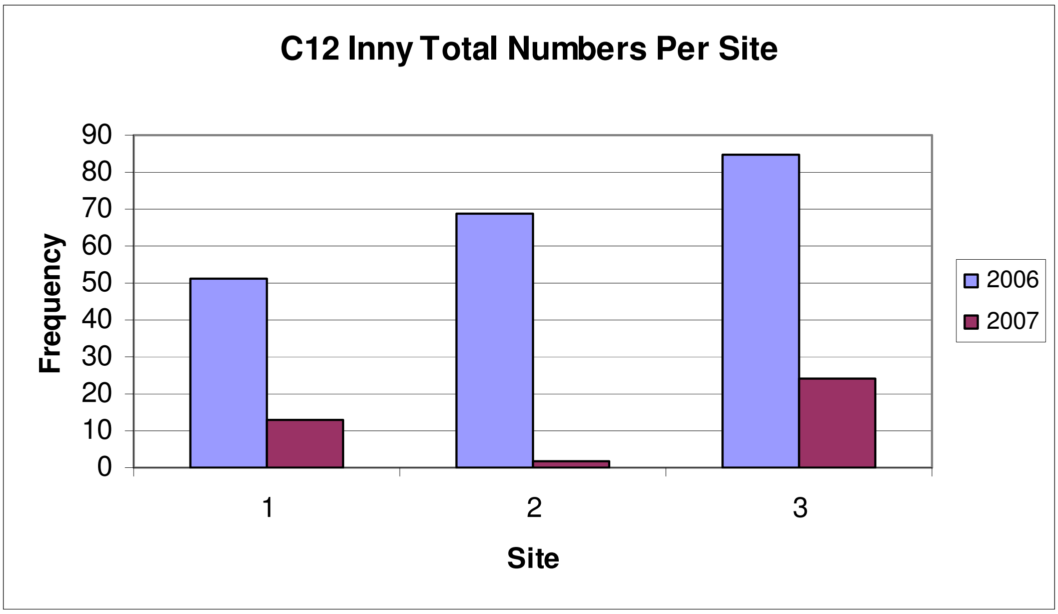


Figure 7. Crayfish total numbers captured per site in 2006 and 2007.

A 12-month time period elapsed between the pre- and post maintenance studies. This channel is a major brown trout spawning and nursery tributary of the R. Inny. The area surveyed for crayfish had a variety of habitats. Site 1 had a soft muddy base with cobbles and some instream vegetation of *Sparganium erectum, Ranunculus* and *Apium*. Site 2 was located in a tree tunnel section of the river with gravel and cobble on a silt bed. Substrate at site 3 was sandy sediment with gravel and stones. Significant differences existed between the total number of crayfish caught pre and post maintenance. The loss of overhanging bank vegetation and loss of instream vegetation may be responsible for these reduced numbers. Females were more dramatically affected than males.

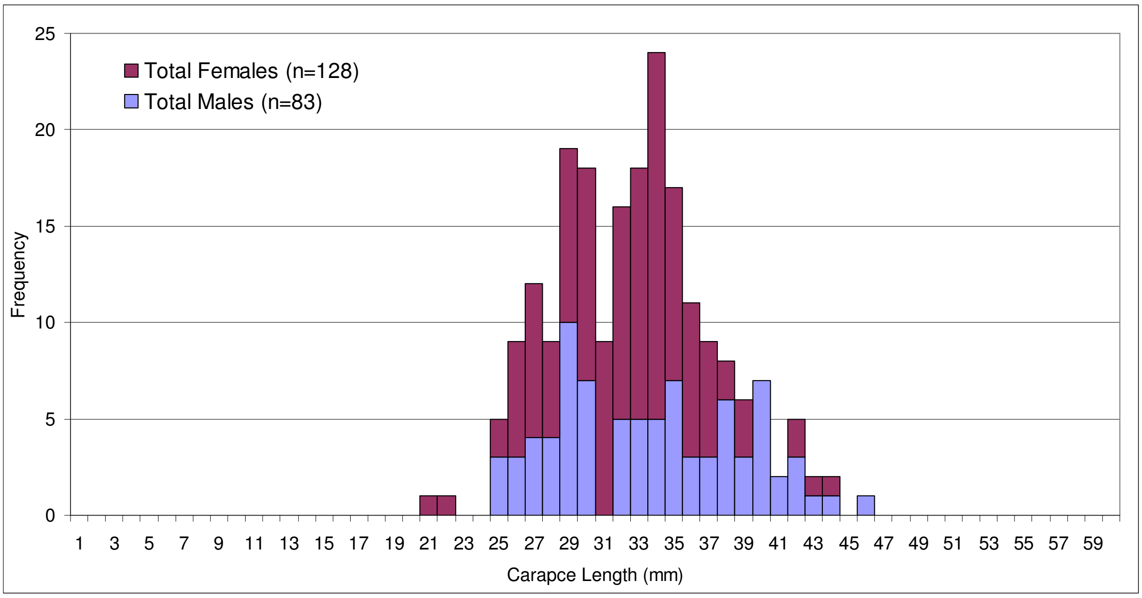


Figure 8. ***Pre maintenance crayfish length frequency distribution for the C12, Inny CDS, 2006.***

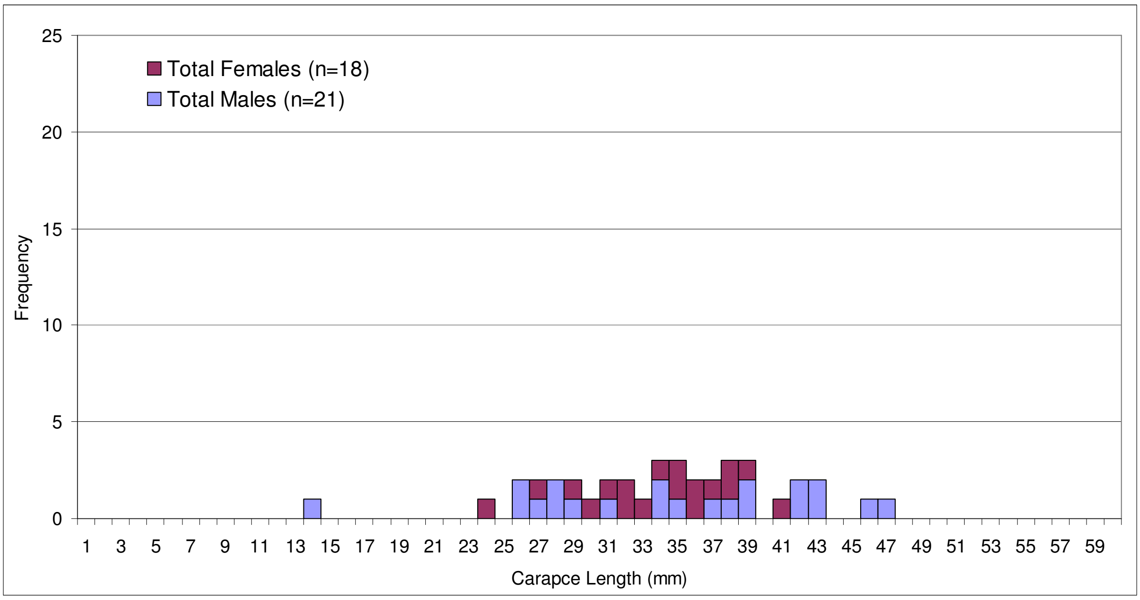


Figure 9. Post maintenance crayfish length frequency distribution for the C12, Inny CDS, 2007.

A similar set of results, in terms of numbers captured and population structure, was obtained in the Tullamore River (C10/1) of the Brosna CDS in the 2006 – 07 period. This channel is of similar width to the R. Rath (5 – 6 m) and carries substantial local cover of

Sparganium erectum. This cover was impacted in maintenance with large-scale removal. This is consistent with the plant's capacity to grow across the full channel basewidth and act as a conveyance obstruction. The plant's capacity to stabilize sediment and to provide cover in its basal areas may facilitate niche creation for immature crayfish.

The reduction in crayfish numbers recorded over the 12-month period in both the R. Rath and R. Tullamore mirrored the end-of-season outcome on the R. Glore (see previous case history). In all three cases, major removal of marginal and instream vegetation stands took place. All three rivers were of similar width and had a habitat of relatively low-gradient, streamy, deep (to 1 m) character with heavy instream *Sparganium erectum* ('flagger') growth on a clay-sand type bed. This would not be considered to be characteristic crayfish habitat. The presence of crayfish in such habitats must be considered when similar channels are encountered in future maintenance operations.

Case History III: C1/34/12 (Maigue) and C38/1 (Brosna) – 12-month study 2006-07 in two small channels


C1/34/12, Maigue CDS pre- (LHS 2006) and post- (RHS 2007) maintenance.

C38/1, Brosna CDS.

Both channels are relatively small, *circa* 2 – 3 m width. Both carried substantial cover of marginal vegetation. The two channels function as spawning and nursery waters for brown trout. In addition, the C1/34/12 contains some areas of salmon spawning. The findings of the 12-month study showed contrasting results between the two channels.

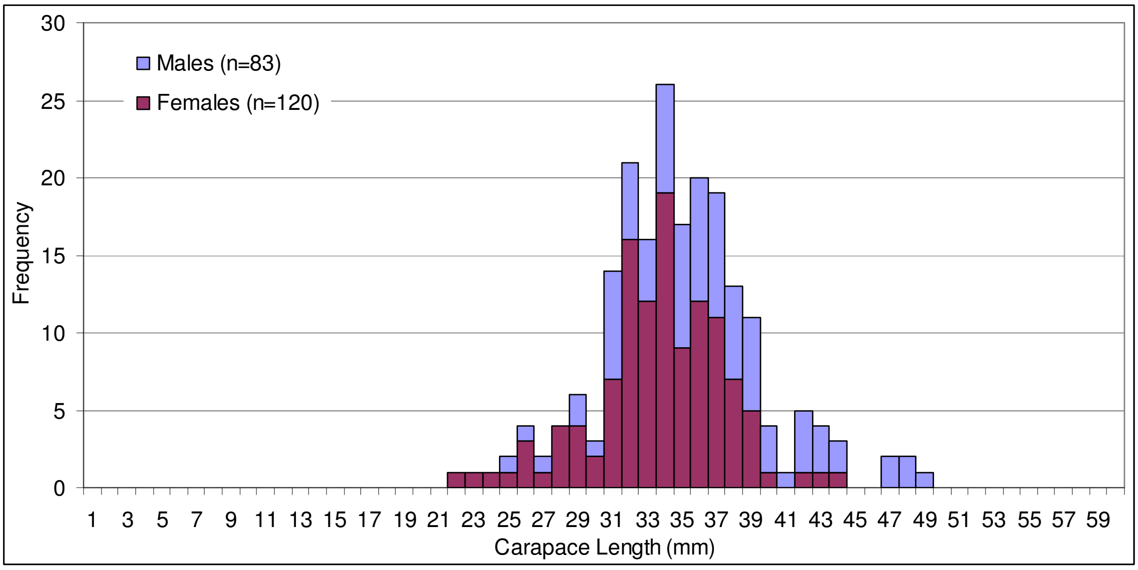


Figure 10. Crayfish length frequency distribution for ‘mini’ fyke sampling on C1/34/12 channel, Maigue CDS, 2006.(Pre-maintenance)

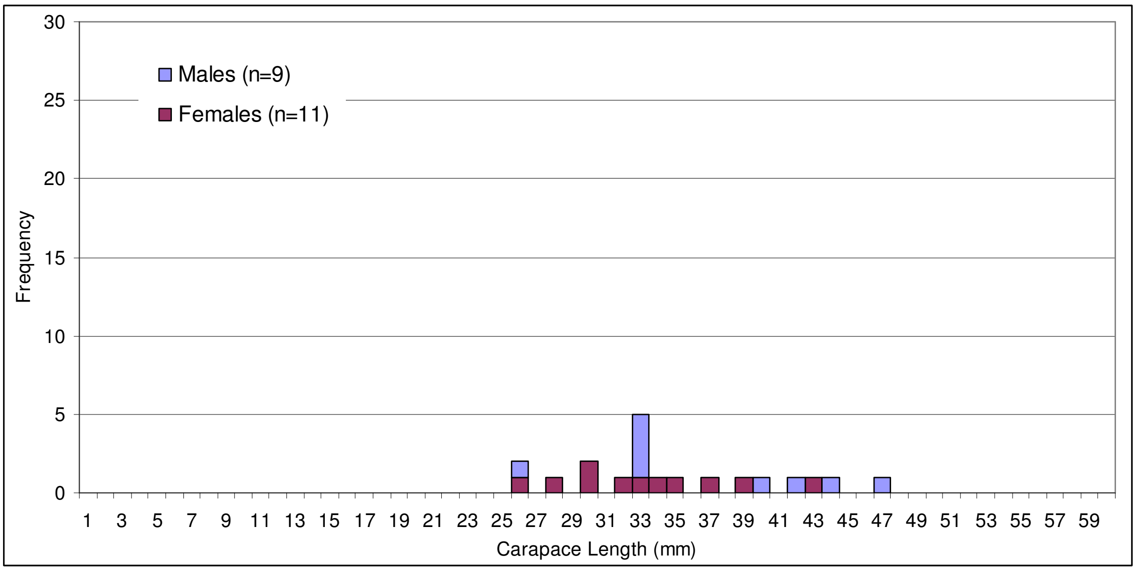


Figure 11. Crayfish length frequency distribution for 'mini'fyke sampling on C1/34/12 channel, Maigue CDS, 2007.

In the C1/34/12 of the Maigue system in Co. Limerick, optimal habitat of stony/cobble substrate with overhang from marginal vegetation was present at sites surveyed. In 2007 loss of marginal cover of *Phalaris* was evident and local loss of patchy instream cover also occurred. Overall the number of crayfish decreased by 53% in 2007 and females were more heavily impacted than males. Significant differences existed between the pre and post maintenance numbers per net.

The Brosna tributary (C38/1) was a fast flowing stream which created areas of pools and riffles. It had a rocky bed with loose gravel substrate and an average width of 1.7m.

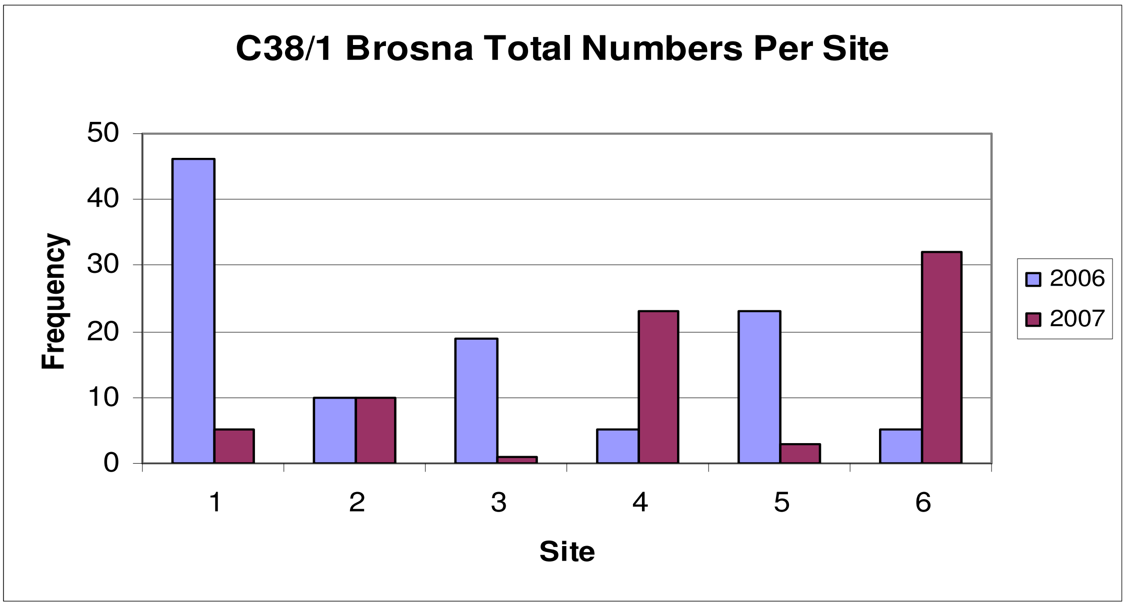


Figure 12. Crayfish data, total number captured per site in 2006 and 2007 on the C38/1, Brosna CDS.

Rocks, riparian overhang and instream vegetation of water celery (*Apium)* and 'flaggers' (*Sparganium erectum)* provided refuges for crayfish from predators making it ideal crayfish habitat. Isolated trees occurred along both banks along the 600m section that was surveyed. Given the narrow nature of the channel, there was a high degree of habitat retention undertaken in the maintenance work of 2006. Trees were retained along the channel length. There was a decrease of over 71% in males and an increase of 11.5% in total female numbers in the year following maintenance. Not all sites showed a decrease in crayfish numbers following the maintenance operation. However, overall difference in the total number of crayfish found in 2006 and 2007 were not statistically significant.

Case History IV: Keoltown Stream tributary (C40/2 Brosna CDS) – immediate impact of instream vegetation cover removal

The majority of studies undertaken here used netting techniques to sample crayfish in pre-and post maintenance situations. The nets used collect crayfish of larger size, in excess of 20 mm carapace length (Lordan et al 2008). The limited degree of spoil sampling undertaken pointed to loss of smaller crayfish as well, as a consequence of

maintenance. It was evident from the R. Glore study (Case History I) that losses of crayfish < 20 mm might be greater than losses of larger animals. The section of Kelotown stream examined had heavy cover of water celery and maintenance involved skimming this off the channel surface and placing it on the bank, without disturbance of the channel bed. This approach was advocated in training provided to OPW field crews.

The study on the Kelotown involved examination of paired samples – one of vegetation removed and one of bed material removed immediately underneath – for the presence of crayfish. The results indicated a prevalence of crayfish in the vegetation (Figure 13) and pointed to substantial losses of this taxon in the course of weed removal.

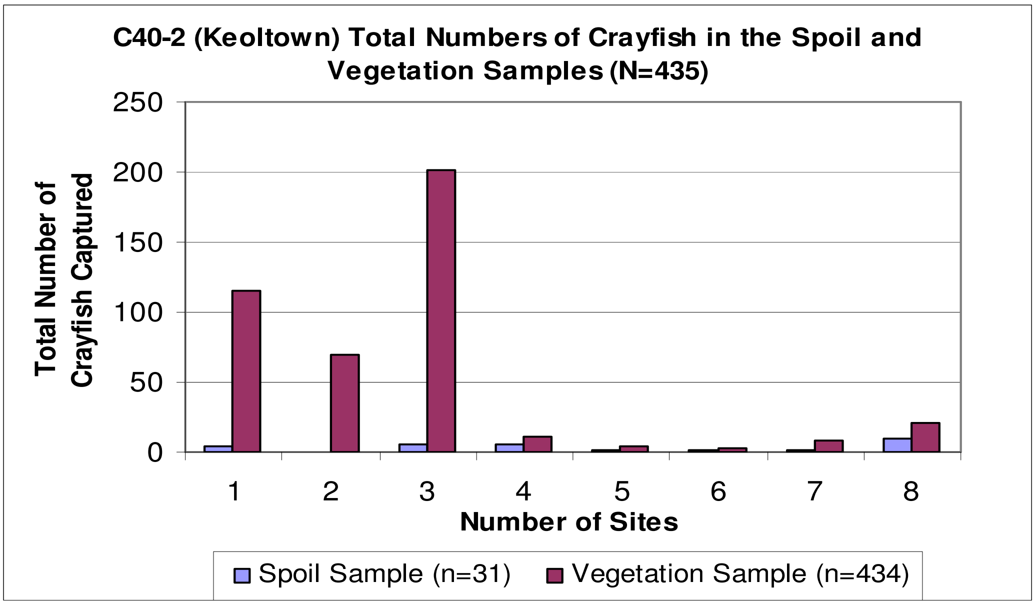
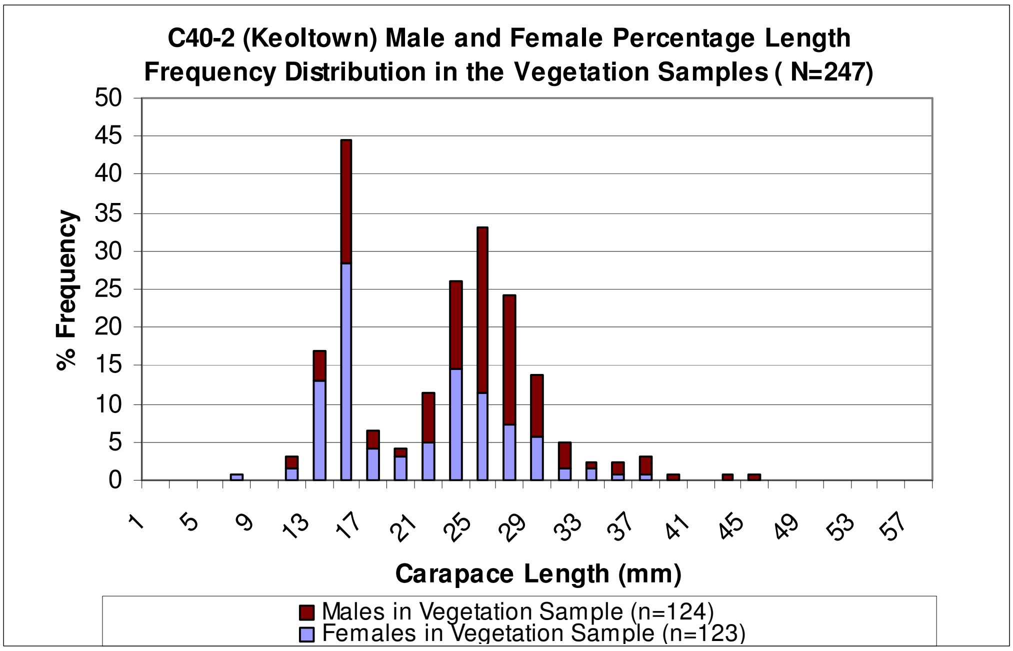
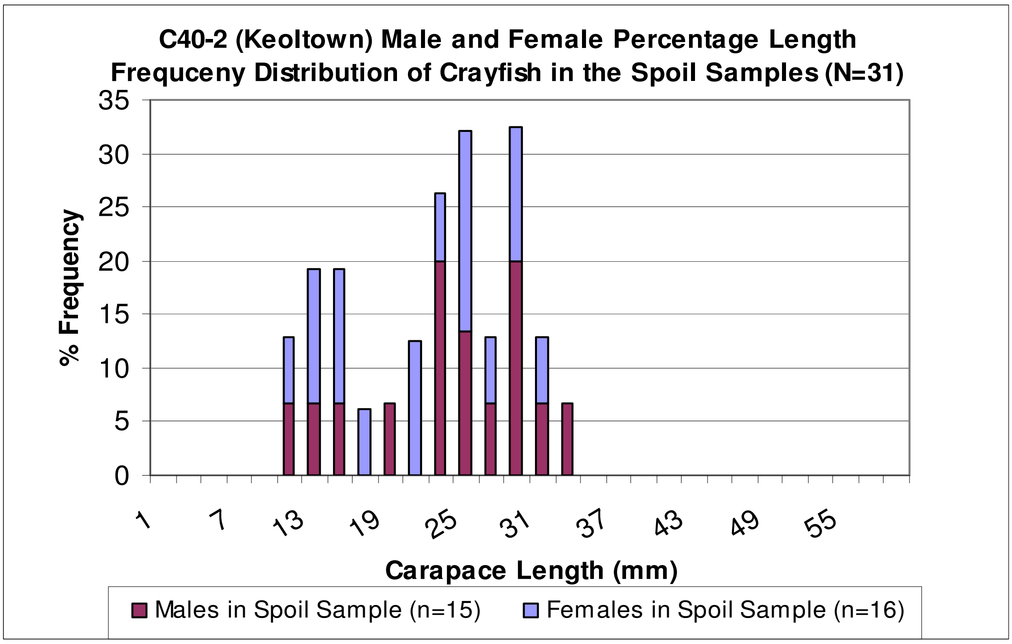


Figure 13. Distribution of crayfish among vegetation (water celery) and bed material (Spoil) in eight replicates on C40/2, October 2008.

The numbers captured per replicate varied widely, dependant on the degree of weed cover. Smaller crayfish (< 20 mm individuals) were very prominent in the samples. Removal to spoil would, in essence, lead to mortalities of crayfish (in vegetation and bed material combined) in this section of channel.





6.4 Review of impacts

The results of impact assessment indicate a general trend of reduced numbers of crayfish following maintenance.

The findings from the short-term studies indicated, in two separate channels, that numbers of crayfish > 20 mm carapace length were not immediately adversely impacted by the works process. However, a further study several weeks later indicated a severe reduction in numbers.

Proportionally larger numbers of small crayfish, < 20 mm carapace length, were found in spoil samples relative to large crayfish.

The two previous observations point to a possible capacity of more mobile, adult crayfish to avoid the excavation bucket by active swimming. It is considered that the bough wave effect created by the machine bucket being drawn through the water column may cause sufficient turbulence to disturb and displace the crayfish in the immediate affected area. Immature crayfish, often associated with basal areas of plants may have a lesser capacity to swim and are more likely to be removed along with plant material.

While crayfish are generally considered to be associated with hard-bed areas with cobble and gravel substratum, relatively fast flow and associated streaming forms of aquatic plants, substantial populations have been recorded in slow-flowing, low-gradient channels in this study. This creates additional difficulties for OPW as it becomes impossible to predict the presence/absence of crayfish and population size in any channel scheduled for maintenance.The available data from NPWS surveys and data from CFB/OPW surveys could be combined on a GIS layer by OPW to allow a determination of presence/absence on channels scheduled for maintenance.

7. Crayfish Mitigation Measures

It is evident from the previous section that channel maintenance has the potential to impact substantially on both the habitat and populations of crayfish. As shown in the case studies (Chapter 6), this is the case in a wide range of habitat types, including those that might not normally be considered as characteristic of white-clawed crayfish. Younger life stages appear more susceptible to removal from the channel while both young and older classes are likely to experience habitats loss as a consequence of maintenance.

The study on catchment-wide distribution and status of crayfish populations in the Inny catchment (Lordan *et al* 2008) indicated a frequently-disparate distribution with a wide dispersal of both presence and of population size, where present, both within channels and between channels. This dispersal is commonly unrelated to presence of suitable or, indeed, optimum habitat. Thus the occurrence of substantial areas of crayfish habitat may not signify the presence of such populations. By way of example, the adjacent Tullamore River (C10/1) and Tullamore Silver River (C9/1) are broadly similar in their ecology and physical habitat. Both contain several kilometres of continuous uniform glide of water depth to 1 m carrying substantial populations of brown trout and large areal cover of *Sparganium erectumn*. The former carries a significant population of crayfish (see Chapter 6) whereas the latter has not yielded crayfish in the course of several years of fish stock assessment. Similar paired cases were noted in the Inny catchment study of Lordan *et al* (2008). However, it is considered appropriate that maintenance operations be mindful of the presence of such habitat areas and retain the integrity of such areas as being suitable habitat for crayfish.

A series of mitigation measures present themselves. These are listed below and are grouped into Strategic or Operational measures. The Strategic measures require an element of forward planning by OPW. Some of these would require allocation of resources to expedite the survey programme and populate the databases proposed and may only be fully achievable over a period of years. Others would simply require a re-focusing of certain existing planning practices and procedures with OPW’s three

maintenance regions to incorporate consideration of crayfish issues. There are strong convergences with the suite of mitigations proposed in respect of lamprey conservation in the course of channel maintenance work (King *et al* 2008).

On the Operational front, it is considered that implementation of the 10-point environmental training programme would provide a substantive basis for mitigations. This potential is also recognized in other EcIA documents submitted to OPW. However, the implementation of these points may not always be fully appropriate where crayfish is the pre-eminent conservation issue and, in those circumstances, some of the points may need to be modified to suit the particular requirements of the crayfish habitat – as discussed below. A second suite of Operational mitigations emerges from direct observation of the OPW's machinery in operation and of channel/structures management issues.

7.1 Strategic Measures – medium / longterm planning

- *Catchment surveys*: Crayfish are mobile and, unlike juvenile lamprey, are not confined to a highly-specific habitat type. Studies for this report (see Chapter 6) have indicted the presence of crayfish populations, in substantial numbers, in a variety of habitat types and hydraulic regimes in the OPW channels examined. In the light of this, it is not possible to categorise channels or channel segments as crayfish habitat or NON crayfish habitats. Ideally intensive catchment surveys should be undertaken to identify all crayfish channels within OPW catchment drainage schemes. A 10-minute timed rapid assessment of shallow channels using either hand-grabbing or electrofishing, in conjunction with fyke netting of deeper channels, in key locations throughout schemes could determine crayfish distribution, as per the study of Lordan *et al* (2008) on the Inny system. This method would provide a baseline on distribution and status or size of populations and would index channels in terms of importance for conservation-based approaches to maintenance. It would also identify those channel with, and those without, crayfish populations.

  In the absence of such a survey programme, it is imperative to work with and augment datasets available. This may consist of collation of information coming in on weekly Time Cards from OPW driver crews, presence/absence data from CFB datasets and additional new studies and database material that may be available from the NPWS dataset.

- *Development of GIS database:* This mitigation arises naturally from the previous section. Areas of potential crayfish habitat identified during walkover surveys and areas which have previously been shown to contain crayfish should be mapped onto a GIS database. The same would apply to information coming from OPW machine drivers' time cards, where there is a facility to record occurrence of key species. Using these data a GIS layer could be created which would highlight key areas. This layer would be accessible to OPW technical staff programming

maintenance operations and appropriate maintenance procedures could then be factored in well in advance for implementation.

It may be argued that often appear ubiquitous, once present, and that mapping locations of occurrence in a channel might impede all future maintenance operations in that channel. The mapping should indicate the importance, in terms of density, of individual sites and this would serve to highlight particular channels. The mapping of spot locations should be clearly distinguishable from the detailed catchment surveys (see above) within the GIS layer, as the latter provides continuity information and would be the primary guidance element in planning for works and mitigations.
This process of GIS database building has commenced and the OPW GIS presentation of the Annual Works Programme, as developed over the last few years, offers an effective way of recording and displaying this information.

7.2 Strategic Measures –short-term or immediate implementation

- 'No Go Areas': The strategy of 'leaving sections alone' is one that is embraced in the environmental training protocol delivered to OPW's drivers. In that context, sections to be left alone were generally of a relatively high gradient and pertained to aspects of salmon and trout ecology, particularly to spawning. During the course of this project, areas of crayfish abundance were identified. It is important that such areas are noted from previous studies and during walkover surveys and highlighted as potential 'no go areas' for maintenance on GIS maps. Juvenile crayfish are not highly mobile and tend to be associated with a slight burrowing habit, being found associated with root wad areas of plants linked with maintenance issues. As such, the juveniles are not capable of moving out of reach of the excavator bucket. All possible efforts to reduce impacts should therefore be put in place. Where significant areas of optimal habitat are observed and/or population densities have been recorded, these areas should be specifically addressed. There may be channel conveyance issues associated with 'leaving sections alone', particularly when these relate to low-gradient locations that may be facilitating instream weed growth and, hence, channel impedance. If it is not an option to leave such areas alone then particular other measures may be required. These might include retaining a significant portion of the habitat and/or collection and return of juveniles removed with spoil.

- *Maintenance frequency:* Maintenance cycles generally occur every 4-7 years and potentially more frequently on certain channels. If maintenance were to occur too frequently entire age classes could be lost from the population. This could lead to reduced numbers of crayfish available to spawn, which, over time, could lead to the elimination of crayfish from the channel. Crayfish populations can re-colonise an area with suitable habitat within 18-24 months (Hogger *et al.*, 1982). However, rates of re-colonisation are slow after a population is lost from an area (Demers *et al.*, 2002; Peay, 2003). A potential mitigation for this problem would be to leave longer time periods between maintenance cycles in channels known to have

substantial crayfish habitat and substantial crayfish populations. This may need to be balanced with overall river ecology where long cycles may lead to more heavy scale works.

- *Maintenance of channel segments:* OPW treats many of its larger channels as a series of segments, with maintenance operations moving sequentially upstream on an annual basis. This approach could also be extended to minor channels, of reasonable length, which contain known significant crayfish habitats or populations. Maintaining a reduced number of segments on a specific crayfish-bearing channel in any year would aid in the reduction of adverse impacts on crayfish populations. Studies involving fish species have found that undisturbed sections of channel provide refugia during maintenance as well as a seed population for recolonisation post maintenance (Kennedy 1980, Sedell *et al.* 1990). Recovery rates of fish populations following a disturbance are strongly influenced by the presence of undisturbed sections up and downstream of the disturbance (Niemi *et al.* 1990). These same principals are considered to apply to crayfish populations. Crayfish are mobile species and adjacent areas of channel could be utilised by the displaced population.

- *Timing:* Presently OPW maintenance is restricted in salmonid spawning channels from October to May. However, this time frame does not encompass the entire breeding cycle of the white-clawed crayfish. Breeding or 'berried' females are still common in June of any year, carrying their young attached to their abdomens. Loss of berried females leads to loss of both parentals and the next age class. Peay (2000) advises that May-June is critical in terms of berried females and should be avoided in regard to inchannel works. The optimal window is identified as being July – October inclusive (Peay 2000). The process of 'tagging' crayfish channels, in respect of timing of works, would be facilitated by a GIS database. This GIS information together with the ongoing consultations that take place across the country with the Regional Fisheries Board staff and personnel of

National Parks and Wildlife Service would allow for a rebalancing and refinement of the environmental “window “where the presence of crayfish is suspected or known.

- *Directions of work:* Maintenance is generally carried out in an upstream direction It is noted that in some low grade channels maintenance is carried out in a downstream direction using the existing vegetation as a filter to reduce siltation.. It is the recommendation of this study that maintenance be carried out in an upstream direction on channels known to contain crayfish. If maintenance were to be carried out in a downstream direction, crayfish which have been displaced from upstream and have managed to find suitable downstream habitat will be impacted upon for a second time as the excavator tracks downstream. This would further reduce the chances of survival.

7.3 Operational Issues I – a review of OPW's 10-point environmentally-sensitive protocol - options and potential conflicts with crayfish status

During the 5-year Environmental Drainage Maintenance (EDM) study (2002 – 2006) a training programme was agreed with OPW and rolled out to all staff of OPW's Drainage Maintenance division staff in the winter-spring period of 2002-03. Follow-up site visits were made to driver crews over the period 2003 – 2006.

The training provided an overview of river corridor ecology and biodiversity and also included a series of 10 practical elements that drivers could implement on-site. These were designed to reduced habitat damage and, in certain cases, provide a fisheries or wildlife benefit. The 10 practical elements were agreed to by OPW at a senior strategic and operational level and incorporated as part of normal practice for machine drivers in channel maintenance. Some of these elements have a particular relevance in crayfish mitigation terms while others may require modification to fully accommodate crayfish issues. Being in place already, these could be actively advanced as contributing to crayfish mitigation. It is of interest to note that several of these measures are identified as significantly lessening the potential impacts of maintenance activities on the freshwater pearl mussel (Anon 2008).

- *Non-working bank:* As part of the driver training programme, one of the recommended steps requires that the non-working bank should be left completely untouched. This would include the marginal vegetation. By ensuring that the non-working bank, along with its waters edge, marginal vegetation and the bank slope, are left completely intact, it is assumed that 50% of the marginal habitat is left completely undisturbed. Unfortunately, the crayfish is mobile and uses the entire channel bed area in foraging. In the case studies (Section 6 above) it is apparent that in some cases, even with retention of the non-working bank habitat, crayfish numbers were adversely impacted in maintenance. In important crayfish areas, it may be

necessary to retain the water's edge habitat on both banks during maintenance.

- *Confining excavation/maintenance to open-water area of channel:* This measure was one of the core points for implementation in the OPW's environmental protocol. It was devised to optimise conveyance while minimising ecological impact in the wetted channel. The velocity distribution and volume discharge tend towards a maximum in the mid-channel areas and maintenance can ensure that this pattern is continued by removing obstacles in the open channel area. By obtaining conveyance benefit in the open water area, adverse marginal impacts may be avoided. However, any scraping or digging activity is likely to displace or remove niche areas used by crayfish as cover. This 'cover' element is integral to good crayfish status in any channel. The case studies (Section 6) have indicated substantial crayfish populations in low-gradient channels with extensive instream cover of 'flaggers' (*Sparganium erectum*). This plant creates a conveyance issue in elevated summer flows but its removal is considered associated with substantial decline in crayfish numbers in two channels studied (see Lordan *et al* 2008 and Section 6 above).

- *Weed management:* The maintenance requirement in many channels relates to heavy, often annual, growth of vegetation in the open-water. Such vegetation may consist of monocultures of water-celery type forms (*Apium* and *Rorippa*) or of tall emergents or 'flaggers' (principally *Sparganium erectum*). While these die back in autumn they can lead to elevated stage flow in summer conditions. The case studies in Section 6 (above) have identified that crayfish may be present in substantial numbers in channels displaying both weed types. In such circumstances, the weed management proposals enshrined in the OPW-10 point environmental guidelines would require modification to take account of crayfish issues. Conveyance improvement would require to be balanced

with adverse impact potential and a reduced digging regime, focusing on the mid-channel area, may be required for 'flagger' management. This balancing would retain a proportion of habitat and reduce direct loss of crayfish individuals and of their habitat.

One of the training items for OPW proposed use of the machine bucket as a rake to collect up, and then lift out, all water celery type vegetation from the channel. This would remove the conveyance constriction with minimal damage to the channel as no instream digging or desilting would be required. However, use of this strategy in a water celery habitat (Section 6, Case history IV) led to substantial numbers of crayfish, of varying sizes, being stranded on the spoil line. OPW now have weed cutting buckets that serve a similar purpose, in removing vegetation from the channel without impacting on sediment. The use of the weed cutting bucket is considered appropriate for the removal of water celery in early autumn. However, such use must now be tempered by a knowledge of the status of crayfish in the channel to be maintained. The weed cutting bucket could safely be operated in 'flagger' channels with no adverse impact on crayfish. However, its use on such vegetation may serve to boost the growth of the aerial parts of this plant, with a rapid return of the conveyance problem.

- *Tree management:* Shading is a physical feature considered important for good crayfish status in a channel. Shading is, in a sense, a form of cover. Cover can be provided by depth regime, in a deeper channel, by marginal overhang of tall plants such as *Phalaris* grass and by presence of structures on the channel bed where crayfish can hide or shelter. For crayfish, tree cover creates a varied light environment over the water, provides shading from elevated temperatures and provides a food source in the form of fallen leaves. The OPW guidance, of retaining tree cover where it is not causing a hydraulic obstruction, contributes to a positive approach to habitat provision for crayfish. Similarly, the guidance in terms

of managing low-level branches and handling situations of excessive shading are all consistent with crayfish conservation.

- *Skipping sections / Leaving sections alone:* This option has been used for some time by OPW engineering staff and civil foremen, based on their expert local knowledge, and may involve skipping short sections of channel, frequently riffle or elevated-gradient areas, where no maintenance requirement arises. This local decision-making option should continue as it can retain habitat and populations. Crayfish would be a likely beneficiary in riffle areas skipped. Such areas can function as seed-beds for downstream colonization into areas impacted by maintenance. The option of skipping sections has been discussed above (Section 7.2) in the context of longer-term strategies.

- *Returning stone material to the channel:* This proposal was made in the context of material being removed from the channel in the course of digging operations and of the potential for this to be collected up and returned, along with any other stone material occurring, easily to hand, in spoil lines or otherwise deposited adjacent to the bank-full line along which the maintenance machine was tracking. The proposal primarily relates to material of a size consistent with the category of 'small cobble' and upward to boulder size. This approach has obvious benefit as a crayfish mitigation, returning or introducing material that may, potentially, function as 'cover' for individuals. The advantage will be optimized if material is placed on existing bed that consists of coarse alluvial material – from coarse sands and fine gravels upward in size to cobbles. Placement onto soft material such as marl or fine muds will probably lead to sinking of the introduced material and loss of benefit.

- *Loosening channel-bed gravel:* Gravel shoals tend to collect on points of inflection or grade breaks of the channel bed. These areas are naturally

self-cleansing of silt and deposition and do not, as a rule, require maintenance. As a matter of course, OPW will frequently skip over such areas in maintenance. This approach is further encouraged in the OPW driver training programme. Loosening or tossing has the effect of washing out fines from the gravel beds and, in the case of compacted or concretised gravel shoals, this can loosen the individual alluvial particles of appropriate spawning size. Such loosening is seen as a mitigation option of potential benefit to fish species using gravel for spawning – Atlantic salmon, brown trout and the lamprey species. However, such loosening may lead to mortality or displacement of crayfish using the habitat. Riffle areas with larger bed material may have a loose, lattice network suitable for use as cover areas by crayfish. On the other hand, the habitat may be more suited to crayfish following the loosening operation. This potential mitigation may require review in individual circumstances or channels. It should only be practised in the July – October period, in respect of crayfish, but timing must also accommodate salmonid sensitivities. Regular consultation with the Regional Fisheries Boards and National Parks and Wildlife Service staff will assist OPW in regard to both the timing and suitability of this measure.

- *Managing berms:* The topping of berms was identified as retaining the fisheries benefit of narrowing surface width, caused by berm development, while improving conveyance. In the case of crayfish, berm topping will lead to loss of physical cover, via lowering of bank height and loss of vegetation cover, and would diminish the ‘value’ of the habitat. However, the topping would not reduce water depth – and this, in itself, provides cover for foraging crayfish. The loss of vegetation on the impacted berm can be offset by ‘re-sodding’ the impacted bank, at the new stage level, with vegetative sod from immediately upstream on the berm. The ‘basic’ and ‘advanced’ berm management strategies have been tested on-site by OPW drivers and presented in driver training. Where substantial

populations of crayfish are known to be present in a channel or zone the more advanced strategy of re-sodding should be implemented as a mitigation when managing berms.

- Digging pools: This strategy was designed to enhance hydraulic and physical diversity instream – forming a mix of riffle, glide and pool habitats to replace the extended glide sequences of the original arterial drainage scheme designs. The initial digging work may impact adversely on crayfish. However, as no material is removed from a site, but is redistributed to augment riffles or form low-level structures, it is not envisaged that crayfish mortality or loss of habitat would be significant. The pool digging strategy is one of localised digging and material rehandling but it may be applied over extended channel segments when channel conditions permit. Excavation would increase instream physical heterogeneity and, as such, would enhance the general habitat. It is envisaged that the strategy would benefit crayfish; enhanced depth would provide cover which is often lacking in glide areas; placement of some large stone material in the bottom of pools would provide additional refuge sites for crayfish; the reduced velocity regime in pools could permit deposition of allochthonous carbon material, such as leaf litter and small woody debris, that would encourage a range of invertebrates on which crayfish can feed.

7.4 Operational Issues II - Additional On-site mitigation measures

- *Bucket management - Increased draining times and holes:* Allowing the water to drain from the excavation bucket, while suspended over the channel, for longer periods of time before the spoil is placed on the bank full/slope would permit a potentially greater degree of escapement by crayfish displaced into the bucket. The implementation of such a mitigation factor could be addressed as part of new driver training programmes. At present there are a number of holes in the excavator buckets. the number of holes in the buckets along with increasing the drainage times could increase the number of crayfish returning to the channels. A technique implemented for the protection of crayfish in the UK (Hogger and Lowery 1982) involves the operator 'dunking' the excavator bucket into the river in order to rinse plant material, thus removing back to the channel some of the crayfish which have become entangled in plant material. This measure may require some trials and could be looked at as part of the EREP ongoing research on crayfish & lamprey.

  Bucket management – trial sweeps with bucket and jib: Findings from short-term studies (see Section 6, Case history I) indicated similar numbers of crayfish at sites prior to and immediately following works. This may be due to the bough-wave created by the machine bucket as it displaces water before it in sweeping or dragging across the water column. Observation suggests that this displacing action either physically displaces crayfish or induces an escape reaction involving rapid swimming movement. A strategy of taking a 'dry run' or practice swing, involving the driver sweeping the bucket and jib across the water column, without any digging or scraping action, prior to undertaking the maintenance sweep would provide a doubling-up of any displacement action and would

be of obvious benefit to crayfish. It is considered that this approach would be of particular benefit to adult (> 20 mm) crayfish. As with the proposal above, this measure may require to be further assessed.

- *Checking spoil and reporting:* Increased checking of the spoils by driver crews is essential for the identification of new crayfish habitats and populations. Properly managed, it has the potential to deliver good data on presence and absence of crayfish on drained channels, with reporting from individual machine sites weekly over a period of five to seven years. This would add to our current data base detailing the national distribution of the species. If crayfish are identified as being regularly found in an area by drivers, a protocol should be put in place whereby that section of channel would receive an appropriate maintenance protocol - or no maintenance - depending on the density of crayfish present.

- *Returning crayfish to the channel:* It is important that crayfish found on spoil heaps are returned to the channels, especially in channels designated Special Areas of Conservation (SAC). This mitigation requires that one team member of the OPW machine crew picks over spoil excavated by his/her colleague, placing any crayfish into a bucket of fresh water. To be any way effective, the spoil must be spread thinly. This is a tedious process but has been shown to be effective in quantitative pilot-scale scientific studies. It is not clear how feasible such a process would be in extended whole-scale situations. It does represent a positive option in a situation where the works process is clearly having an adverse impact on the crayfish habitat and populations. However, it may require to be viewed in a context of maintenance logistics and cost:benefit appraisal of slowed machine time V extent of retrieval of crayfish and their replacement into an impacted habitat. This strategy would require that spoil be placed on the bankfull line or on spoil heaps and not on the bank slope, as it is not considered satisfactory for crew to carry out such picking on the bank

slope itself. Working on the slope may have H&S implications and does not permit a proper spreading of spoil for examination and picking.

Picking over spoil would be relatively easy and cost-effective for larger crayfish – essentially those with carapace length of 20 mm and larger. It would be less effective for immature crayfish. Observations from Lordan *et al*(2008) and this study (see Section 6.3) indicate a greater likelihood of finding substantial numbers of smaller crayfish in spoil relative to larger crayfish

- *Enhancements:* Traditionally OPW channels have been characterised by their trapezoidal cross sectional shape. 'Naturalisation' of the cross-section occurs over time and this trend has obvious benefits to crayfish ecology, introducing physical and biotic diversity.

  Some of the elements of the OPW's 10-point environmental guidance notes contribute further to channel diversity and creation of additional niches of benefit to crayfish. An accelerated programme of implementation of the 10-point guidance notes will occur under the OPW's new Environmental River Enhancement Programme (EREP), which has identified a target of 100 km, annually, of river channel for 'enhancement work' over the five-year study (2008 – 2012). The 'enhanced maintenance' element of EREP will focus on use of strategies within the 10-point programme that will benefit biodiversity in its broadest sense in the course of normal river maintenance work.

  Additionally, the 'enhancement' strand within EREP will undertake capital works in selected channels geared to reinstate a more natural hydromorphology and river corridor regime, replacing uniform glides with a range of appropriate instream structures and fencing banks to encourage robust growth of riparian vegetation. Considerable use will be made of stone material to construct such features as weirs, marginal rock armour, deflectors and bolder clusters. Such structures will create a mosaic of three-dimensional features that will be conducive to crayfish habits. The

fencing of banks will foster growth of marginal vegetation, including tall grasses, such as *Phalaris*, that provide overhead cover at the water's edge to the advantage of crayfish.

- *Modification of OPW inchannel structures:* Where OPW structures, such as weirs and bridges, are blocking the upstream movement of crayfish, modifications to these structures must be considered, in order to conform with hydromorphological continuity/fish passage as required in the Water Framework Directive.

  Bridges are an issue where flow continuity can be disrupted, with adverse impact on crayfish dispersal upstream. Observations have identified channels where maintenance was undertaken, in an upstream direction, to the extent that overdeepening of the channel bed took place. This resulted in lowering of bed level, and hence water surface level, up to the bridge but the 'regrading' could not be continued through the bridge floor, creating a step from low flow water level up onto the floor or apron of the bridge. Such stepping can result in isolation of crayfish populations both physically and, ultimately, genetically.

  The elimination of barriers to hydromorphological continuity is integral to requirements of the Water Framework Directive. Lengths of overdug channels create problems for stability of bridge structures and aprons. Undertaking works to protect the infrastructure should also eliminate the physical 'stepping' effect and thus facilitate unimpeded crayfish passage to spawning areas. Such works may simply require placement of necessary amounts of rock armouring at the downstream end of the structure. This would serve the twin purposes of dispersing any downcutting by falling water as well as providing a continuum between the downstream water level and the bridge floor level.

8. Conclusion and Summary

It is apparent from Chapter 6 that OPW's maintenance programme has the capacity to have severe adverse impacts on populations of crayfish, resident in a wide range of habitat types in river channels. Their prevalence in such diverse areas as rooted vegetation in fine sediment, associated with stands of *Sparganium erectum*, in low gradient channels, in water-celery dominated gravelled or stony channels and in more high-gradient riffle-glide habitats is a further complication for OPW, in terms of addressing conservation issues with channel conveyance issues in a range of habitat types. There is no 'one-size-fits-all' solution in endeavouring to mitigate for crayfish.

A number of the mitigation measures proposed, particularly those strategic ones, will create a management climate where potentially significant crayfish issues will be flagged well in advance of maintenance, enabling appropriate measures to be taken. Similarly, some of the strategic measures are already in place in OPW's general work processes but are not necessarily seen as pertinent to crayfish conservation and mitigation.

Operationally, there is, potentially, a real dilemma if OPW maintenance machines excavate moderate – substantial numbers of crayfish during maintenance. CFB has direct experience of sampling the contents of machine buckets in a quantitative manner. A decision to implement such an approach as standard when crayfish, especially juveniles, are encountered would have significant organisational ramifications for OPW, many of which are not the domain of this report. Such a protocol does represent a realistic response to conservation of stranded crayfish and OPW should give consideration to the incorporation of this approach into standard operating procedures (SOPs) currently being developed by them. The loss of habitat and the potential for survivors to find new living spaces are additional issues of concern.

Going forward, it is clear that OPW can anticipate encountering crayfish in a large number of its channels that require maintenance. In many cases, numbers will be small and populations patchily distributed. In many other cases, however, it is very likely that

substantial population densities will be encountered in a range of habitat types. It is inevitable that loss of habitat will occur and that mortalities will occur. The only way to attempt to offset this is to only implement channel conveyance improvement measures that do not impact on the channel bed. This would, in turn, preclude management of sediment deposition and of marginal and instream vegetation associated with such soft sediments, leading to conflict with the OPW's conveyance management role.

The impacts identified will occur in both SAC and non-SAC channels. The occurrence of crayfish habitat and populations presents a real conservation dilemma to OPW in expediting its legal obligations to channel maintenance under the1945 Arterial Drainage Act. The dovetailing of such obligations with conservation requirements of crayfish and development of agreed outcomes will, it is hoped, be advanced through use of this EcIA document and its proposals. In particular, close liaison between OPW, National Parks and Wildlife Service and the Fisheries Boards service is required to develop consistent and agreed processes in regard to channel maintenance in crayfish habitats.

The findings of the OPW-funded two-year study, reported in Lordan et al (2008) and used here (Section 6), are seen as highly important by OPW in identifying the real scale of impacts and in pointing to workable mitigation solutions. The post-maintenance impacts will continue to be studied within the new EREP investigations of OPW with a view to assessing duration of impact and nature and degree of recovery of impacted populations of crayfish and their habitat.

9. References

Brewis, J.M. and Bowler K. 1982. The growth of the freshwater crayfish *Austropotamobius Pallipes* in Northumbria. *Freshwater Biology,* 12, 187-200.

Brewis, J.M. and Bowler, K. 1983. A study of the dynamics of a natural population of freshwater crayfish, *Austropotamobius pallipes. Freshwater Biology,* 13, 443-452.

Brookes, A. 1987 The distribution and management of channelised streams in Denmark. *Regulated Rivers* 1, 3-16.

Byrne, C.F., Lynch, J.M. and Bracken, J.J. 1999. A sampling strategy for stream populations of white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet) (Crustacea, Astacide). *Biology and Environment: Preceedings of the Royal Irish Academy*, Vol. 99B, No. 2, 89-94.

Demers, A. 2001. A survey of the distribution and relative abundance of the white clawed crayfish, *Austropotamobius pallipes*, in the rivers Barrow, Multeen and Awbeg. Dúchas, Heritage Service.

Demers, A. and Reynolds, J.D. 2002. A survey of the white-clawed crayfish, *Austropotamobius Pallipes* (Lereboullet), and of water quality in two catchments of eastern Ireland. *Bulletin Français de la Pêche et de la Pisciclture,* 367: 729-40.

Demers, A. Lucey, J. McGarrigle, M.L. and Reynolds, J.D. 2005. The Distribution of the White-Clawed Crayfish, *Austropotamobius Pallipes*, in Ireland. Biology *and the Environment: Preceedings of the Royal Irish Academy*, Vol. 105B, No. 2, 65-69, Royal Irish Academy.

EIRE 1945 Arterial Drainage Act 1945, No. 3 of 1945. Stationery Office, Dublin.

Gardiner, M.J. and Radford, T. 1980 *Soil associations of Ireland and their land use potential*. An Foras Taluntais, Dublin 142pp.

Gilligan, N. and Dooley, R. 2007 Screening of Natura 2000 sites for impacts of arterial drainage maintenance operations. *Series of Ecological Assessments on Arterial Drainage* Maintenance No. 1. Office of Public Works, Dublin.

Hockin, D.L. 1985 The impact of river channelization II Channelization : Some engineering aspects. *The Geographical Journal* 151, 54-57.

Hogger, J.B. & Lowery, R.S. 1982. The encouragement of freshwater crayfish populations by attention to the construction and maintenance of waterways. *Journal of Institution of Water Engineers and Scientists*, 36, p214-220.

Holdich, D.M. 2003. Ecology of the White-clawed Crayfish. Conserving Natura 2000 Rivers Conservation Techniques Series No. 1. English Nature, Peterborough.

Howard, J. 1980 Current practise in assessing drainage impacts. IN : *Impacts of Drainage in Ireland*. NBST workshop, Dublin. Paper 7, 1-39.

IEEM 2006 *Guidelines for Ecological Impact Assessment in the United Kingdom*. Institute of Environmental Ecology and Management http://www.ieem.net/ecia/index.html 17.9.2008

Jay, D. and Holdich, D.M. 1981. The distribution of the crayfish, *Austropotamobius pallipes,* in British waters. *Freshwater Biology*, 11: 121 – 129.

Kennedy, G.J.A. 1980 Drainage related changes in salmonid and invertebrate populations in the River Camowen. *Proceedings of the Institute of Fisheries Management Conference*, Magee University College, 63-80.

King, J.J. 1996. Channel maintenance in drained Irish catchments : experimental strategies, ecological impacts and management implications. Ph.D. Thesis, National University of Ireland, 160pp.

King, J.J, O'Grady, M.F. and Curtin, J. 2000. The Experimental Drainage Maintenance (EDM) Programme: engineering and fisheries management interactions in drained Irish salmonid channels. *Verein Internationale Verein Limnologie.* 27: 1532-1535.

King, J.J., Hanna. G. and Wightman G.D. 2008. Ecological Impact Assessment (EcIA) of the effects of statutory arterial drainage maintenance activities on three lamprey species (*Lampetra planeri* Bloch, *Lampetra fluviatilis* L. and *Petromyzon marinus* L.). *Series of Ecological Assessments on Arterial Drainage Maintenance* No.9, Environment Section, Office of Public Works, Galway.

Lordan, M., Wightman G.D. and King J.J. 2008 Impacts of OPW's Channel Maintenance Programme on the status and distribution of crayfish (2005-2007): Technical Report to OPW Environment Unit.

Lowery, R.S. 1988. Growth, moulting and reproduction. *Freshwater Crayfish* (Holdich, D.M. and Lowery R.S. Eds.), 83-113.

Lucey, J. and McGarrigle, M. L. 1987. The distribution of the crayfish *Austropotamobius pallipes* (Lereboullet) in Ireland. *Irish Fisheries Investigations* Series A. *(Freshwater)* 29 1-13.

Lynn, M.A. 1980 The arterial drainage programme : its background, economic and environmental effects. IN : *Impacts of drainage in Ireland.* NBST Workshop, Dublin. Paper 1, 1-12.

Matthews, M. and Reynolds, J.D. 1992. Ecological impact of crayfish plague in Ireland. *Hydrobiologia,* Volume 234, No. 1, 1-6.

Matthews, M. and Reynolds, J.D. 1995. A population study of the white-clawed crayfish *Austropotamobius pallipes*(Lereboullet) in an Irish reservoir. Biology and the Environment: Proceedings of the Royal Irish Academy, 95B, (2), 99 - 109.

Matthews, M. Reynolds, J.D. and Keatinge, M.J. 1993. reduction and benthic community alteration by the crayfish *Austropotamobius pallipes*(Lereboullet). of southwestern Louisiana, LaFayette, USA, 289-299.

McFadden, Y.T. and Fairley, J.S. 1984. Food of otters *Lutra lutra* (L.) in an Irish limestone river system with special reference to the crayfish *Austropotamobius pallipes* (Lereboullet) in Ireland. *Journal of Life Sciences, Royal Dublin Society, 5,* 65-76.

Moriarty, C. 1971. The crayfish *Astacus* of an Irish lake. *Irish fisheries investigations*, 6(A): 12-20.

Moriarty, C. 1973. A Study of *Austropotamobius pallipes* in Ireland. In S. Abrahamsson (ed.) *Freshwater Crayfish, the First International Symposium on Freshwater Crayfish,* Austria 1972, 57 – 68. Lund. Studentlitteratur.

Niemi G. J., DeVore P., Detenbeck N., Taylor D., Lima A., Pastor J. 1990 Overview of case studies on recovery of aquatic systems from disturbance. *Environmental Management* 14, 571-587.

O'Flynn, T.P. 1932 Notes on the design of arterial drainage schemes. *Transactions of the Institution of Civil Engineers of Ireland*, 58, 233-274.

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

Peay, S. 2000. Guidance on works affecting white-clawed crayfish, prepared for English Nature and the Environment Agency, p.27.

Peay, S. 2003. Minimising loss of crayfish and habitat during works on watercourses. *Bulletin Français de la Pêche et de la Pisciclture,* 370-371: (CRAYNET Vol. 1): 193-207.

Peay, S. 2004. Keynote A cost-led evaluation of survey methods and monitoring for white clawed crayfish –Lessons from the UK-. *Bulletin Français de la Pêche et de la Pisciclture,* (2004) 372-373: 335-352.

Peay, S. Proud, A. and Ward, D. 2006. White-clawed crayfish in muddy habitats: monitoring the population in the river Ivel, Bedfordshire, U.K. *Bulletin Français de la Pêche et de la Pisciclture*, 380-381: 1079-1094.

Pratten, D.J. 1980. Growth in the crayfish *Austropotamobius Pallipes* (Crustaces: Astacidae). *Freshwater Biology,* 10, 401-412.

Reynolds, J.D. 1978. 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 Biographical Society,* No.6, 18 – 24.

Reynolds, J.D. 1988. Crayfish extinctions and crayfish plague in Central Ireland. *Biological Conservation,* 45, 279 – 285.

Reynolds, J.D. 1997. The present status of freshwater crayfish in Ireland. *Bulletin Français de la Pêche et de la Pisciclture,* 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. Gouin, N. Pain. S. Grandjean, F. Demers, A. and Souty-Grosset, C. 2002 a. Irish crayfish populations: ecological survey and preliminary genetic findings. *Freshwater Crayfish,* 13, *Systems, genetics and evolution*, 584-593.

Reynolds, R.J. Demers, A. Marnell, F. 2002 b. Managing an abundant crayfish resource for conservation – *A. Pallipes* in Ireland. *Bulletin Français de la Pêche et de la PiscicIture,* 367: 823-832.

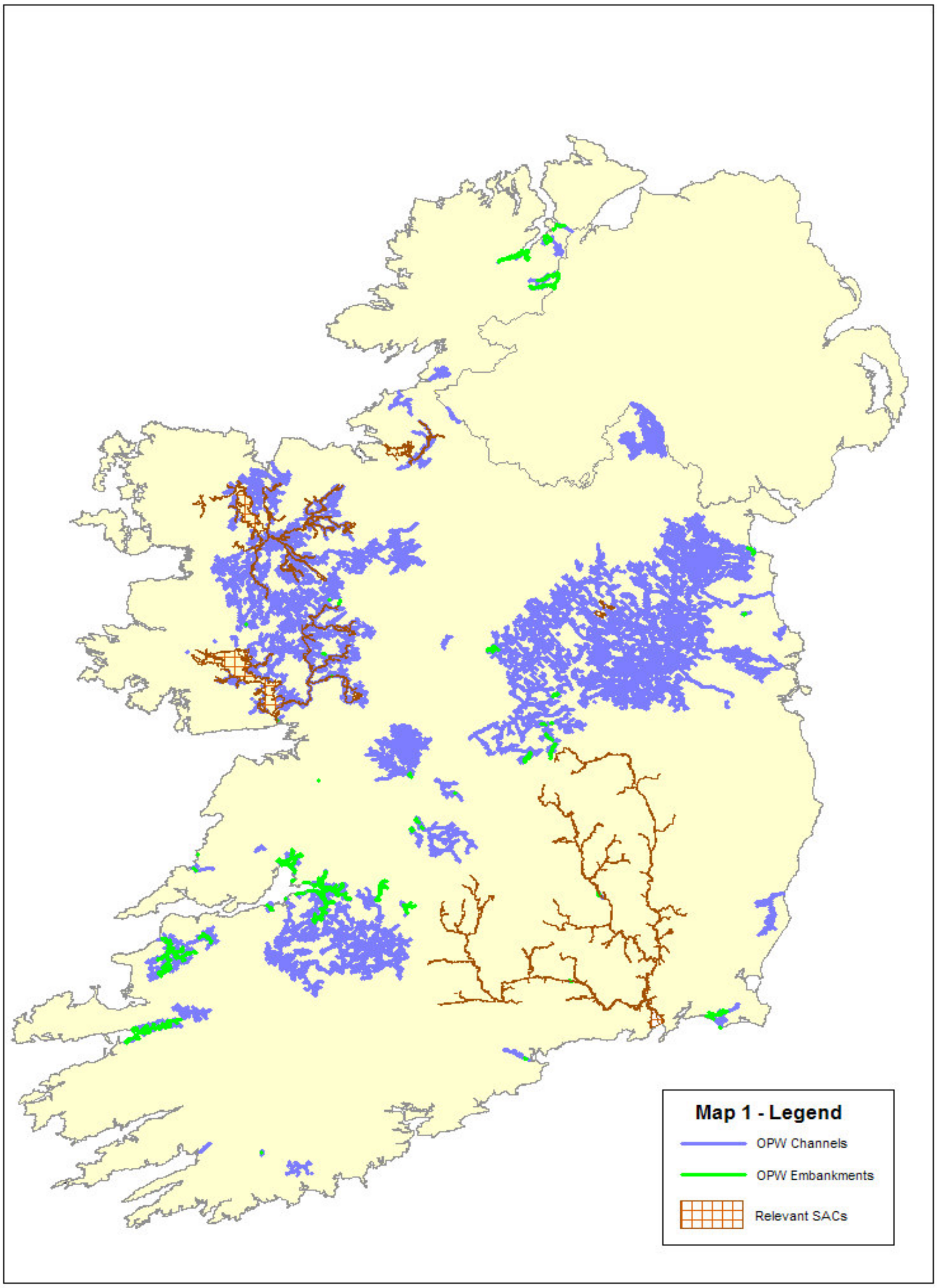
Robinson, C.A. Thom, T.J. and Lucas, M.C. 2000. Ranging behaviour of a large freshwater invertebrate, the white-clawed crayfish *Austropotamobius pallipes. Freshwater Biology,* 44, 509-521.

Ryan, T.D. 1986 Agricultural drainage practises in Ireland. *Environmental Geology and Water Sciences* 9, 31-40.

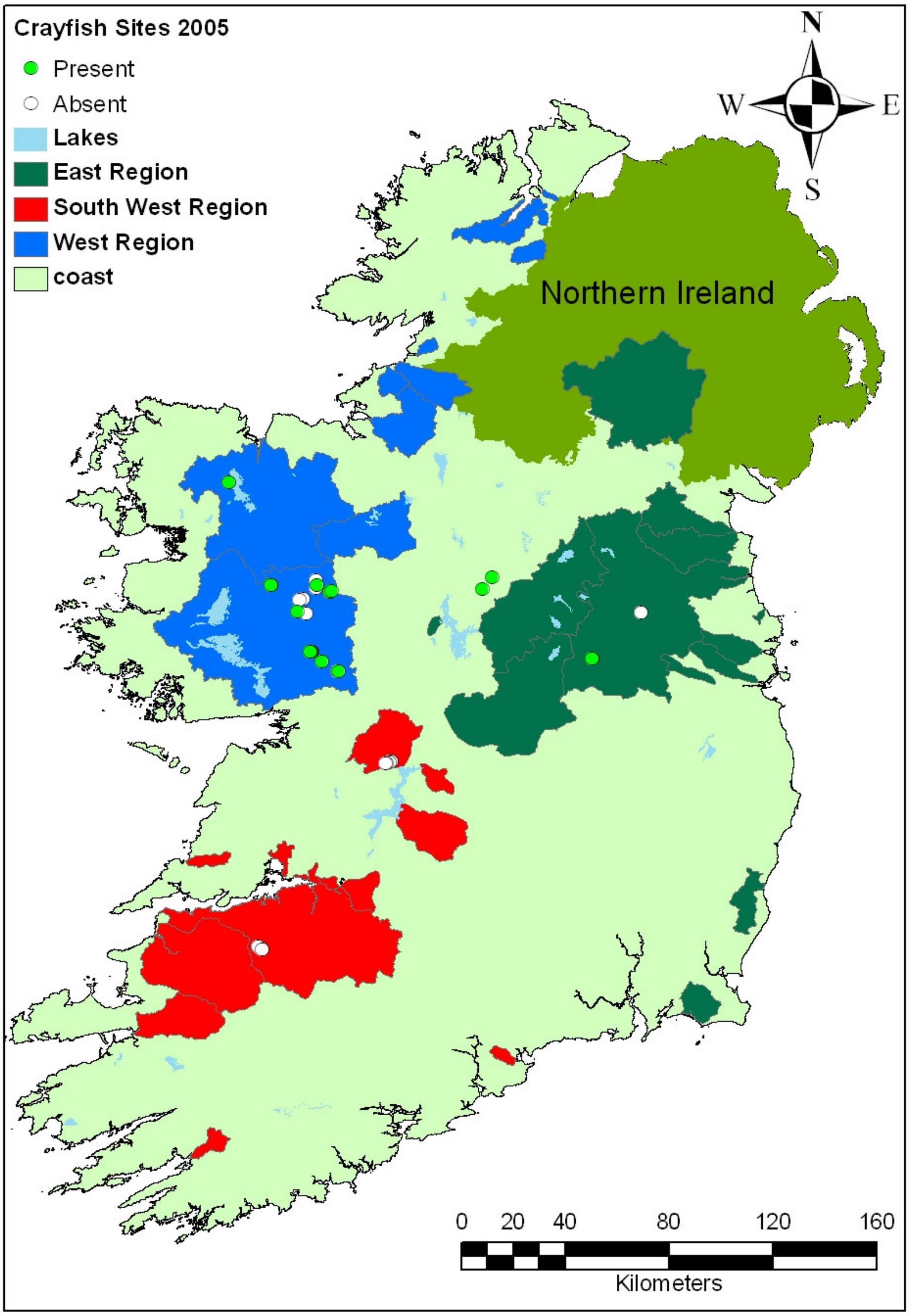
Schoof, R. 1980 Environmental impact of channel modification. *Water Resources Bulletin* 16, 697-701.

Sedell J. R., Reeves G. H., Hauer F. R., Stanford J. A., Hawkins C. P. 1990 Role of refugia in recovery from disturbances: modern fragmented and disconnected river systems. *Environmental Management* 14, 711-724.

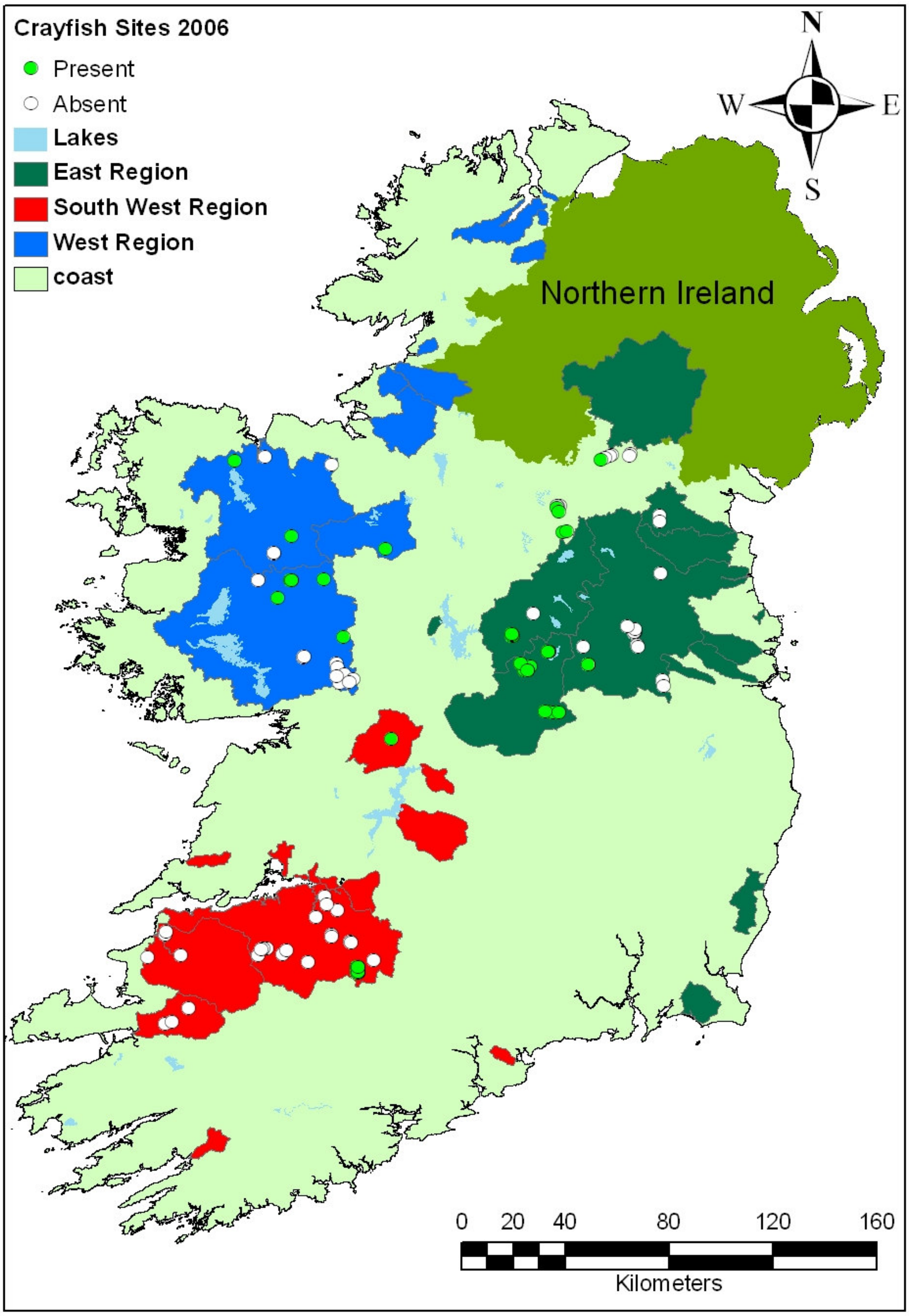
Souty-Grosset, C. 2005. Introduction: The EU-Network Craynet – Impacts on Fundamental Questions. *Bulletin Français de la Pêche et de la PiscicIture,* 376-377: 495-503.



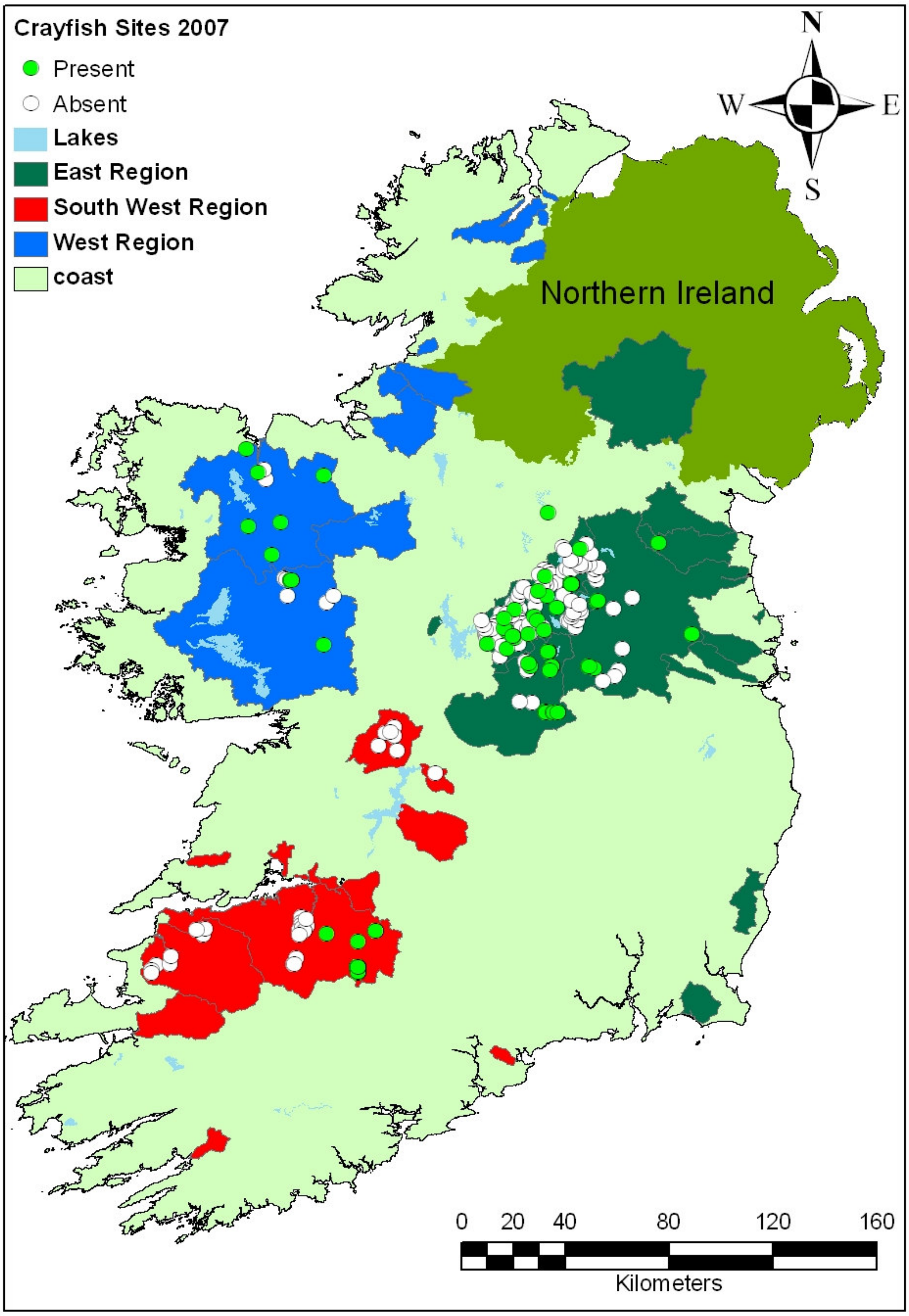
Map 1: OPW Channels & Embankments with relevant Special Areas of Conservation



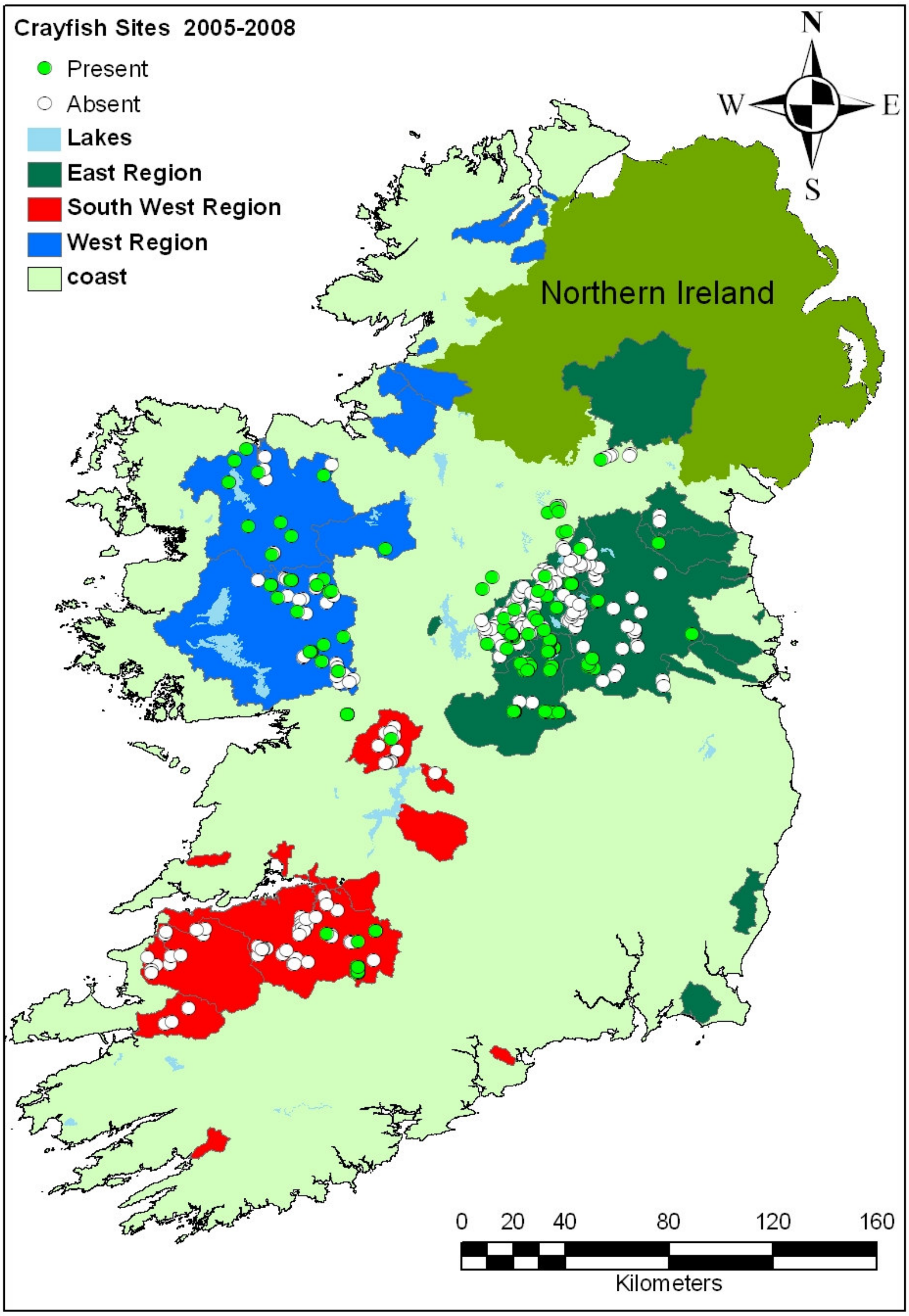
Map 2: Crayfish Survey Sites 2005



Map3: Crayfish Survey Sites 2006



Map 4: Crayfish Survey Sites 2007



Map 5: Crayfish Survey Sites 2005-2008