Management measures for self-propagated future recovery of crawfish, *Palinurus elephas*, in Welsh waters

B. Leslie & R. L. Shelmerdine

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CRYNODEB GWEITHREDOL

Mae poblogaethau'r cimwch coch, Palinurus elephas, yn nyfroedd Cymru wedi dirywio'n sylweddol ers yr 1960au a'r 1970au pan ddigwyddodd newid mewn arferion pysgota. Mae'r cramennog môr-waelodol mawr hwn yn rhywogaeth allweddol mewn nodweddion riffiau yn yr Ardaloedd Cadwraeth Arbennig (ACA) morol presennol a hefyd yng nghyd-destun ehangach ecosystem forol Cymru. Ystyrir ei bod yn bwysig adfer poblogaethau'r cimwch coch er mwyn sicrhau Statws Amgylcheddol Da i ecosystemau morol dan Gyfarwyddeb Fframwaith y Strategaeth Forol (MSFD). Mae'r adroddiad hwn yn asesu potensial y mesurau rheoli presennol a darpar fesurau rheoli i gynorthwyo i adfer poblogaethau'r cimwch coch yn nyfroedd Cymru drwy hunan-luosogi ac yn gwneud argymhellion ar y gofynion o safbwynt casglu data i'r dyfodol.

Un o'r prif anawsterau wrth wneud asesiad o'r mesurau rheoli i hwyluso adferiad y cimwch coch yw'r diffyg data ar fioleg a physgodfa'r rhywogaeth hon, ac mae hynny'n golygu nad yw'n bosibl gwneud asesiadau dadansoddol o'r stoc. Mae'r potensial i'w hadfer felly'n cael ei asesu ar sail y wybodaeth bresennol am fioleg y rhywogaeth hon o'i holl ddosbarthiadau daearyddol, ac o astudiaethau a wnaed ar gimychiaid pigog eraill. Bu data pysgodfeydd, ar ffurf glaniadau am bob uned ymdrech (LPUE), yn cael ei gasglu ar gyfer pysgodfeydd cimwch coch yn ne Cymru ers y 1980au dan gynllun trwydded pysgod cregyn a sefydlwyd gan Bwyllgor Pysgodfeydd Môr De Cymru (SWSFC). Mae'r set ddata hon wedi'i dynodi fel meincnod i gynrychioli adferiad tuag at darged adfer interim sy'n anelu at boblogaeth sydd â'r nodweddion perthnasol i gynrychioli Statws Amgylcheddol Da.

Ymysg y mesurau rheoli presennol y mae maint lleiaf ar gyfer glanio (MLS), dynodiadau cadwraeth natur, a chyfyngiad ar ddal anfasnachol. Er bod y cyfyngiadau ar ddal a'r MLS yn benodol i'r cimwch coch, nid ydynt wedi esgor ar ddim cynnydd mewn LPUE ers eu cyflwyno. Nid oes gan y dynodiadau cadwraeth natur sydd wedi'u sefydlu ar hyn o bryd ddim mesurau rheoli gorfodol yn benodol i'r cimwch coch, er bod ardal gaeedig i rwydo yn cael ei gweithredu'n wirfoddol yng ngwarchodfa natur forol (GNF) Skomer ac ymrwymiad gwirfoddol ymysg deifwyr hamdden i beidio â chymryd dim cimychiaid coch. Mae'r asesiad yn dod i'r casgliad nad oes dim un o'r mesurau rheoli sydd wedi'u sefydlu ar hyn o bryd yn debygol o gyfrannu at adfer cimychiaid coch yn nyfroedd Cymru.

O'r mesurau rheoli posibl a aseswyd, ystyriwyd mai'r rheini sy'n rheoli gweithgaredd pysgota yw'r rhai sydd â'r potensial mwyaf i gynorthwyo adferiad y cimwch coch, yn hytrach na dynodiadau cadwraeth natur newydd. Wrth gau ardaloedd dethol a gwahardd glanio'r cimwch coch, fel ei gilydd, ceir y potensial i leihau marwolaethau yn sgil pysgota a chynyddu allbwn atgenhedlu'r boblogaeth. Wrth gyflwyno maint glanio lleiaf a mwyaf priodol ar y cyd, ceir y potensial i gynyddu allbwn atgenhedlu'r boblogaeth. Ystyriwyd bod rhai o'r mesurau rheoli pysgodfeydd y'u haseswyd yn fwy addas i'w defnyddio gyda phoblogaeth sydd yn adfer. Ymysg y rhain yr oedd cyfyngiadau ar offer, gwaharddiadau ar ddulliau pysgota unigol, cyfyngiad ar faint dalfeydd, a chyfnodau cau tymhorol. Cafodd Gwarchodfeydd Morol Gwarchodedig Iawn (HPMCZ) yng Nghymru a Pharthau Cadwraeth Morol (MCZ) yn Lloegr hefyd eu hasesu, fodd bynnag, gallai eu maint cymharol fychan a'r ffocws ar gefnogi swyddogaeth ac amrywiaeth ecosystemau gyfyngu ar eu potensial i fod o fudd i adfer y cimwch coch.

Mae ymchwil pellach yn ofynnol er mwyn penderfynu pa rai o'r mesurau rheoli fyddai fwyaf effeithiol yn hwyluso adferiad poblogaethau'r cimwch coch yn nyfroedd Cymru. Ar hyn o bryd nid yw'n glir a fyddai cynnydd yn allbwn atgenhedlu'r boblogaeth yn arwain yn uniongyrchol at gynnydd mewn lefelau recriwtio i'r boblogaeth. Mae'r cysylltiad rhwng poblogaethau yn nyfroedd Cymru hefyd yn bwysig i benderfynu ar ba lefel y byddai angen cyflwyno mesurau rheoli o bosibl. Oherwydd diffyg gwybodaeth am recriwtio i boblogaethau'r cimwch coch yng Nghymru, mesurau rheoli a fydd yn cyfyngu ar dynnu oddi wrth y boblogaeth ac yn cynyddu'r allbwn atgynhyrchu posibl sy'n debygol o fod yn fwyaf effeithiol i hwyluso eu hadferiad. Mae

gwybodaeth bellach hefyd yn ofynnol i benderfynu a fyddai poblogaethau Cymru yn elwa o fesurau rheoli a weithredir ar lefel y moroedd rhanbarthol neu’r UE. Mae’r fframwaith deddfwriaethol ar gyfer gweithredu mesurau rheoli pysgodfeydd yn ystyriaeth bwysig o safbwynt effeithiolrwydd mesurau rheoli a dylid rhoi ystyriaeth i hwn yn ystod y broses benderfynu.

EXECUTIVE SUMMARY

Populations of the crawfish, *Palinurus elephas*, in Welsh waters have declined significantly since the 1960s and 1970s when changes in fishing practice took place. This large benthic crustacean is a key species in reef features within existing marine Special Areas of Conservation (SACs) and also within the wider context of the Welsh marine ecosystem. Recovery of crawfish populations is considered important in gaining Good Environmental Status (GES) for marine ecosystems under the Marine Strategy Framework Directive (MSFD). This report assesses the potential for both existing and potential management measures to aid in the self-propagated recovery of crawfish populations in Welsh waters and makes some recommendations on future data collection requirements.

One of the main difficulties in carrying out an assessment of management measures in facilitating crawfish recovery is a lack of data on both the biology and fishery of this species, which means that analytical stock assessments are not possible. The potential for recovery is therefore assessed based on existing knowledge of the biology of this species from throughout its geographical distribution, and from studies carried out on other spiny lobsters. Fisheries data, in the form of landings per unit effort (LPUE), has been collected for crawfish fisheries in south Wales since the 1980s under a shellfish permit scheme put in place by the South Wales Sea Fisheries Committee (SWSFC). This dataset has been identified as a benchmark to represent recovery towards an interim recovering target heading towards a population with the relevant characteristics to represent GES.

Existing management measures include minimum landing sizes (MLS), nature conservation designations, and a non-commercial catch limit. While the catch limits and MLS are specific to crawfish they have not elicited any increase in LPUE since they were introduced. The nature conservation designations currently in place do not have any mandatory management measures specific to crawfish, although there is a voluntary closed area to netting within the Skomer Marine Nature Reserve (MNR) and a voluntary no-take of crawfish by recreational divers. The assessment concluded that none of the management measures currently in place are likely to contribute to the recovery of crawfish in Welsh waters.

Of the potential management measures assessed, those which controlled fishing activity were deemed to have the most potential to aid crawfish recovery, as opposed to new nature conservation designations. Both appropriately selected area closures and a prohibition on the landing of crawfish have potential to both reduce fishing mortality and increase the reproductive output of the population. The introduction of appropriate minimum and maximum landing sizes concurrently, and prohibitions on the landing of berried crawfish, both have the potential to increase the reproductive output of the population. Some of the fisheries management measures assessed were deemed to be more suitable for application within a recovering population. These included gear restrictions, prohibitions of individual fishing methods, catch limits, and seasonal closures. Highly Protected Marine Conservation Zones (HPMCZ) in Wales and Marine Conservation Zones (MCZ) in England were also assessed, however, their relatively small size and focus on supporting ecosystem diversity and function may limit their potential to benefit the recovery of crawfish.

Further research is required in order to determine which of the management measures would be most effective in facilitating the recovery of crawfish populations in Welsh waters. At present it is not clear if increases in the reproductive output of the population would directly result in increased recruitment to the population. The connectivity of populations within Welsh waters is also important in determining at what level management measures may need to be introduced. Due to the lack of information surrounding recruitment to Welsh crawfish populations, management measures which both reduce removals from the population and increase the potential reproductive output are likely to be most effective in facilitating recovery. Further information is also required to make a determination of whether or not Welsh populations would

benefit from management measures implemented at the EU or regional seas level. The legislative framework for implementing fisheries management measures is an important consideration on the effectiveness of management measures and should be taken into consideration during the decision making process.

1 INTRODUCTION

The crawfish, *Palinurus elephas*, is a large benthic crustacean found mainly on rocky seabeds from the Azores in the south to Norway in the North and throughout the Mediterranean. This species is commercially valuable and has been targeted by fisheries for over a century; however, fisheries in Wales and beyond have seen a steep decline in landings since the 1960s which coincided with the introduction of net fisheries for this species.

The crawfish is a priority species for the UK Biodiversity Action Plan and is also an important component of Special Areas of Conservation (SACs) designated for rocky reefs. It has been identified by the National Assembly for Wales as one of the species of 'principle importance for the purpose of conserving biodiversity' in Wales and is listed in the Natural Environment Rural Communities (NERC) Act 2006. This act requires that steps be taken that are 'reasonably practicable to further the conservation of the living organisms' listed and to 'promote the taking by others of such steps'. It is therefore important to understand the potential impact of fisheries management measures, and other management measures, on the recovery of this species both in designated areas and within the wider context of Welsh waters as a whole, including the potential impact of regulations or management measures in adjacent waters.

The aim of this report is to establish the potential effectiveness of existing and possible management measures (both fishery and nature conservation based) to enable self-propagated recovery of *P. elephas* populations in Welsh waters, within the context of their declined status. This is to be carried out through a review of relevant literature on this and other crustacean species to determine, using the best available data and information, the potential benefit of the different management measures.

1.1 Biology

Two reviews have been carried out presenting the body of information on the biology of *Palinurus elephas* (Hunter, 1999, Goñi and Latrouite, 2005). The following sections focus on the aspects of biology which are most relevant to the self-propagated recovery of crawfish in Welsh waters.

1.1.1 Distribution and Habitat Preferences

The European spiny lobster, or crawfish (*Palinurus elephas*, Fabricius, 1787), is widely distributed from its southern limit in west Africa to its northern limit off western Norway (Mercer, 1973) but also includes the Mediterranean, Azores, and the Adriatic and Aegean Seas (Goñi and Latrouite, 2005, Jackson *et al.*, 2009). Around the British Isles, *P. elephas*, has been found to occur mainly along the west coast although some historical records have recorded sightings of *P. elephas* on the Scottish east coast (Ansell and Robb, 1977). The authors also noted the occurrence of *P. elephas* larvae in this area.

Palinurus elephas show a preference for exposed areas of reef with strong currents and often steep topography with crevices. Mercer (1973) reported that *P. elephas* preferred reef areas close to relatively deep water of at least 30 m. All *P. elephas* collected by Ansell and Robb (1977), using SCUBA divers, were from areas of strong tidal currents on shallow inshore reefs which were interspersed with steep vertical rock faces. The authors noted that the majority of specimens were found on rocky surfaces in the open or among weed but occasionally some were found in crevices. This has particularly been noted for juveniles which can be found grouped together, although in separate crevices within a gully (Jones, in prep). Ansell and Robb (1977) noted a varying depth of capture from 5 to 20 m. Hayward and Ryland (2004) reported a depth distribution of between 20 and 70 m. However, information cited in Goñi and Latrouite (2005) suggest that their distribution extends down to 200 m.

There is no known published information available on the depth distribution and habitat preference of *P. elephas* within Welsh waters. Underwater SCUBA diving between 1960 and 2006 documented 62 records of *P. elephas* (records held by Marine Recorder and supplied to the authors by CCW). Of these, only 24 had a biotope code assigned to the location and these consisted of either Infralittoral Rock (IR) or Circalittoral Rock (CR). Where the classification extended beyond this, both rock habitats were classed as either high energy or moderate energy sites. A large amount of habitat data for the southern Irish Sea is available through the HABMAP project (see Robinson *et al.*, 2009a; Robinson *et al.*, 2009b; Robinson *et al.*, 2011). The majority of the area presented utilises predictive habitat mapping based on existing data, but some sub-areas were intensively surveyed with a higher degree of confidence closer to shore. The results do show that, based on the biotope classification, suitable habitat for *P. elephas* is present within Welsh waters, including within the existing SACs of Pembrokeshire Marine and Pen Llŷn a'r Sarnau. Due to the predictive nature of the HABMAP data it is not possible to utilise it to make any precise estimates of the actual extent and distribution of available crawfish habitat within Welsh waters.

Ansell and Robb (1977) suggested that *P. elephas* may have a seasonal migratory pattern in Scottish waters as there is an increased catch in shallow waters during spring and summer, moving to deeper waters in the winter. Although the authors note this pattern may be due to a seasonal variation in the fishing pattern rather than an actual seasonal migration, the findings are corroborated by Mercer (1973). Mercer (1973) also recorded smaller scale movements of *P. elephas* moving to deeper water, during moulting, for shelter from swell and strong currents. Mercer (1973) defined seven different types of movement carried out by *P. elephas* in Irish waters. These movement types were:

Type A Regular onshore/offshore migrations of seasonal occurrence

Type B Large-scale migrations involving a major proportion of the population moving either in single files or 'en masse'

Type C Reproductive migrations and movements

Type D Relatively small local movements for feeding and moulting

Type E Migrations due to weather conditions

Type F Isolatory movements of animals of the same sex or juveniles

Type G Random wanderings

The author noted that although other studies did not record all of the above movement types, this was most probably due to the methodology used rather than the lack of movement type within a particular population. Movement Type G was considered a source of natural repopulation of reef systems which had experienced heavy fishing pressure with repopulation estimated to take between a week and ten days (Mercer, 1973). However, this would only apply if there was a thriving, widespread *P. elephas* population in the near vicinity. Goñi and Latrouite (2005) reported on tag-recapture studies which suggested a maximum movement of *P. elephas* of 20 km after one to eight years at large, although most animals were found to move less than 5 km (see also Follesa *et al.*, 2009). The authors also noted some additional studies in the Mediterranean which report movements of 50 and 70 km. Follesa *et al.* (2009) reported on a total of 389 recaptured, tagged animals and showed that 60% of recaptures moved less than 2 km from the release site (nearly 80% were found <5 km from the release site) and only 2.3% of crawfish moved further than 20 km. The greatest movement was made by an 80 mm CL female which covered a distance of 134 km over 712 days. However, these results should be treated with a degree of caution as all animals were initially released in the centre of a protected area irrespective of their initial catch location. This may have had a corresponding effect on the distance travelled with regard to potential disorientation effects.

Tagging of *Panulirus argus* has shown that juveniles appeared to be more mobile than mature individuals, which were more residential in nature (Davis, 1977). Goñi *et al*. (2001) suggested that juvenile *Palinurus elephas* settled in shallow water but then underwent a migration to deeper water at between two and three years of age. The authors suggested that this migration took place during winter or spring.

1.1.1.1 Distribution of larval and post-larval stages

Palinurus elephas hatch from the egg into a planktonic larval stage, termed a phyllosoma. Phyllosoma go through several stages of development within the plankton before metamorphosing into the puerulus stage. The puerulus stage is a transitional stage to a benthic existence prior to becoming an adult (see section 1.1.3 for further information).

There are no free-swimming larval stages in *P. elephas* (Mercer, 1973). The author reports phyllosoma larval Stages I and II as common in inshore waters, close to shore off west Ireland, from May to early July. Stage III larvae were rare and only found in July and August off Ireland with a possible Stage IV recorded in mid-August (Mercer, 1973). The author noted no recordings of further larval stages or of the puerulus stage off Ireland. The later stage larvae are not found in near-shore environments but are found at variable distances, possibly 100 miles or more, offshore (Mercer, 1973). The phyllosoma larval stages are poor horizontal swimmers but are competent in making vertical movements within the water column (Goñi and Latrouite, 2005). Several studies were cited by Mercer (1973) with regard to larval distribution and corresponding interconnectivity. All the studies cited were from exposed areas such as California, Hawaii, and South Africa with all studies suggesting an initial offshore movement of larvae followed by a corresponding onshore movement driven by eddies potentially operating off the main current system. The author also noted that a lack of information on currents would make predictions of larval distribution very hard. It is not clear whether such a system would function in a more enclosed area such as that off Wales. It has been suggested that larvae produced in south Wales could be taken offshore by the Carnsore current and then return to Welsh waters via the Lands End Corner current (Davies, 1999).

Lambkin *et al.* (2010) carried out an in-depth analysis of residual currents around British and Irish coasts extending out into the Atlantic. The work carried out by Lambkin *et al.* (2010) had several caveats, two of which were in regard to; proximity to shore, and vertical movements. Confidence in the model produced by Lambkin *et al.* (2010) is reduced in areas close to shore, at and around headlands, and when depth of the animal or particle does not remain constant. Overall there seemed to be very little residual currents at 50% depth in Welsh waters off the Cardigan Bay/south Irish Sea area for all four seasons (Lambkin *et al.*, 2010) suggesting phyllosoma larvae may remain within the area for a substantial period. Annual residual current and direction for 50% depth reported by Lambkin *et al.* (2010) are shown in Figure 1.1. As mentioned previously, the phyllosoma stages exhibit an initial close correlation with inshore waters before being carried offshore where they are able to undertake vertical migrations in the water column (Mercer, 1973). Based on the data from Lambkin *et al.* (2010) connectivity in terms of larval supply to other *P. elephas* populations may be possible via a southerly distribution out of the Irish Sea along the south Irish coast to the Atlantic and also north along the west of England coastline into Scottish waters. Incoming residual currents would, in the south, come from the southwest of England and from the north along the Northern Ireland coast. This is based on residual currents at 50% depth and assumes no vertical movements. Detailed information on localised currents would have to be applied to the larval biology in the area while considering natural variation of larva release due to climatic conditions (see Section 1.1.3).

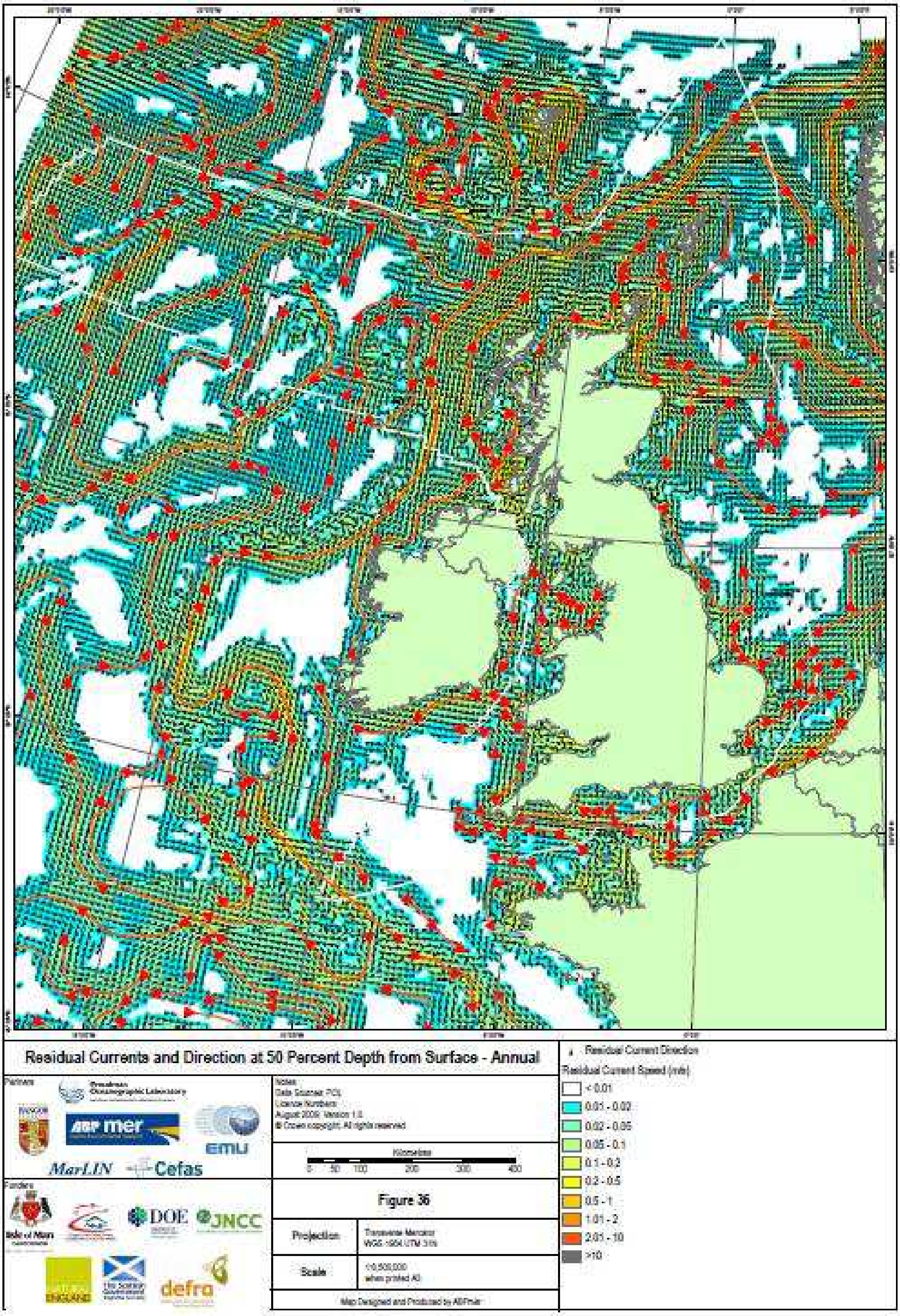

Figure 1.1 Annual residual currents and direction at 50% depth from surface obtained from Lambkin *et al.* (2010). This data should be taken when interpreting this data in relation to *Palinurus elephas* larval distribution, as discussed in the text.

1.1.2 Growth

Growth, of no more than four millimetres carapace length, has been recorded at the moult for *P. elephas*, although in some cases change in length was non-existent but weight increases, in some cases of over 50%, were observed (Ansell and Robb, 1977). Such small growth increments, sometimes negligible, were also reported by Mercer (1973) who also noted that such small increases were not uncommon in captive animals. Hepper (1977), studying 46 recaptured animals off Cornwall, recorded a range of growth increments of one to eight millimetres and calculated a mean growth increment of 1.96 ± 1.38 mm. The mean annual length increase of an Irish *P elephas* population, measured in their natural habitat, was calculated as 12.2 mm CL (30.5 mm total length, n = 7) for males and 12.0 mm CL (35.1 mm TL, n = 8) for females (Mercer, 1973). A larger growth study was conducted off Corsica but these results should be treated with caution when comparing to the colder climes of the Atlantic (cited in Hunter, 1999) as it is well known that temperature has an effect on growth rates. Age at length data was estimated by Mercer (1973) but extreme caution should be taken when applying the estimates (see Table 1.1). The author estimated males of 111 mm CL and females of 110 mm CL both to be about four to five years old.

Table 1.1 Estimated age at size for *Palinurus elephas* taken from Mercer (1973)*. Lengths refer to carapace lengths (CL).

Male		Female	
CL (mm)	Age (years)	CL (mm)	Age (years)
87	2-3	86	2-3
99	3-4	98	3-4
111	4-5	110	4-5
123	5-6	122	5-6
136	6-7	134	6-7
148	7-8	146	7-8
160	8-9	158	8-9
172	9-10		

* The author attached a cautionary warning to the data and recommended that if used, the lower age estimates should be considered.

Males are larger than females (Ansell and Robb, 1977, Hepper, 1977, Goñi and Latrouite, 2005) throughout their geographic distribution. The largest animals caught off the west coast of Scotland were measured as 170 mm carapace length (CL) in males and 158 mm CL in females (Ansell and Robb, 1977). The authors noted a similarity from studies in other geographic areas, namely an Irish population (males: 165 mm CL; females: 151 mm CL) and one from Cornwall (males: 182 mm CL; females: 152 mm CL).

1.1.3 Reproductive Biology

The reproductive biology of an Irish population of *Panulirus elephas* was extensively examined by Mercer (1973) with several additional studies reporting on the reproduction of *P. elephas* from various geographic locations. Much of this information has been summarised in two reviews (see Hunter, 1999, Goñi and Latrouite, 2005).

In UK waters female *P. elephas* moult in the summer months from July to September, (Mercer, 1973, Ansell and Robb, 1977, Hepper, 1977, Hunter, 1999) and the moult is completed in ten to 15 minutes (Mercer, 1973, and see Hunter, 1999 for a review). In Irish waters, *P. elephas,* move to deeper water to moult (Mercer, 1973) but on the Scottish west coast, moulting was observed to occur in inshore areas (Ansell and Robb, 1977). After moulting, the new shell hardens within seven to 19 days (see Hunter, 1999 for a review). Mating has been observed to take place within two weeks of the female moult (Ansell and Robb, 1977) with egg laying occurring five to ten days after this. The positioning of the spermatophore during mating is important and therefore the male and female must be of a similar size (Davies, 1999). The female then carries the eggs throughout the winter before they hatch in the following spring (Ansell and Robb, 1977). Mercer (1973) found egg hatching to have occurred by mid-May, although the author noted that this can vary depending on seasonal temperature fluctuations. In the Atlantic, incubation lasts around nine months and hatching takes two to eight days (Hunter, 1999). In the Atlantic, post hatching *P. elephas* spend up to a year in the water column as a larva (see also Section 1.1.1.1), termed phyllosoma (see Hunter, 1999, and Goñi and Latrouite, 2005 for reviews). There is very little observed information from post larva, termed puerulus, through to adulthood (Hunter, 1999).

Goñi *et al.* (2003a) found that there was considerable variation in egg production between females of similar size. The number of eggs per clutch was found to increase linearly with increasing body size, however the maximum reproductive yield, in terms of eggs per unit weight, occurred in females from 100 to 110 mm CL (Goñi *et al.*, 2003a). Hunter (1999) stated that, "as a general rule, fecundity in *P. elephas* is three to five times smaller than in spiny lobsters of the genera *Jasus* and *Panulirus*". Egg loss during incubation under laboratory conditions has been shown to vary from 10 to 30% (Mercer, 1973, and see Hunter, 1999 for a review) but this may not be representative of conditions in the wild.

The smallest berried female varied geographically, ranging from 67 mm CL to 121 mm CL with the smaller animals recorded in warmer waters (see Hunter, 1999 for a review). Hunter *et al.* (1996) reported the smallest berried female in southwest England measuring 90 mm CL and 121 mm CL in Wales while the smallest berried female in Scotland, measured by Ansell and Robb (1977), was 98 mm CL. Sexual maturity in an Irish population was estimated between 70 and 94 mm CL, with 50% maturity at 82 mm CL (Mercer, 1973). An assessment of the female reproductive biology of *P. elephas* in the Spanish Mediterranean indicated that females reached physiological and functional maturity at 76 to 77 mm CL, although individuals with ripe ovaries were observed as small as 69 mm CL (Goñi *et al.*, 2003a). Information on particular size at 50% maturity is summarised in Table 1.2. Males were slightly larger, reaching physiological maturity at 82.5 mm CL (Goñi *et al.*, 2003a). When looking at the female size where 50% of individuals are mature this varied from 95 mm CL in Brittany (Goñi and Latrouite, 2005) to 139.9 mm CL in Wales (Hunter *et al.*, 1996), as shown in Table 1.2.

There is a difference in reproductive behaviour relative to female size with larger females mating and laying eggs early in the breeding season and smaller females laying eggs later in the season. Male *P. elephas* have been shown to mate repeatedly throughout the breeding season (Goñi *et al.*, 2003a).

1.1.4 Biology Summary

The biology of *Palinurus elephas* has been studied in several geographic locations within its distribution. On a large geographic scale, two distinct areas of investigation were identified from the literature; the cooler Atlantic and the warmer Mediterranean. In the context of Welsh populations, studies from the latter region should always be treated with a degree of caution as temperature is a known variable affecting growth rates and the reproductive cycle. Interpretation of data collected from other species should also be carried out with caution, as aspects of their biology and location will be different to populations of *P. elephas* in Welsh waters.

Many studies have examined the reproductive biology of *P. elephas* in different geographic areas (see Section 1.1.3). There is a substantial amount of information available, although some data is deficient or scarce (e.g. information on male maturity and female fecundity in Welsh waters, see Table 1.2). The reproductive cycle from the female moult through to egg hatching, larval phase, to puerulus stage can range from around 21 to 22 months, based on the findings in Section 1.1.3, with the puerulus stage probably occurring from around April through to July, based on a moulting period of July to September. There is very little information in the literature regarding the puerulus stage to adulthood. It was suggested by Mercer (1973) from *in situ* observations that this stage may “prefer low salinity environments” but little to no data is available regarding aspects such as; time spent in low salinity environments, growth rates, and ecology to name but a few. Larval connectivity is one of the main areas of data deficiency with regards to the biology of *P. elephas* in Welsh waters (see Section 1.1.1.1). Further work would have to be conducted in order to investigate this fully.

Table 1.2 Data on size at maturity and fecundity from *Palinurus elephas* in different areas. The relationship between number of eggs (E) and carapace length (CL) are shown when available.

Location	♀ size at 50% maturity (mm CL)	Smallest ovigerous ♀ (mm) (n=total females sampled)	♀ fecundity	♂ size at maturity	Reference
Wales	139.8 (mean size of berried ♀)	121 (n=135)			Hunter *et al.* (1996)
SW England	135.0 (mean size of berried ♀)	90 (n=1592)			Hunter *et al.* (1996)
East Cornwall			65 000 to 184 000		Hepper (1977)
Ireland	82	70-90	E = 2553CL – 165602 40 560 to 214 128	84.5	Mercer (1973), cited in Hunter *et al*. (1996)
NW Ireland	119 (mean size of berried ♀)	85 (n=232)			Robinson *et al.* (2008)
Scotland		98			Ansell and Robb (1977)
Bay of Biscay			100 000		Valenciennes (1858)
Brittany	95 (mean size of berried ♀**)**	92			cited in Goñi and Latrouite (2005)
Portugal	110	84	E = 3355CL – 283832		Galhardo *et al.* (2006)
Portugal			82 000 to 209 000		as reported by Hunter (1999)
Portugal			E = 2520CL – 196225		cited in Galhardo *et al.* (2006)

Spanish Mediterranean	76.5 (n=192)	69	23 483 to 201 549 E = 2428CL – 148998	82.7 (n=94)	Goñi *et al.* (2003a)
Corsica		70	20 000 to 210 000		Campillo and Amadei (1978)

1.2 Fishery

Palinurus elephas command a high market price and have been subject to fishing activity for centuries, with fisheries in the UK and Ireland developing in the early 1900s. These fisheries were mainly carried out using pots until the introduction of trammel (and tangle) nets in the 1960s and 1970s (Groeneveld *et al.*, 2006). This resulted in increased fishing effort and greater efficiency of gear, and stocks declined. More recently there have been reported declines in *Palinurus* spp (*P. elephas* and *P. mauritanicus*) throughout all European and African countries between 1988 and 1996 (e.g. Galhardo *et al.*, 2006). It is generally accepted that that modernisation of fishing fleets and changes in fishing gear have resulted in over-fishing of crawfish stocks during these periods. However, in some cases, there is a lack of fisheries data with which to scientifically corroborate this.

1.2.1 Fishing Methods

The three main methods for catching *P. elephas* are netting (tangle and trammel), potting, and dive fisheries. Historically fisheries began by potting for crawfish and this was followed by the introduction of more efficient dive and net fisheries. Crawfish caught in pots in Welsh waters are a bycatch of fisheries for lobsters and crabs, there is no targeted pot fishery. Traditional rush traps have been used to catch crawfish in the Mediterranean. However, as the skills required to produce them are lost, modern plastic traps have been looked at as an alternative to trammel nets which are considered to be unsustainable due to high catch rates. A study by Gristina and Gagliano (2004) showed, under experimental conditions, that there was not a difference in catch rates between traditional rush traps and modern plastic traps. The efficiency of targeted trap fisheries is affected by soak time with the catch rate falling after two nights fishing (Robinson and Dimitriou, 1963). Potting activity for lobsters and crabs around the Welsh coast is widespread and there are several different kinds of pots in use (CCW, 2010).

Netting is a more effective method of fishing for crawfish than potting (Hepper, 1977, Gristina and Gagliano, 2004). In Welsh waters crawfish are caught as a bycatch in spider crab fisheries. A comparison of percentage catch rates between tangle nets and pots in south Wales during 1997, showed that nets represented 37,850% of the pot catch (Davies, 1999). Goñi *et al.*(2003b) have reported that there are differences in the catchability of male and female crawfish in both pot and trammel net fisheries. This showed that the pot fishery did not accurately represent the size structure of the population and preferentially caught females.

Net fisheries are carried out all along the Welsh coast although tangle netting appears generally to be concentrated along the Pembrokeshire coast and the Llŷn peninsula and along the north coast of Wales to the east of Anglesey (CCW, 2010). Within what was the South Wales Sea Fisheries Committee area net fisheries for crustaceans peaked in 1993 when 33 vessels were actively working and 90% of the ten to 12 tonne catch was taken using tangle nets. By 2001 only four vessels were registered to take crustaceans by net with a further six vessels registered to use pots and nets (as reported in Thomas, 2003). Less than one tonne of crawfish was landed in 2001, with net fisheries landing over 260 tonnes of spider crabs.

Scuba diving has been identified as a cause of the population decline in crawfish in parts of Wales in the late 1970s where a dive fishery around the Llŷn peninsula led to a rapid decline in numbers in that area such that within two years, diving for crawfish was no longer economically viable (R. Sharp pers. comm.). In dive fisheries from the south of Wales it has been reported that they preferentially removed females from an area leaving males behind, this would then attract more females into the area which could be fished again a few weeks later (P. Coates pers. comm.). Preferential removal of females like this could affect the potential for recovery by reducing the reproductive output of the population.

Dive fisheries can also affect the behaviour of spiny lobsters. A study in Florida observing *Panulirus argus* showed that there was increased dispersal of individuals following a period of fishing in an area that had been previously closed to fishing (Davis, 1977). It was suggested that this dispersal may be as much related to perturbation by divers as reduction in numbers and indicated that increased dispersion could have impacts in terms of exposure to predators, and disruption of social structure.

1.2.2 Status of the fishery

A shellfish permit scheme introduced in the South Wales Sea Fisheries Committee (SWSFC) area in 1980 has resulted in the collection of catch and effort data for the crawfish fishery in this area. The annual landings data, broken down by fishing type, are shown in Figure 1.2. A report on data collected via this scheme was produced by Davies (1999) for the period 1980 to 1997. This showed that landings were under two tonnes per year with the exception of the period from 1990 to 1993 which saw a peak to 12 tonnes in 1992 (Davies, 1999). The peak in landings observed around 1992, which can be attributed to three boats, was due to the identification of an area of inshore reef where crawfish were carrying out a migration and nets were specifically set between two areas of kelp (P. Coates, pers. comm.); however, the fishery became uneconomic by 1993. Landings from the pot fishery have shown a general pattern of decline since 1980 when annual landings were around 1.2 tonnes, to recent years where landings have remained largely below 0.5 tonnes since 1993 (Figure 1.2). That is with the exception of 2007 which saw the highest annual landings from the pot fishery during the data collection period at 1.4 tonnes. The dive fishery landed around 0.4 tonnes in 1980 and 1981 but no commercial dive fishing has been recorded in the south Wales area since 1986. Data from the Marine Management Organisation for the period 2000 to 2011, show that some commercial diving took place in 2010 but that it made up a small proportion of the total catch (<10 kg). Total annual landings of crawfish since the peak in 1992 have remained relatively low and landings from Welsh vessels have remained at less than two tonnes per year since 2000 (Marine Management Organisation). Although the volume of catch remains low and it is not a targeted fishery, it is of significant value to fishermen with the two tonnes landed by nine vessels in 2007 having a value of £56,000.

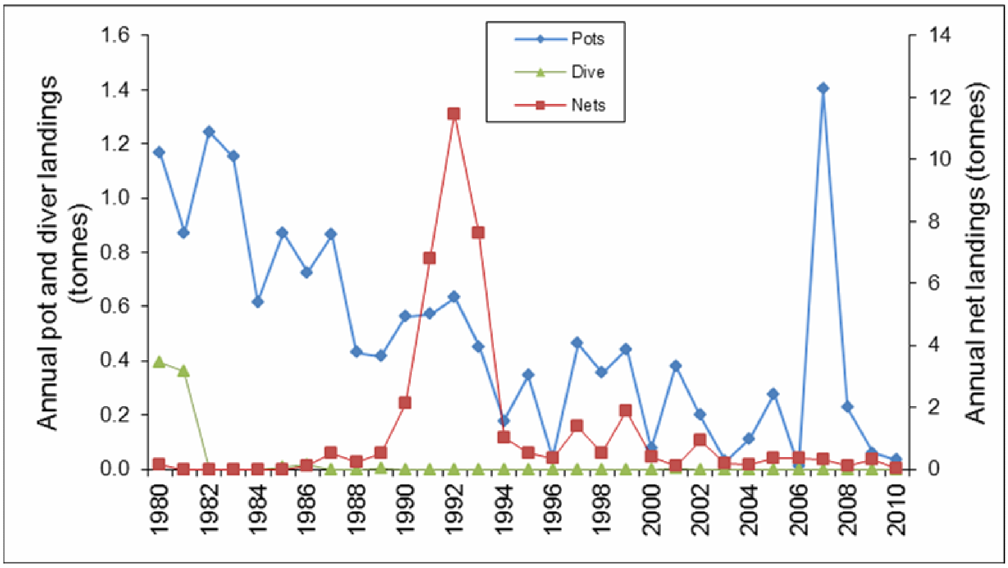

Figure 1.2 Annual *Palinurus elephas* landings from all fishing gears (not effort related) in the south Wales shellfish permit area (formerly the South Wales Sea Fisheries Committee Area). Data from the Welsh Government.

Landings per unit effort (LPUE) calculated from the pot fishery (Figure 1.3) have also shown a pattern of decline from a high of 0.65 kg per 100 pot hauls in 1980 to below 0.1 kg per pot haul since 1988, with lows of around 0.003 kg per pot haul in 2003 and 2010 (Figure 1.3). Again the exception to this was in 2007 when LPUE increased to 0.15 kg per pot haul. The reason for the observed increase in both landings and LPUE from the pot fishery in 2007 is not clear. Mean monthly LPUE for the period 1980 to 1997 showed a peak in June, this coincided with the peak activity in the fishery whereby the landings between May and September represented between 77 and 90.5% of the total for the year (Davies, 1999). The lowest catch rates were recorded in the period from October to March. LPUE from tangle nets were also calculated (1991 to 1997) and ranged from 0.93 to 1.37 kg per100 meters of net between 1991 and 1993 followed by a sharp decline in 1994 to a low of <0.13 kg per100 m net in 1996. This increased slightly to 0.52 kg per 100m net in 1997. During this period the total number of shellfish permits issued by SWSFC, and the number of full time fishermen in the area, both increased as did the total number of pots fished (Davies, 1999). This increase is not specific to crawfish fisheries however, and interpretation in this context should be taken with care. Given the decrease in pot LPUE alongside the introduction and decline of a tangle net fishery, it is probable that there was over-fishing of crawfish in this area during this period.

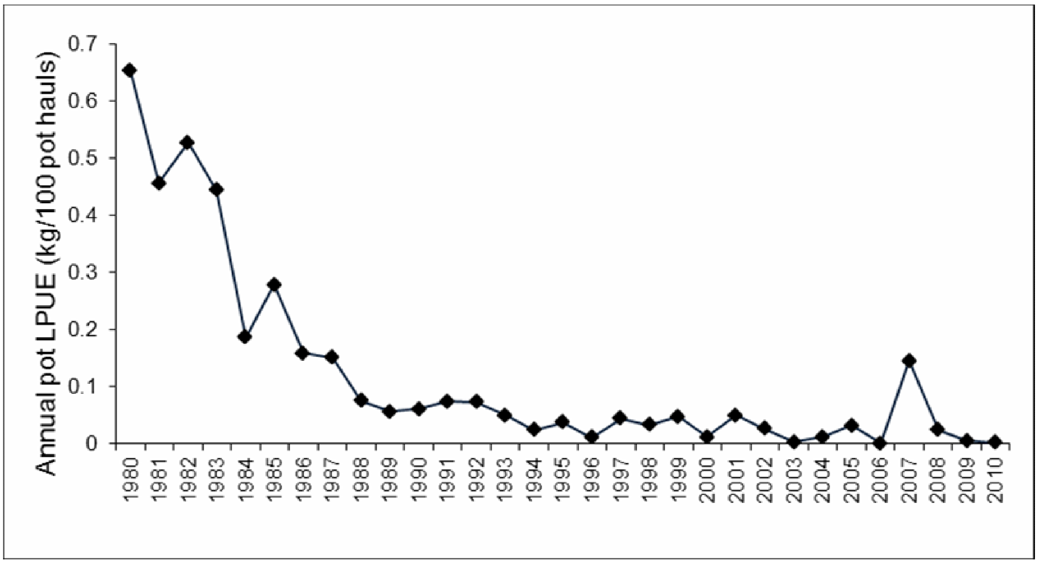

Figure 1.3 Annual Landings Per Unit Effort (LPUE) from the pot fishery for *Palinurus elephas* from the south Wales shellfish permit area (formerly the South Wales Sea Fisheries Committee Area). Data from the Welsh Government.

A shellfish permit scheme also applies to the North West and North Wales Sea Fisheries Committee area which also collects data on catch and effort from the fishery (P. Coates pers. comm.). Although more detailed analysis of this data set is not currently available it should be possible to compare this with information from the south.

Data from the Marine Management Organisation show that Welsh registered vessels fishing for crawfish have landed just under five tonnes since 2000 which is a relatively small amount when compared to landings from other areas of the UK (Figure 1.4)

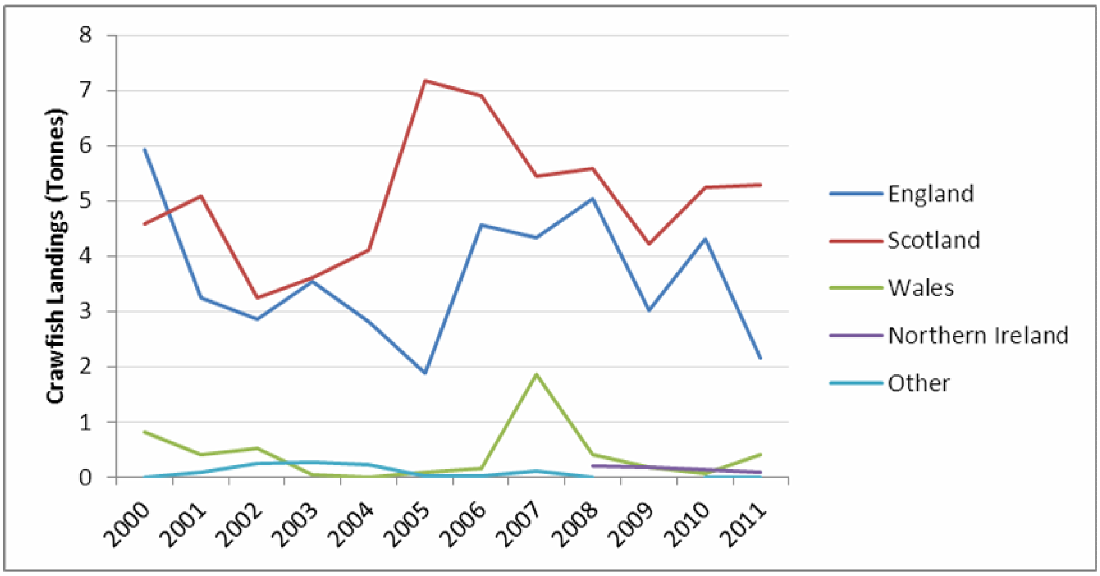

Figure 1.4 Annual UK landings of *Palinurus elephas* by nationality of vessel (Data from the Marine Management Organisation).

In addition to the fishery for crawfish in Wales there have also been targeted crawfish fisheries around Cornwall. These were mainly carried out using pots until the introduction of diver fishing in the 1960s. However, dive fishing was considered to be uneconomical by the end of the 1960s (Hunter *et al.*, 1996). The introduction of net fisheries in the 1970s gradually replaced pot fisheries and landings have reduced considerably since that time. There has also been a change in the length frequency distribution of crawfish from the Cornish fishery, whereby the distribution has skewed to a higher proportion of smaller individuals (Hunter *et al.*, 1996).

Hunter (1999) reported landings of *P. elephas* in Scottish waters from 1983 up to 1997. All landings up to, and including, 1991 were below five tonnes per year. Landings increased in 1992 to more than 40 tonnes per year and remained high (above 30 tonnes per year) until a peak in 1995 of about 54 tonnes per year. The peak landings between 1992 and 1995 corresponded with the introduction of tangle netting. Landings for the years following the peak in 1995 were of a similar size to those prior to the increase: less than about six tonnes per year. Landings data for 2000 to 2011 are presented in Figure 1.4 and show a continuing trend of yearly landings less than 7.2 tonnes.

The Irish fishery for crawfish in the late 1960s, was a pot fishery which targeted both lobsters and crawfish simultaneously (Molloy, 1970). Although the extent and location of the fishery was not thought to have varied much at this time, the annual catch was shown to fluctuate considerably and there was an overall decline in landings. It was also reported that the mean length of crawfish was lowered in some areas (Molloy, 1970), although it was not possible to determine if this was caused by over-fishing. More recently fisheries in Ireland have been carried out using trammel nets, with a bycatch of crawfish taken in other set nets (Goñi and Latrouite, 2005). This change from pot to net fishing is reported to have resulted in depletion of the stocks and a reduction in the mean size of individuals (Goñi and Latrouite, 2005).

A recurring trend in the literature on crawfish fisheries, as reviewed by Goñi and Latrouite (2005), is the decline in population levels due to changes in fishing practice from the use of relatively inefficient pot and trap fisheries to much more efficient net fisheries from the 1960s to 1980s. Stocks of *P. elephas* are depleted over much of its European range, including Wales.

1.3 Legislation

This section outlines fisheries legislation that is relevant to crawfish fisheries, although this report is not intended to provide a full review of fisheries legislation. Definition of the geographical boundaries at which relevant legislation applies is also pertinent to the assessment of management measures. The fisheries legislation that applies to Welsh waters is listed in the Sea Fishing Atlas of Wales (CCW, 2010) and this includes regulations from the European Union, the United Kingdom, and the Welsh Government. The Marine Management Organisation also produces a Blue Book[1] which consolidates UK and EU legislation.

Within six nautical miles, only vessels registered in the UK may fish. Crawfish fisheries are regulated through bylaws which were implemented by the Sea Fisheries Committees (now the Welsh Government) and have been transferred to Statutory Instruments which apply within the 6 nm limit. These specify a 95 mm carapace length (CL) minimum landing size (MLS) in the north and a 110 mm CL MLS in the south. Between 6 nm and 12nm historical fishing rights permit vessels from outside the UK to fish. These include vessels from France, Belgium, and Ireland and the distribution of these rights is reported in CCW (2010). Welsh Statutory Instruments, such as the Lobsters and Crawfish (Prohibition of Fishing and Landing) (Wales) Order 2002, SI2002/676, apply within the 12 nm limit but only to UK vessels. In order to extend management measures within the 12 nm limit to include all vessels it is possible to obtain derogations for the conservation and management of fisheries resources under Article 9 of Council Regulation 2371/2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy.

Within the six nautical mile limit all fisheries management powers are devolved to the Welsh Government. In 2010 the area of responsibility for fisheries policy, management, and marine enforcement was extended to the median line border with the Republic of Ireland, Isle of Man, and England via The Welsh Zone (Boundaries and Transfer of Functions Order) 2010. Under this legislation Welsh Statutory Instruments could be extended to the median line border but would still remain applicable only to UK vessels. EU legislation, including a MLS of 95 mm CL for crawfish, applies to all Welsh waters.

The Habitats Directive has resulted in the designation of marine Special Areas of Conservation (SAC) in Welsh waters. The scope of the sites relevant to crawfish is set out in Section 3.1.2. The Sea Fishing Atlas of Wales (CCW, 2010) lists Competent Authorities for different fishing techniques and the relevant fisheries legislation which applies within Welsh marine SACs. The Skomer Marine Nature Reserve was designated under the Wildlife and Countryside Act and its relevance is set out in Section 3.1.3.

[1] http://www.marinemanagement.org.uk/fisheries/monitoring/regulations_bluebook.htm

2 METHODS

For the purposes of this report the term "crawfish" is used to represent *Palinurus elephas* and both terms are used interchangeably throughout. Where necessary, in order to provide the most complete assessment of potential management measures, examples have been drawn from studies on other Palinurid species, and other exploited crustacean species.

2.1 Assessment of Management Measures

In order to assess the potential effectiveness of existing and potential management measures for the recovery of Welsh populations of *P elephas* a review of available information has been carried out in the form of a literature review, including grey literature, and through liaison with persons with specific relevant expertise. Where possible direct examples of recovery attributed to different management measures are reported including timescales (see also Table 3.1). Where direct examples are not available, comparisons are drawn and aspects of the biology of *P. elephas* are interpreted with regards to the specific management measure in question. Where relevant management measures are applied in adjacent areas with the potential to aid recovery in Welsh waters, these are also included. The limitations of each management measure in aiding the potential recovery of crawfish populations in Welsh waters are also discussed.

The assessment provided in this report is not intended to provide recommendations on future management of crawfish in Welsh waters or to review the socio-economic implications of each management measure, nor does the scope of the project include any proactive recovery measures such as husbandry techniques.

2.2 Definition of Recovery

The Marine Strategy Framework Directive (MSFD) sets out in its quantitative descriptors for determining good environmental status that; **"Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock"**, thus setting a mandate for recovery of crawfish populations in Welsh (and UK waters). For the purpose of the MSFD "within safe biological limits" is defined as being **exploited sustainably consistent with high long-term yields and to have full reproductive capacity** (Piet *et al.*, 2010). The authors also add that in assessing these attributes a precautionary approach be taken in setting target levels of fishing effort and spawning stock biomass. The age and size distribution of a healthy stock is considered to consist of greater numbers of older and larger individuals. Achieving these targets would result in good environmental status (GES) for the stock.

Currently there is no information available on the historical, or current, stocks of *P. elephas* from Welsh waters, or indeed from the UK with which to define "safe biological limits", nor with which to compare a population size distribution that is indicative of a healthy stock. It is not possible therefore to make any formal analytical fisheries assessment on the stocks of crawfish around the Welsh coast, nor to determine what population size and structure would represent GES. Neither is it possible to draw direct comparisons with other spiny lobster fisheries, as in most cases it has not been attempted to calculate the absolute abundance. Where the relative abundance has been estimated from catch rate in fished populations the differing gear used in each fishery precludes any comparison between species (Morgan, 1980).

In addition to the identified areas of data deficiency with regards to the fishery which prohibit the use of formal assessment techniques, there are also biological knowledge gaps with respect to the behaviour and reproduction of crawfish in Welsh waters. It is nevertheless important to utilise the available information to make reasoned judgments on the potential for different management measures, alone or in combination, to contribute to the recovery of crawfish populations.

A demarcation of what constitutes ‘recovery’ is needed to undertake this review of management measures for their effectiveness in enabling self-procreated recovery of crawfish. The MSFD target is an acceptable descriptive recovery target for crawfish, but these targets are not, and can not be, defined numerically. However, it is important to know what the status of the crawfish population in Welsh waters currently is, what the desired population status is and hence the magnitude of recovery that the various management measures need to redress.

Landings Per Unit Effort (LPUE) data are available for the South Wales Sea Fishery Committee area since 1980 when declines in crawfish had already become evident. In 1980 when the population was already being exploited LPUE was recorded at 0.7 kg per 100 pots, while current LPUE is much lower and has remained at around 0.05 kg per 100 pots as recorded in 1997 (Davies, 1999). It is recognised that data from a pot-hauled method is not an accurate representation of a crawfish population as it is a relatively inefficient fishing method and has been shown to be selective for females (Goñi *et al.*, 2003b). LPUE does, however, provide a relative index of abundance in the crawfish population.

This data from south Wales can be used to indicate the status of crawfish populations in Wales historically and to indicate the magnitude of recovery that is desired (bearing in mind that declines in crawfish were already evident during the period for which this data exists). Use of this data as a benchmark does not facilitate numerical modelling of effectiveness of management measures, but serves as a context in which logical judgements can be made about the effectiveness of the management measures in enabling recovery. This will be based on an appreciation of their declined status in Welsh, UK, and European waters, and using knowledge of crawfish biology and ecology, of Palinuridae/lobster population dynamics and the effects of fishing on populations.

LPUE data does not represent all attributes of crawfish recovery, for example it does not encompass the age and size distribution in a population. Therefore, historical Welsh LPUE data from the 1980s can be viewed as only an interim ‘recovering’ target heading towards a population with a density, size distribution and geographical distribution that would represent the achievement of GES and recovery of crawfish. LPUE data should also be considered as an interim target because crawfish have been fished for several decades before the 1980s and LPUE data from this period is unlikely to represent a ‘recovered’ state.

This report assesses the potential effectiveness of each management measure with respect to their ability to reduce or restrict fishing effort, increase reproductive output or reduce catch rates, and provides indications on the potential scale of recovery and time implications where possible. The future implementation of any management measures may be assessed through the collection of new LPUE data and comparisons made with the historical data that is available. The aim being to reach a population level where LPUE values are greater than those observed in the early 1980s and are able to be maintained within prescribed limits in order to maintain GES.

3 ASSESSMENT OF MANAGEMENT MEASURES

Management measures for the protection of *Palinurus elephas* populations include those affected both through fisheries legislation and through nature conservation legislation as set out in Section 1.3. Potential recovery rates, relating to the different management measures, reported from different areas or with regards to other species are summarised in Section 3.3.

3.1 Existing Management Measures

3.1.1 Minimum Landing Sizes

The main function of a minimum landing size (MLS) is to allow individuals to reach sexual maturity and to reproduce prior to entering the fishery. The aim of this is to prevent recruitment over-fishing, by which the individuals remaining in the population do not have a sufficient reproductive output to replace those removed by fishing. It is important therefore that the MLS set for a fishery is greater than the size at first maturity of the target species within the area of the fishery. Two separate MLS are currently in force within Welsh waters. This is as a result of differing management measures put in place by the two Sea Fisheries Committees whose role has now been taken over by the Welsh Government. The EU minimum landing size of 95 mm carapace length (CL) is in force in the North West and North Wales Sea Fisheries Committee (NW&NWSFC) area, while in 1997 the South Wales Sea Fisheries Committee (SWSFC) adopted a more conservative MLS of 110 mm CL. As this bylaw only extends to the six nautical mile limit, it does not provide protection for crawfish caught further offshore which would be subject to the EU limit.

The mean size at maturity (SOM) of crawfish has been shown to vary regionally (Goñi and Latrouite, 2005) and examples from the literature are presented in Table 1.2. Research on *Jasus edwardsii* has also shown that SOM can vary with depth (Linnane *et al.*, 2009). The size at maturity is often taken to be the size of the smallest berried female and this varied from 69 mm CL in the Spanish Mediterranean to 121 mm CL in south Wales. These data provide an indication of the possible individual SOM; however this value may not be representative of the population as a whole. A study in Portugal showed that 50% of females were mature at a carapace length of 110 mm (Galhardo *et al.*, 2006), although the smallest ovigerous female was 84 mm CL. The authors showed that an increase in MLS from 80 to 95 mm CL had little potential to increase reproductive output as less than 20% of females under 95 mm were mature (Galhardo *et al.*, 2006). Goñi and Latrouite (2005) also report that MLS in fisheries from Croatia (80 mm CL) and Brittany (> mean SOM) were not sufficient to protect stocks from over-fishing or to elicit recovery of stocks.

A study carried out in south Wales (Hunter *et al.*, 1996) between Strumble Head in the north and St Govan's Head in the south reported that the mean size of males was 155.5 mm CL (range 89 to 182 mm CL) and the mean size of berried females was 138.7 mm CL (range 121 to 150 mm CL, see Table 1.2). The smallest unberried female recorded was 113 mm CL. The results of this study would indicate that the current EU MLS is not appropriate for crawfish in this area and that even the higher MLS introduced by the SWSFC of 110 mm CL would do little to increase the reproductive output of the population as all reproductively active females, and the majority of males, were larger than the MLS. The sample sizes in this study were relatively small however and the smallest ovigerous females found in Cornwall, Ireland, and Scotland were smaller than that reported for south Wales (see Table 1.2). It may be that there are smaller individuals within the Welsh population, but for some reason, they were not captured during this particular study. Hunter *et al*. (1996) also examined physiological maturity in 40 females (including the smallest individuals from the Cornish fishery) and surmised that the majority of crawfish from around the UK would be sexually mature before they entered the fishery (i.e. at 95 mm carapace length). As data from Mediterranean populations of crawfish indicates that females become both physiologically and functionally mature at the same time (Goñi *et al.*, 2003a) this would indicate that the SOM in Welsh populations could be smaller than the size range of berried females described by Hunter (1996), but further data collection is required to affirm this.

Given the disparity between the existing MLS and somewhat contradictory length frequency and SOM data presented by Hunter *et al.* (1996), it is possible that a substantially higher MLS would be required to increase the reproductive potential of crawfish populations in Wales. The scale of any recovery of crawfish populations through increased MLS is difficult to predict for several reasons. It is not clear what the current length frequency distribution of the population is and therefore what proportion of individuals would be removed from the fishery. Length frequency data, along with information on SOM, are also required to determine the potential gains with respect to egg production. Should increased egg production occur and result in enhanced recruitment in Welsh populations it would be expected to take a minimum of four to five years before any upturn was observed in the fishery, as this is the predicted length of time it would take for both males and females to reach a carapace length similar to the current MLS (see Table 1.1). Should populations in Wales be clearly linked to larval production from a population outside UK waters then an increased MLS set at the European level, or another appropriate sea area, may be considered appropriate in order to facilitate recovery in Welsh waters.

A further consideration with regards to the recovery of crawfish populations is the attainment of an age and length structure that is indicative of a healthy stock, which is considered to consist of greater numbers of larger and older individuals (Piet *et al.*, 2010). The use of MLS alone may not provide a means by which GES, with regards to length frequency, could be attained or maintained, as larger individuals would be the focus of the fishery. This could be particularly important should any recovery in terms of abundance attract greater fishing effort.

3.1.2 Marine Special Area of Conservation Management Measures

Marine Special Areas of Conservation were designated under the European Habitats Directive, which has been transposed by The Conservation of Habitats and Species Regulations 2010 in England and Wales. The legislative process requires the Secretary of State to propose a list of sites which are important for habitats and/or species (listed in Annexes I and II of the Habitats Directive respectively) to the European Commission. Sites are then identified as Sites of Community Importance (SCI) and must then be designated as a Special Area of Conservation (SAC) within six years (JNCC; http://jncc.defra.gov.uk/page-1379). Features of the Pembrokeshire Marine SAC include eight habitat types listed in Annex I of the Habitats Directive, one of which is ‘reefs’, and seven species groups listed in Annex II of the Habitats Directive (www.pembrokeshiremarinesac.org.uk). Features of the Pen Llŷn a’r Sarnau SAC include eight habitat types listed in Annex I of the Habitats Directive, one of which is ‘reefs’, and four species groups listed in Annex II of the Habitats Directive (www.penllynarsarnau.co.uk). Reefs form important habitats for *Palinurus elephas* (see Section 1.1.1) and, although *P. elephas* are not listed in Annex II of the Habitats Directive, they are one of the largest benthic predators in Welsh waters and as such having a healthy crawfish population would contribute to attaining favourable conservation status for the reef habitat.

3.1.2.1 Pembrokeshire Marine SAC

The management scheme for Pembrokeshire Marine SAC identifies that net fishing (fixed, gill, tangle, and trammel) is increasing within the site. The report also indicates that there is the potential for this to have an effect on the designated features of interest, but that at present there is not sufficient data to determine if any adverse effects are actually occurring. This is also the case with continuing potting activity, which is widespread throughout the site (CCW, 2010). It should be noted that any fishing activity within the site which removed crawfish would be affecting the status of the features of interest as crawfish are part of the reef feature.

There are no fisheries specific management measures within the SAC management scheme which would enable crawfish recovery. There are aspects of the management of the site which have potential benefits for the local population but which are unlikely to contribute to any recovery. These include the possible introduction of biodegradable latches in pots. This might benefit crawfish through the reduced potential for mortality of individuals by ghost fishing of lost gear. The extent to which this occurs within the site is unclear, and pot fishing for crawfish is not as efficient as other methods so it is likely that the impacts of this management measure would be relatively minimal. Management measures which protect the water quality within the area may well have a beneficial effect with regard to the planktonic life stages of crawfish, however, the sensitivity of this species to contamination in the water column, including eutrophication, is not well described (Jackson *et al.*, 2009).

The management scheme action plan does include an action to "establish sustainable limits for each species/stock and a range of appropriate management measures to maintain catches within those limits". With regards to the recovery of crawfish, the setting of sustainable limits would need to be applied within the context of Good Environmental Status as required by the Marine Strategy Framework Directive, as it is possible that a sustained fishery can be carried out on a depleted population. A further proposed item listed in the management scheme is the establishment of unexploited scientific "control" sites, although the plan, timescale, and likelihood of their introduction is not clear. These could potentially provide refuges for populations of *P. elephas*, and would also provide the ideal situation to assess potential recovery of populations. Site selection specifically for crawfish study would be desirable in order to gain the greatest possible benefit from such a management measure (see also Section 3.2.7). The management scheme includes actions on the collection of fisheries data including spatial distribution and effort within the site, and specifically in the Skomer Marine Nature Reserve (MNR), to inform SAC management. Whilst this could provide a valuable source of baseline data on which future assessments could be based, these actions do not relate to direct management action and would not contribute to recovery. A permit scheme exists for shellfish fisheries in the south Wales area. This was implemented by the SWSFC (now the Welsh Government) and although it is not implemented through the SAC management scheme, it would mean that annual licence applications could be considered a plan or project and would therefore trigger an appropriate assessment.

3.1.2.2 Pen Llŷn a'r Sarnau Marine SAC

Potting for crustaceans and tangle netting for fish and crustaceans is carried out within the Pen Llŷn marine SAC. Fishing activity around the Llŷn Peninsula is reported as being predominantly part-time (Thomas, 2003), with potting carried out during the summer months and netting in spring and autumn. Diving is carried out within the site and recreational catch limits apply, with permits required for any proposed collection activity greater than the limits would allow. A shellfish permit system was also put in place by the NW&NWSFC (now the Welsh Government) as in the south. Although these permit systems are not implemented through the SAC management plan, applications for permits could constitute a plan or project and therefore be subject to appropriate assessment.

The management plan for this SAC states that there is no evidence at present to suggest that either netting or diving is having an adverse effect on either the features of interest within the site or the wider coastal ecosystem through the removal of target species. It should be noted, however, that as fishing with both pots and nets is carried out within the site, there is the potential for crawfish populations to be reduced. As crawfish are a component of the reef this could be considered to be detrimental to the features of interest.

With regards to the self-propagated recovery of crawfish there are no management actions within the SAC management plan which specifically relate to crawfish or which would confer any benefits to recovery of this species within the site boundary, or beyond.

3.1.3 Skomer Marine Nature Reserve

Fishing activity within the Skomer Marine Nature Reserve (MNR) is regulated through two fisheries byelaws. These are Byelaw 27 which prohibits the use of dredges and beam trawls within the Skomer area; and Byelaw 28 which prohibits the removal of any scallops (*Pecten maximus* and *Chlamys opercularis*) from the MNR area. These measures do not specifically protect crawfish, and although it is possible that a small bycatch of *P. elephas* in mobile fishing gear may have been prevented, this is unlikely to be significant (P. Newman, pers. comm.).

Both pot and net fisheries are permitted within the site with pots targeting lobsters (*Homarus gammarus*), brown crabs (*Cancer pagurus*), spider crabs (*Maia squinado*), and velvet crabs (*Necora puber*). In the last decade potting has been carried out by up to ten vessels although this activity has covered between 55 and 85% of the site. There has been a marked increase in potting effort around Skomer since 2001, and although levels were reported to have reduced somewhat in 2010 they remain around three times higher than they were in 1989 (Newman *et al.*, 2011).

There is currently a voluntary netting exclusion zone, which covers 50 m from the island coast, but netting elsewhere in the MNR is permitted. There is currently little net fishing activity within the MNR area and no activity at all was recorded in 2010 (Newman *et al.*, 2011). Crawfish were targeted through the use of nets in the 1970s and 1980s (B. Bullimore, pers. comm.) within the MNR and were also targeted through nets elsewhere along the Pembrokeshire coast during this same period.

There is a voluntary no take policy (which includes crawfish) in the MNR's code of practice for recreational divers and this is largely adhered to by visiting divers (P. Newman, pers. comm.). Whilst recreational divers did take crawfish from both within the MNR and elsewhere around the Pembrokeshire coast in the 1970s and early 1980s, the intensity of this activity has never been documented. There was a short lived and intensive commercial dive fishery in the late 1970s, but this was not within the MNR itself and mostly focussed on the offshore reefs around west Pembrokeshire, such as at the Hats and Barrels reefs, approximately 10 - 15 miles west of the MNR (B. Bullimore, pers. comm.).

Whilst MNR monitoring does not specifically gather data on crawfish, non-systematic observations by MNR staff and volunteer divers have reported increasing sightings of juvenile crawfish within the reserve since 2000, although adults are less common (P. Newman pers. comm.). These informal observations of juveniles were not made by MNR staff prior to this time, despite the same sites being surveyed each year. Although these observations are not backed up by quantitative data they suggest an apparent increase in recruitment, either via larval advection to the area or through migrations of juveniles into the MNR area. The source of the juvenile crawfish within the site is not clear however, and this should be taken into consideration when assessing the effectiveness of the MNR to aid in the recovery of crawfish.

In the case of an increase in recruitment to the MNR, the adherence by recreational divers to the voluntary no take policy, including crawfish, within the MNR area will contribute to survivorship of juveniles to adulthood and reproductive maturity, with possible spill over effects outside the MNR area in the future (see also Section 3.2.7). Any spill over effects would be dependent on the increased numbers of juveniles only being found within the site, and would assume that the increase was a direct result of management measures within the MNR, as opposed to a general increase in recruitment within the wider area. The reduction in netting occurring within the site is likely also to contribute to increased survivorship of juveniles to adulthood.

3.1.4 Non-Commercial Catch Limit

Non-commercial catch limits apply to divers/snorkelers and recreational potting vessels. The bylaws introduced by the sea fisheries committees state that in the both the NW&NWSFC area and the SWSFC area there is a catch limit of one crawfish per person per day. All persons wishing to fish using pots or traps are limited to five pots per person and the catch limits set out above still apply. The introduction of voluntary codes of conduct in some diving organisations, which promote a no take policy, may also have reduced the potential for divers to remove crawfish when they are found. For all non-commercial fishing activity the existing MLS of 95 mm CL in the north and 110 mm CL in the south still apply.

Davis (1977) observed a recreational diver fishery within a protected area which allowed each diver to take two *Panulirus argus*. The area observed within this study was a national park area which attracted a large number of recreational divers and the sport fishery had a significant impact both on the behaviour and numbers of *P. argus* within the area. In this specific instance the author reported that such a level of removal would not have been sustainable within the area and reported substantial decreases in experimental catch rates and lair occupancy after eight months of fishing (see also Section 3.2.3.2). Given the current depleted status of the Welsh crawfish fishery, and the fact that this study was carried out on different species, the catch limit and scale of change reported may not be directly relevant to Welsh waters. This example does, however provide a useful context within which to interpret the potential for such a measure to aid in the recovery of Welsh crawfish populations.

The determination of a specific catch limit for a population within a specified area, such that it contributed to population recovery, would need to be based on an assessment of the abundance of crawfish within the area and on the potential for the population to recover. The potential benefits of the non-commercial catch limit are difficult to assess. This is largely due to difficulties in quantifying the level of recreational fishing and its potential to impact upon populations. It has been shown that for a *Panulirus argus* non-commercial dive fishery, restricted by catch limits, can cause significant disturbance to the distribution and social structure of the population and that while distribution can recover in a period of months, the recovery in terms of numbers of individuals may take several years (Davis, 1977). This may need to be factored into assessments of recovery in areas where diver fisheries are prevalent.

As there is no information available on the levels of non-commercial removal of crawfish within Welsh waters it is not clear what benefit this management measure has. The presence of a non-commercial catch limit is certainly preferable to free access; however it is unlikely that it is providing any current benefit to the recovery of depleted crawfish populations, as non-commercial catches are likely to be low. In a recovering population however, where crawfish were more abundant and therefore more available for capture, the existence of appropriate catch limits could prove beneficial, supporting recovery by limiting any renewed interest in non-commercial collection. This would be particularly relevant for recreational diver collection, which is a more efficient and selective method of collection than potting and which may also have wider effects on the population as described above.

3.2 Potential Management Measures

3.2.1 Maximum Landing Size

The introduction of a maximum landing size ($M_{ax}LS$) is carried out in order to protect the largest and most fecund individuals in the population from fishing mortality. The fecundity of female

Palinurus elephas has been shown to increase linearly with size (Goñi *et al.*, 2003a) and therefore by protecting the larger females in the population it is possible to attain a greater reproductive potential from the protected individuals. Larger females have also been shown to produce larger eggs and it is suggested that these may produce larvae that are better able to survive when the food supply was low (Goñi *et al.*, 2003a). While absolute fecundity increases with size, maximum relative fecundity (the greatest number of eggs per gram of body weight) is seen in females with a carapace length of 100 to 110 mm in the Mediterranean (Goñi *et al.*, 2003a). Maximum relative fecundity for Welsh populations is likely to differ from this range given the differing environmental conditions. Galhardo *et al.* (2006) showed that in a Portuguese population 50% of females were mature at a carapace length of 110 mm, and that although females above this size represented only 5% of the population they produced 59% of the egg production. It can therefore be seen that the introduction of a $M_{ax}LS$ could protect and increase the reproductive potential of a population with regards to egg production.

A $M_{ax}LS$ for male lobsters can be effective in protecting the reproductive potential of a fished population where sperm limitation may be a factor affecting reproduction. Introducing a $M_{ax}LS$ for females only can have implications on potential increases in the reproductive output of the population through increased fishing pressure on males. Sperm limitation can become an issue if large females are unable to find a suitable male to mate with, either through reduced numbers of males due to fishing mortality, or through a lack of males of a suitable size with which to mate. Reducing the numbers of males within the population can result in the remaining males being unable to produce enough sperm to successfully fertilise all of the receptive females through sperm depletion resulting in an inability to mate.

Egg production can also be reduced through insufficient numbers of sperm being transferred to the female. A reduction in the numbers of sperm transferred to females has been shown for several species of crab, for example *Callinectes sapidus* (Kendall *et al.*, 2002) and *Paralithoides brevipes* (Sato *et al.*, 2006). In *Panulirus argus* the size of the spermatophore transferred has a greater impact on the brood size than the size of the female (MacDiarmid and Butler, 1999b). In both *P. argus* and *Jasus edwardsii* females that mated with smaller males produced smaller broods than those females that mated with large males (MacDiarmid and Butler, 1999a, 1999b). For *J. edwardsii* it was shown that female size, male size, and mate order all affected the number of eggs produced by the female (MacDiarmid and Butler, 1999a). Female *J. edwardsii* are reported to have only a short window of opportunity for mating and should there be a lack of suitable mates, the female will resorb her eggs (MacDiarmid *et al.*, 1999). This resorbtion of ovarian tissue has repercussions in the following breeding season where females were seen to have largely atrophied ovaries, and the small amount of normal egg development resulted in very small brood sizes.

Davies (1999) states that successful mating in crawfish will only occur where the mating pair are similar in size as the positioning of the spermatophore is important. It would therefore be prudent to introduce a $M_{ax}LS$ for both sexes in order to achieve the maximum possible gains in terms of egg production and reducing the potential for sperm limitation. This would be especially important if there were other measures also protecting females (e.g. prohibitions on landing berried females). It is however, difficult to determine the relationship between increased egg production and recruitment levels. Factors such as predation on each of the different larval and juvenile life stages, and density dependence, can affect recruitment. The relationships between these different factors are often complex and hard to assess making it difficult to determine the relationship between egg production and recruitment.

A possible concern with the introduction of a $M_{ax}LS$ is that it could result in larger individuals utilising the resources which would otherwise be available to smaller, faster growing individuals, which can be considered detrimental to the stock (Chapman, 2003). In such a case it is possible that the benefits of increased egg production could be negated by a decrease in numbers. As crawfish populations within Welsh waters are currently depleted it is unlikely that resources would be a limiting factor. The potential for limited shelters/habitat to limit numbers of crawfish in an area is reduced as crawfish can sometimes be found sharing refuges in suitable habitats.

Setting locally appropriate and meaningful M_{ax}LS within Welsh waters will be important. The length composition of crustacean populations can vary, sometimes over relatively small spatial scales (e.g. Tuck *et al.*, 2000). In *Jasus edwardsii* it has been shown that SOM can vary by depth (Linnane *et al*., 2009). If significant spatial variability was observed in Welsh crawfish populations it may be that more than one M_{ax}LS could be appropriate in order incorporate local variability. Given the depleted status of the crawfish populations in Wales it may be the case that fewer large individuals are currently present within the population, as has been observed in other areas (Galhardo *et al*., 2006). This could compromise the initial potential for the introduction of a M_{ax}LS to increase the reproductive output of the population. It may be that a M_{ax}LS could be introduced, along with appropriate area closures (see also Section 3.2.7), within which individuals would be allowed to reach these larger sizes through protection from fishing effort. Data on the length frequency distribution of populations would be required in order to determine the scale and level of such a measure and whether or not it should be implemented alongside area closures.

The aim of this management measure is to increase the reproductive output of the population. If this is successful, and results in increased recruitment, it would take a minimum of four to five years for this to translate into increased catch rates in the fishery, based on the growth rates of crawfish and the current MLS (see Table 1.1). The scale of any recovery may be limited by the current depleted status of crawfish in Welsh waters. Benefits with regards to a return to an age length frequency that is indicative of GES may be achieved more quickly (depending on the current length frequency distribution) with the retention of older larger individuals within the population.

As there is uncertainty about the source of recruitment into the Welsh crawfish population it is not possible to determine the impacts on recruitment of the introduction of a M_{ax}LS at a European scale or other relevant sea area. However, should connectivity between populations be identified then a M_{ax}LS, at an appropriate scale, would be important to maximising recovery potential. In the absence of firmly establishing connectivity between Welsh populations and those in other areas, the main benefit the introduction of an EU or sea area M_{ax}LS would be if it was introduced to mirror a management measure implemented for Welsh waters. As Welsh Statutory instruments would only apply to UK vessels this would mean that all vessels fishing crawfish populations in Welsh waters would be subjected to the same M_{ax}LS.

3.2.2 Landing Prohibition

As crawfish are captured as a bycatch in other fisheries, prohibitions in the context of this section of the report are taken to mean the prohibition of landing crawfish rather than a direct prohibition of all fishing activity. A landing prohibition as discussed here would apply to all crawfish caught, irrespective of the fishing method used.

A prohibition on landing crawfish using a Welsh Statutory Instrument could be applied to the Welsh Zone, i.e. out to the meridian line with Ireland, England and the Isle of Man (see Section 1.3); this would only apply to UK vessels fishing in this area. However, this would not prevent UK vessels, including Welsh vessels, from landing their catch in another country. Depending on the extent to which this would be an issue, consideration could be given to inter-country landing prohibitions on crawfish. It is known that Belgian beam trawlers do catch crawfish in Welsh waters (P. Coates, pers. comm.) and that French and Irish vessels also have historical fishing rights within the six to 12 nm limit. The total UK landings of crawfish by non-UK registered vessels in the period 2001 to 2011 was 0.0457 tonnes and of this less than 2% of this total was landed in Wales (data from the Marine Management Organisation). The Marine Management

Organisation does not hold information on fishing being carried out by foreign vessels within the six to 12 nm zone that is landed outside the UK. It is possible therefore that a proportion of fisheries removals from the Welsh crawfish population is not accounted for nationally and would not be able to be controlled through the introduction of Statutory Instruments. If the catch by foreign vessels was found to be significant or increasing, this could be addressed by seeking a derogation to make the Welsh SI applicable to the relevant Member States in order to facilitate and maintain recovery of crawfish in Welsh waters.

Prohibitions on landing are likely to be most effective in pot and dive fisheries as there are likely to be high survival rates of live returns from these fisheries. Net fisheries can however result in mortalities of captured crawfish depending on the length of time they have been caught in the net and on levels of damage through contact with the net. Further information on the spatial distribution of crawfish captured in net fisheries could permit area prohibitions in order to mitigate any fishing mortality if it was considered to be a significant problem.

The effectiveness of a Welsh landing prohibition, in terms of recovery of stocks, will also be affected by the source of recruitment into Welsh populations. If larvae are being produced by populations in other areas and then brought to Welsh waters through the movement of tides and currents, the level of recruitment will not be affected by a Welsh prohibition on landing crawfish. However, in this situation a landing prohibition would increase population numbers and could eventually benefit recruitment in an area outside Welsh waters. A regional sea or EU level prohibition could aid recovery in Welsh waters if it was implemented to protect an area with proven larval connectivity to Welsh crawfish populations. Should the source of recruiting individuals be from within Welsh stocks, the potential rate of recovery could be increased through both the reduction in removals from the population by fishing, and through increased recruitment to the resident population.

A prohibition on the landing of crawfish in Welsh waters could contribute to the recovery of crawfish. The rate of recovery facilitated by such a management measure in the context of the depleted status of Welsh crawfish populations is not clear however. Preventing the removal of individuals and potentially enhancing recruitment would both increase the abundance of crawfish and result in changes in length frequency distribution towards one that was indicative of GES. These potential benefits may make this a more effective management measure in terms of recovery, than one which only protects part of the population (e.g. MLS) or has a spatial or temporal component (e.g. area or seasonal closures) which still permitted fishing activity. It may be appropriate to review a landing prohibition in a recovering population in order to determine if other management measures, which allowed the removal of individuals, could be introduced.

3.2.3 Gear Restrictions

It has been shown that pot fishing is the least effective method for catching crawfish although it is relatively environmentally benign (Eno *et al.*, 2001). Dive fishing has the potential to cause the least disturbance to the surrounding habitat; however it can result in quite high catch rates and the potential for localized depletion of the stocks. The use of nets for capturing *P. elephas* is the most effective, from a fisheries point of view, and there are concerns relating to damage to other marine life and potential bycatch issues.

Prior to considering any prohibitions relative to fishing gear it is important to assess to what extent the different methods are used and in what areas. Both net and pot fisheries have continued to land crawfish in recent years, however, the dive fishery has declined and is now almost non-existent (Marine Management Organisation; Figure 1.2). It is important to gather further data about the geographical extent of each fishery and the effort deployed in order to determine the potential for any prohibition to affect a recovery in the population. A further consideration would be changes in fishing type due to the prohibition of a single fishing gear and what the implications of this change would be for population levels of crawfish. As with other potential management measures the implications of the legislative framework will need to be considered with regards to the effectiveness of each measure.

3.2.3.1 Prohibition of tangle netting

Prohibitions, as discussed in this section, refer to measures implemented in discrete areas rather than a prohibition of the tangle net fishery as a whole. Tangle netting is one of the most effective methods for catching crawfish and is therefore popular with fishermen. It can, however, have an impact on the surrounding environment both through the bycatch of non-target species and also by causing damage to fragile sessile reef species. This is particularly relevant to marine SAC sites that have been designated for reef features. The total landings of crawfish from all set net fisheries carried out by Welsh vessels were 2,373.6 kg in the period 2000 to 2011 (Marine Management Organisation). Data collected in south Wales showed that the catch rate of nets, expressed as a percentage of catch rates for pots, was 37,850% (Davies, 1999). It is also possible for fishermen to set nets on crawfish migration routes which can significantly increase catch rates (see Section 1.2), whereas pot fisheries rely on individuals being attracted to the fishing gear. It would therefore stand to reason that, for comparable levels of effort, the prohibition of fishing for crawfish by tangle netting could provide much greater potential for recovery than a prohibition of potting. Although general data is available on the distribution of net fisheries (CCW, 2010) more detailed data on effort and spatial resolution for each gear type in use within Welsh waters would be very useful in determining the potential recovery of crawfish through the prohibition of netting.

There are also potential benefits of a prohibition on net fisheries in terms of reduced fishing mortality on the non-commercial component of the catch. As nets are not very selective they can result in catches of undersized individuals. If nets are not cleared regularly, this can result in juvenile mortalities, which would normally be returned live to the sea (M. Robinson, pers. comm.). Nets can also cause considerable damage should they trap recently moulted individuals which are soft, although catch rates of such individuals tend to be low (Galhardo *et al.*, 2006).

Prohibitions on net fisheries could contribute to the recovery of crawfish, through reduced removals from the population. There would also be less chance of mortality of undersized individuals being caught in gear. This would in turn provide the potential for greater reproductive output of the population and possible increased recruitment. Reduced fishing effort could also result in changes in the length frequency distribution to one that better represented GES. Should prohibitions of netting be carried out in isolation however, the benefits of any recovery could be reduced through pot or dive fishing. This could reduce the impact of any increase in population numbers and would limit any potential changes in the length frequency distribution of the population relative to GES.

3.2.3.2 Prohibition of diver collection

Commercial diver collection of crawfish can be an effective fishing method, particularly in areas where potting or netting is not possible, for example on steep rock faces. Diver collection does have the potential to severely deplete localised populations, although the extent of removals would be limited by the depth at which divers can fish and there will therefore be a depth refuge for this species where collection cannot take place, although other fisheries can.

The effects of diver collection have been shown to be two-fold in populations of *Panulirus argus* (Davis, 1977), with both a behavioural aspect and reduction in numbers. *Panulirus argus* populations have been shown to recover reasonably quickly from the behavioural effects of diver capture, however, recovery in terms of numbers of individuals was much slower and may take several years. The introduction of a recreational dive fishery for *P. argus* in a previously closed area showed a reduction in trap catch rate by 58% and a 42% decrease in lair occupancy rates, over a period of just eight months, even with a catch limit of two *P. argus* per diver (Davis, 1977). The recovery of this area post fishing was observed and it was shown that the catch rate increased to 78% of the pre harvest level after one year and lair occupancy levels recovered to 71% after 16 months, however, overall numbers of *P. argus* did not recover quickly.

There has been little commercial collection of crawfish carried out in Welsh waters in recent years with a total of only 8.8 kg landed over two separate years (Marine Management Organisation). It therefore stands to reason that a prohibition of commercial diver collection at current levels would have little or no impact on the recovery of crawfish populations. Despite current levels of commercial dive fishing being at a low level, this fishery could become viable again in a recovering population of crawfish. In this situation a prohibition on dive fisheries could be a necessary management measure to prevent efficient dive fisheries from reducing the impact of any recovery. If commercial diving was considered to be a threat to recovery, it would also be appropriate to introduce a zero catch limit for recreational divers alongside any prohibition on commercial dive fisheries.

3.2.3.3 Prohibition of potting

Prohibitions of potting activity as discussed in this section refer to the implementation of management measures in discrete areas rather than the prohibition of pot fisheries in general. The total landings of crawfish by Welsh vessels fishing with pots between 2000 and 2011 were 2,554 kg (Marine Management Organisation), which was slightly higher than the landings from net fisheries. The prohibition of potting in discrete areas could therefore provide as much potential benefit in terms of absolute removals from the fishery as a prohibition of net fisheries. It is worth bearing in mind however that pot fisheries also catch other species which are important components of inshore fisheries. Due to the relative inefficiency of pot fisheries in capturing crawfish, a prohibition could have a disproportionate knock on effect on several other fisheries. Should the size of areas required to secure positive benefits for crawfish populations mean that knock on effects on other fisheries are an issue, a prohibition on the landing of crawfish may be a more appropriate management tool (see Section 3.2.2). As noted in Section 3.2.3.1, tangle netting is a much more efficient method for capture of crawfish and also has the potential to cause greater environmental impact. Consideration would need to be taken to fishermen changing to fish with nets should potting be prohibited. Again this may mean that a prohibition on landing crawfish was a more effective management measure.

As for net fisheries, a prohibition on potting would have the potential to benefit the recovery of crawfish in terms of reduced removals from the fishery and the potential for increased recruitment. In terms of reduced landings, the benefits with respect to increased crawfish abundance would be similar to those seen through a prohibition of netting, although the characteristics (e.g. age and length distribution, sex of individuals) of the catch may vary between fishing methods. As potting is a relatively inefficient method for capturing crawfish, which is a bycatch species, it may be more appropriate to look at a prohibition on landing crawfish from pot fisheries, as there is likely to be high survivability of live returns from this fishery.

3.2.3.4 Design specifications for gear

Design features of gear could include features such as escape gaps within pots which would allow smaller or undersized individuals to leave the pot before it is hauled; this reduces any potential handling stress. Specifying the types of pots which could be fished could have an impact on the catch of crawfish. Inkwell pots have larger entrances or eyes than parlour pots and therefore are easier for crawfish to enter and limiting the numbers of these pots could reduce landings of crawfish from pot fisheries.

Nets with greater area appear to have a higher LPUE (Davies, 1999). It may therefore be possible to modify net design to reduce the catch rate to a level which was considered appropriate for a specific area/fishery. The Spanish Mediterranean fishery for *Palinurus elephas* is managed using net regulations which include a specified mesh size and length of trammel net (Goñi and Latrouite, 2005).

Given the depleted status of the fishery it is unlikely that design specifications for gear would have a significant effect on the recovery of crawfish as a stand-alone measure. Design features, such as escape gaps in pots, could be more useful in areas where recovery was observed through increased numbers of juveniles, as these would be able to leave the pot while commercial sized individuals would be retained. The effectiveness of such measures for crawfish pot fisheries is unclear and reducing the catch of smaller individuals would not aid recovery of the population with regards to a length frequency distribution that represented GES. Technical conservation measures such as gear design specifications are more likely to be appropriate in managing a fishery on a recovering population, or one that has made good progress towards recovery, rather than for the purpose of effecting recovery itself.

3.2.4 Catch Limits

The implications of the existing non-commercial catch limits were discussed in Section 3.1.4; however it is possible that a commercial catch limit could also be set to reduce the effects of fishing on crawfish populations. The levels at which such a catch limit should be set would have to be determined based on the current depleted population status and the levels of fishing being carried out.

While the introduction of catch limits would restrict the landings of crawfish, it would not reduce levels of fishing activity. Continued fishing activity can alter the size distribution of a population by removing larger individual with resulting implications for reproductive output of the population (see Sections 3.1.1 and 3.2.1). The removal of larger individuals could well be accelerated where commercial catch limits were applied if fishermen were ‘high grading’, preferentially keeping only the largest individuals for landing due to their higher market value. This could reduce the potential benefits of management with regards to the reproductive output of the population and also result in a length/age frequency distribution which was not representative of GES. As crawfish are a bycatch species caught at relatively low levels care would need to be taken that individuals were not simply stored at sea in keep creels and then landed according to the catch limits in place. While commercial catch limits could provide protection to crawfish populations through limiting landings, in view of the depleted state of crawfish populations, it is likely that this measure would have limited effect on the initial recovery of crawfish as a stand-alone measure. It may be more appropriate to implement a catch limit to manage fishing activity within a more advanced recovering crawfish population where removal of individuals was permitted.

3.2.5 V-notching

V-notching can be an effective methodology for temporarily removing individuals, usually females, from the fished population thus allowing them to continue breeding without the potential of removal. Legislation is already in place for Welsh waters out to 12 nautical miles, which prohibits the landing of v-notched crawfish, through the Lobsters and Crawfish (Prohibition of Fishing and Landing)(Wales) Order 2002. The effectiveness of this management measure will depend on a number of factors: the length of time the v-notch will remain visible in the tail, the frequency of reproduction of the individual, and the ability of the individual to find a suitable mate. In European lobsters (*Homarus gammarus*) it is generally thought that the v-notch will remain visible for around four years, however, in larger individuals that may moult less frequently this period may be longer. Moult frequency in crawfish does decrease with size, particularly in females, with the largest individuals moulting once every two years (Hunter, 1999). It has been reported that v-notching can substantially increase the reproductive potential of highly exploited small scale *H. gammarus* fisheries and increased catch rates of juvenile lobsters were reported four to five years after the implementation of a v-notching scheme (Tully, 2001). However, reports from a v-notching experiment carried out on *H. gammarus* in Orkney indicated that the egg production of v-notched females (totalling 5,728 individuals) represented only a small portion of that produced by the total population (Chapman, 2003). V-notching of crawfish has been carried out in Ireland, however relatively high mortality rates were observed (M. Robinson pers. comm.). The telson of the crawfish is not as calcified as that of a lobster and this could mean that the v-notching process causes greater tissue damage, and healing may not be as straightforward as is seen in *H. gammarus*. This may make v-notching a less relevant option as a management tool to facilitate recovery and it would certainly limit any potential benefits. However, if v-notching was carried out, it might be considered appropriate to notch both males and females in order to prevent any potential sperm limitation, as discussed in Section 3.2.1.

The effectiveness of v-notching in recovery of a population of crawfish will be difficult to determine and any changes in LPUE would be likely to take a minimum of four to five years at the current MLS (see Table 1.1). V-notching ensures the potential for increased levels of egg production within a population; however, this may not translate into recovery in terms of numbers of individuals. The length of the planktonic larval phase and the potential for dispersal of the larvae needs to be taken into consideration. If v-notching is taking place in an area where there is a net removal of larvae from the area then it will not be effective in restoring the local population, but may have benefits in areas remote from the management measure. Given the potentially high levels of mortality associated with v-notching it is unlikely there would be a straightforward gain in increased egg production at the population level. The potential gains through v-notching could also be limited in a depleted population where there would be reduced opportunities to notch individuals through low catch rates. As such this management measure is unlikely to be effective in terms of the recovery of a depleted crawfish population.

3.2.6 Prohibiting the landing of berried females

For some crustacean fisheries the landing of ovigerous or "berried" females is not permitted and these individuals are returned to the sea to complete their reproductive cycle. Such a prohibition exists in the Portuguese fishery (Galhardo *et al.*, 2006) although no assessment of its effectiveness has been carried out. This method can be particularly appropriate where the minimum landing size is close to the size at maturity as it ensures that berried females are permitted to breed prior to entering the fishery. It has been indicated that for the lobster (*Homarus gammarus*) fishery in south Wales, the potential for increased egg production through protecting berried females was much greater than through the introduction of a minimum landing size (Davies, 1999). This is likely to also be the case for crawfish, as larger reproductively active females produce greater numbers of eggs.

In order to assess the potential benefits of a prohibition on the landing of berried females it is important to determine when, and at what levels, they appear in the populations. Hunter *et al.* (1996) reported that the first berried females were observed in August and represented 10% of females caught in the south Wales fishery. By September 23% of females from the Welsh fishery and 17% of caught Cornish females were berried. In the Cornish fishery this increased to 89% in December and 90% in January. No data on the percentage of berried females during the winter for the south Wales fishery were available, although it can be assumed that the values would be similar. Hunter *et al*. (1996) also reported that in May 57% of females caught in south Wales were still carrying eggs. These data indicates that the majority of females are spawning annually and would therefore be protected by a prohibition on the landing of berried females. They would however, still be available to the fishery when not carrying eggs.

It is has been reported that pot fisheries preferentially catch females (Goñi *et al.*, 2003b), which would increase the impact of this management measure on those fishermen using pots to fish for crawfish. Although this is a relatively straightforward management measure to apply, it has resulted in the rather unscrupulous practice of scrubbing the eggs off in fisheries for the European lobster (*Homarus gammarus*). Given the high value of crawfish it is possible that this method could be used to illegally land berried females as it is difficult to detect. Where females are returned to the sea survival rates are likely to be high, however, egg loss through capture is possible and this may particularly be the case for tangle net fisheries where the action of the net could remove eggs. Should these factors be a concern a seasonal prohibition of fishing in areas where berried females were found may be a more appropriate measure should the protection of berried females be considered a management priority.

The scale of recovery produced through the introduction of a prohibition on the landing of berried females is difficult to assess. As the data suggest that the majority of females moult on an annual basis this measure could result in increased egg production. Although a prohibition on the landing of berried females would protect egg production during the winter months when females were berried, it would not prevent them from being caught during the summer months when they were not carrying eggs. Data from the period 1980 to 1997 (see also Section 1.2.2) showed that between 77 and 90% of the catch was landed between May and September (Davies, 1999) when the majority of females would not be in berry. This could compromise the effectiveness of a prohibition on the landing of berried females, should the pattern of fishing activity remain in this seasonal pattern.

Up to date information on the catch rates of berried females, fecundity, and length distribution of females caught in the Welsh fishery would allow calculations of the potential increases in egg production which could be expected through this prohibition. Should larvae produced through this increased potential recruit to the population it would take around four to five years for them to reach the fishery with the current MLS in place (see Table 1.1). If larvae are not retained in the same area as the prohibition there may not be any substantial benefits in terms of population recovery as females would still be available to the fishery for several months of the year.

3.2.7 Area Restrictions

There is a large volume of literature on the effects of area closures on spiny lobster populations, largely through studies on marine protected areas (MPAs). The information provided here is not intended to be a review of the effectiveness of MPAs in protecting fished species in general, but rather a collation of the most relevant information with regards to the recovery of crawfish within Welsh waters.

There are several factors which should be considered in the use of area restrictions for the protection of crawfish. These include the scale and location of the area and its relevance to the behavioural and ecological requirements of crawfish relative to its life history (Childress, 1997). Permanent area restrictions will be most effective where there is a resident population. If the population which is protected within the area is only present for a particular part of the life cycle the closure will not afford protection to the population at other times. MacDairmid and Breen (1993) indicated that extensive migrations of juvenile *Jasus verreauxi* resulted in ineffective protection for this species through a marine reserve. In the same reserve an increase in density of *Jasus edwardsii* was much more stable in females than males and this was linked to the migratory behaviour of adult males taking them outside the reserve where they were subject to fishing activity (MacDiarmid and Breen, 1993). Tagging studies of a Mediterranean population of *Palinurus elephas* have shown that there was little movement of individuals and that larger animals in particular were more likely to remain resident (Follesa *et al.*, 2009), however, it has been shown that some Atlantic populations do undertake seasonal reproductive migrations onshore in spring and offshore in the autumn (e.g. Ansell and Robb, 1977).

There may be habitats which are important to different stages of the life cycle, for example areas with suitable habitat for the settlement of juveniles may be different to those required by adult individuals. In Ireland, high densities of juvenile crawfish were discovered on exposed vertical habitats which had a high proportion of fissures and holes for shelter (Robinson *et al.*, 2008). In the Spanish Mediterranean concentrations of juveniles were found in deeper water after migrating from shallower settlement areas (Goñi *et al.*, 2001). Where specific areas can be identified that are important to the life cycle for part of the year, e.g. spawning grounds, these could also be identified for a seasonal restriction in fishing (see Section 3.2.8).

It has been shown that closing an area to fisheries can have considerable benefits in terms of numbers of crawfish. Goñi *et al.* (2001) calculated an abundance index for *P. elephas* from fished areas and from within a reserve which had been closed to fishing for eight years. They showed that the abundance of crawfish within the fished areas was around 0.6 to 20% of that in the reserve. Catch rates from experimental fishing within the protected area showed CPUE values of four to 154 crawfish per 600 m of net per day while outside the protected area CPUE was in the range zero to ten crawfish per 600 m of net per day (Goñi *et al.*, 2006). Following the establishment of a marine reserve in 1976 the density of *J. edwardsii* was seen to increase 4.5 fold between 1978 and 1983, whereupon density levelled off (MacDiarmid and Breen, 1993). Sampling catch rates in areas closed to dive fishing for *P. argus* showed an increase of 5% after 29 months, compared to a 22% reduction in an area which had been open to dive fisheries (Davis, 1977).

The selection of the location and scale of a closed area will affect the potential benefits to a fished species. Where closed areas are located in areas with unsuitable conditions (e.g. limited habitat, food, or unsuitable temperature or salinity) there can be significantly reduced benefits to exploited species. If suitable habitats are limited for example, there may be no benefit, in terms of increased density, to closing an area (MacDiarmid and Breen, 1993). The size of a closed area is also important. Positive outcomes in the management of spiny lobsters have been observed in the Columbretes Islands Marine Reserve in the Spanish Mediterranean which covers an area of 14 km^2 and has shown benefits to *Palinurus elephas* populations within, and to fisheries outside this area (Goñi *et al.*, 2001, 2006, 2010). Dry Tortugas protected area in Florida closed a total of 19 km^2 to all harvesting of *Panulirus argus* and allowed a temporary recreational dive fishery in a further 95 km^2 (Davis, 1977) which resulted in increased densities of lobsters. In Looe Key National Marine Sanctuary in the Florida Keys, *P. argus* abundance and length frequency were similar, both within and outside the area closed to commercial fisheries, over a period of two years and the authors attributed this to the small size of the protected area 0.5 km^2(Hunt *et al.*, 1991). Although small areas (~4 km^2) have been shown to be effective in the protection and recovery of crawfish stocks with regards to body size (Bevacqua *et al.*, 2010), it has been shown that individuals will be able to move into adjacent areas where fishing is permitted (Childress, 1997, Rowe, 2001, Follesa *et al.*, 2009) and therefore the benefits of the closure will be reduced.

The movement of individuals outside a protected area can have beneficial effects for fisheries (Goñi *et al.*, 2008) which may mitigate to some extent the removal of fishing grounds at closure/designation (Kelly *et al.*, 2002, Goñi *et al.*, 2010). Catch per unit effort was examined for crawfish trammel net fisheries outside a reserve in the Spanish Mediterranean (Columbretes Islands Marine Reserve). It was seen that catch rates were elevated at the reserve edge and there was a gradient of density decrease with increasing distance from the protected area up to 4.5 km

(Goñi *et al.*, 2006). The authors also report that the level of spill over from the closed area had the potential to maintain stable catch rates up to 1,500 m from the edge of the reserve. This potential for increased abundance adjacent to reserves can attract additional fishing effort (Goñi *et al.*, 2006, Goñi *et al.*, 2008). Impacts of this increased effort could reduce the effect of increased numbers of crawfish in the surrounding area (Goñi *et al.*, 2010). There could also be cumulative increases in effort due to displacement of fishing activity from the closed area.

It is important to note that the scale of increase in abundance within an area will be related to the level of fishing within the area. Where the removals through fishing activity are high the provision of a closed area would provide a significant refuge, with resulting proportional increases in abundance within the closed area. In areas where fishing effort is low, the impact of an area closed to fishing crawfish would be likely to be much less significant. This is an important consideration within the current depleted status of Welsh crawfish populations, where crawfish abundance is low and removals through the fishery are low. This may reduce the speed and scale of any recovery that could be brought about through area closures.

When looking at the impacts of protected areas on the recovery of a population it is also important to note that data on the population prior to protection is important in assessing its success. This data is often not collected and it is therefore not possible to quantify effectively the level of protection that such a closed area would affect (Goñi *et al.*, 2001).

The potential rates of recovery from various studies are summarised in Table 3.3. It is possible that in appropriately identified areas, recovery of crawfish populations with respect to abundance (and therefore CPUE) could be observed within a matter of months and that the potential scale of recovery (both abundance and reproductive output) could be high. However, changes relative to the size structure of the population may take longer to achieve and therefore GES may be a longer term objective achieved through the amalgamation of various short term interim gains as indicated in Section 2.2. Care should be taken in interpretation of data with regards to the timing and scale of recovery possible through area closures in Welsh waters, as the environmental conditions are different to those in the examples set out above (see Section 1.1.4).

3.2.8 Seasonal Restrictions

Seasonal restrictions are useful in protecting the population during specific periods of their reproductive cycle, for example mating periods or closures for the avoidance of capture of berried females. Female crawfish have been shown to carry their eggs for a period of eight to nine months (Hunter *et al.*, 1996) with egg bearing females seen in the population from August to May. Should a total closure of the fishery be deemed necessary for the protection of berried females (as opposed to a prohibition on landing berried females see Section 3.2.6) a seasonal closure covering all or part of this time period would protect berried females from the fishery. A six month closed season (September to February) for the protection of berried females is implemented in the Spanish Mediterranean, and studies showed that catch rates of crawfish were higher following this closed period (Goñi *et al.,* 2001). Benefits such as these would depend on the status of the population and fishery. As the Welsh crawfish population is depleted, increases in catch rates of this bycatch species may not be so apparent.

Seasonal closures in isolation may not reduce overall effort on the population as they could result in a shorter more intense period of fishing pressure while the fishery is open. Given the depleted status of Welsh crawfish stocks, seasonal restrictions may be more appropriate as a fisheries management tool to protect a population which has already shown signs of recovery, rather than for the specific purpose of facilitating initial recovery of crawfish.

3.2.9 Highly Protected Marine Conservation Zones in Welsh Waters

The role of Highly Protected Marine Conservation Zones (HPMCZs) in Welsh waters is to "contribute to the recovery and resilience of marine ecosystems" and designation will result in the prohibition of resource extraction, meaning that fisheries would not be permitted within their limits. It is proposed that three to four HPMCZ sites would be identified and that these are likely to be located within existing Marine Protected Areas (MPAs) in Welsh waters (Welsh Assembly Government, 2011). The total area included in any designated area, along with the proportion of suitable habitat contained within, would have an effect on its potential ability to aid recovery of crawfish populations. Areas which are designated for more general nature conservation or ecosystem objectives may have consequential benefits for crawfish populations in providing a refuge from fishing activity; however, it should be taken into consideration that closures designed specifically for the recovery of crawfish in terms of their location and size are likely to be more effective for this species. At the time of producing this report proposed HPMCZs in Welsh waters have not yet gone out to public consultation and therefore the assessment of their potential to aid in the recovery of crawfish populations is limited to theoretical consideration.

The principles and criteria for selecting HPMCZ in Welsh waters were set out in site selection guidance produced by the Welsh Government in 2011 following a period of public comment (Welsh Assembly Government, 2011). Eleven ecological criteria have been set out which will be used to identify Focus Sites, these will then be refined to provide a shorter list of Potential Sites. Of the broad scale habitats identified for protection shallow and deep water rock habitats would be relevant to crawfish (see Section 1.1.1). Areas with high habitat heterogeneity will receive a higher rank in the site assessment process. The stated minimum size for a habitat patch within a site is 500 m to 1 km in diameter, with the initial size for site selection being approximately 5 km^2. The guidance states that "sites will be no larger than is necessary to encompass the minimum patch sizes within them to create a viable site" (Welsh Assembly Government, 2011). This has the potential to result in sites with relatively small areas of habitat suitable for crawfish, which would limit their potential to affect recovery. The size of MPAs which have facilitated spiny lobster recovery in other areas is generally greater than that suggested as the minimum patch size and site size suggested for HPMCZs in Wales (see Section 3.2.7).

The viability of protected areas is set out in the recommendations as requiring a minimum viable area for the sites to be self-sufficient. Viability is linked to the biology of individual species and it is acknowledged that for species with extended planktonic phases the size of the area required to be incorporate their life cycle would be prohibitively large. The estimated size of area needed to encompass the life cycle of *P. elephas*, with its planktonic phase of ten to 12 months, is 1,886 km^2 (Hill *et al.*, 2010). Given this substantial, albeit cautious, estimate the authors suggest that a series of connected MPAs would be the most appropriate approach for crawfish. The connectivity of HPMCZ sites is to be considered at stage two of the process for identifying Potential Sites in Welsh waters and will include all MPAs including Special Areas of Conservation. The other designated sites in Welsh waters will not necessarily provide the same level of protection to fished species compared to the HPMCZs which prevent any fishing activity. In addition other designated sites may not contain current or historical crawfish grounds, and connectivity with specific reference to crawfish recovery will need to be considered when the sites are announced.

The HPMCZ site selection guidance lists various species of conservation concern, which includes those which have declining populations or which are threatened, though crawfish are not specifically listed and priority would be given to those species which contribute to ecosystem structure and/or function (e.g. oysters). It is also noted that the focus of HPMCZ should be ecosystem recovery and resilience, and as such recommends that the protection of individual species should be considered using other designations (Welsh Assembly Government, 2011). Therefore the site selection guidance specifies that the presence of species of conservation concern should not be used to select sites but may be used to decide between otherwise similar sites at subsequent stages in the process.

Social and economic considerations will also be applied to the HPMCZ site selection process both during and after the identification of Potential Sites. While fishing has been identified as an activity which is incompatible with site designation, the Welsh HPMCZ guidance states that consideration should be taken to fishing activity within the site, the potential for displacement of effort, the potential benefits to critical life stages of fished species (Welsh Assembly Government, 2011). The implementation of HPMCZs in Welsh waters could result in displacement of fishing effort into areas that are important for crawfish.

The potential ecosystem benefits of Highly Protected Marine Reserves were discussed by Gubbay (2006). This report also highlighted the difficulties in predicting the potential benefits and their timescales within such protected areas. The author noted that increases in abundance and biomass for species that were commercially fished prior to designation could be observed within a few years. The role of HPMCZ in the context of crawfish population recovery in Welsh waters is likely to be limited however. This is due to the relatively small scale and low number of sites to be considered, their focus on ecosystem recovery and resilience, and the prioritisation of sites with high habitat heterogeneity. It may be that crawfish will be present within some of the sites and therefore offered some protection from fishing pressure; however, this is unlikely to benefit crawfish populations as whole or to contribute significantly to population increases.

3.2.10 Marine Conservation Zones in England

Marine conservation zones (MCZ) in England, adjacent to Welsh waters could have the potential to aid in the recovery of Welsh populations of crawfish through net movement of individuals out of the site or through increased reproductive output which resulted in the transport of juveniles or larvae into Welsh waters. The total area included in any designated area along with the proportion of suitable habitat contained within, would have an effect on its potential for the recovery of the stock. The ability of closed areas outside Welsh waters to elicit recovery of crawfish stocks would depend on the connectivity of sites and on source – sink dynamics of the populations. The direct implications of a closed area, such as an MCZ, are discussed in Section 3.2.7.

As with the guidelines for Welsh sites, priority is given to areas that are representative of several broadscale habitats and habitats of conservation importance. The recommendations for particular habitat patch size is consistent with Welsh recommendations, with additional reference to an average overall site size of ten to 20 km diameter (Ashworth *et al.*, 2010). The ecological guidelines for the selection of sites within English waters also state that “guidelines on connectivity are considered to be secondary to other guidelines for the network design principles”. There is however a commitment from Government and the devolved administrations to deliver “an ecologically coherent network of MPAs”. It is suggested that in the absence of species specific information sites should be within 40 to 80 km of each other. Crawfish have been shown to travel up to 70 km, though many individuals were observed to move much shorter distances than this (see Section 1.1.1). The most recent timetable for the implementation suggests that the first MCZs will be designated in summer 2013. The guidelines set out by Natural England and JNCC (Ashworth *et al.*, 2010) include crawfish on a list of 29 low or limited mobility species of conservation importance which should be protected where they occur. They also set out a minimum viable patch size of 5 km diameter for crawfish. The size of MPAs which have facilitated spiny lobster recovery in other areas is generally greater than that suggested as the minimum patch size suggested (see Section 3.2.7).

English MCZ sites will only benefit Welsh populations if they are a source of net immigration of juvenile or adult crawfish, or if they provide a source of larval advection into the area. Research in the Mediterranean has shown that although some individuals have been observed to move up to 70 km the majority (80%) of crawfish remain within a 5 km radius of where they were tagged and only 2.3% travel further than 20 km (see Section 1.1.1). Although this movement data is not specific to Welsh waters, it does suggest that only MCZs in very close proximity to Welsh waters would have the potential to aid population recovery through immigration of juvenile or adult individuals. Any spill-over would be limited in area (see also Section 3.2.7) and as such juvenile and adult immigration is unlikely to contribute significantly to crawfish recovery within Welsh waters. Spill-over can also attract increased fishing effort; any potential benefits from such closed areas may need to be augmented by additional fisheries management measures. Residual current movements suggest that it may be possible for larvae to be transported from the Southwest England into Welsh waters and also from north west England via the Irish Sea; however, this more information on currents relative to the behaviour of larvae and seasons would be required before any larval connectivity links could be proven.

3.3 Potential Recovery Rates

The following table outlines the potential scale of recovery which has been observed through the introduction of management measures for *Palinurus elephas* in other areas, and also for other Palinurid species. In interpreting this data care should be taken as the scale of recovery can potentially be affected by the geographical location of each study, the original status of the population and the biology of the population/species under investigation (see also Section 1.1).

Table 3.1 Examples of *Palinurus elephas* recovery in other areas, and for other species, with potential timescales for recovery where the information is available.

Management Measure	Examples	Recovery	References
Minimum landing size	Predictions using LCA on brown crab (*Cancer pagurus*) populations	Large percentage increases in yield per recruit and biomass per recruit predicted. Increases in yield per recruit for males ranging from around 5 to 35% in three years.	(Addison and Bennett, 1992)
V-notching	V-notch programme for *Homarus gammarus*	Catch rates of juvenile lobsters increased four to five years after v-notching	(Tully, 2001)
Area restrictions (including Marine protected areas)	Reserve closed to fishing for *Palinurus elephas*	Population index 80 to 99.2% higher than fished areas. Spawning potential five to 20 times greater than fished areas. 10% net increase in catch weight eight to 17 years	(Goñi *et al.*, 2001) (Goñi *et al.*, 2003a) (Goñi *et al.*, 2010)
	Closed area for diver caught *Panulirus argus* (closed for 29 months followed by an eight month experimental sport harvest then a further closure to assess recovery)	CPUE at 78% of pre-harvest levels after one year Lair occupancy rate 71% of pre-harvest levels after 18 months	(Davis, 1977) (Davis, 1977)
	Small MPA (~4 km^2) closed to commercial fishing	Body size dispersion (interquartile range) increased by 0.9 mm $year^{-1}$ within the MPA and decreased by 0.6 mm $year^{-1}$ outside	(Bevacqua *et al.*, 2010)

		A ten year study can provide only partial evidence of the recovery of populations of *P. elephas* with regards to body size.	(Bevacqua *et al.*, 2010)
		Over a period of ten years the percentage of individuals greater than the MLS was 33% inside the closed area and 4% outside	(Bevacqua *et al.*, 2010)
		Increase in density (×4.5) observed over a seven year period	(MacDiarmid and Breen, 1993)
		Increase in size of individuals	(MacDiarmid and Breen, 1993)
	Marine reserve closed to fishing of *Jasus edwardsii*	Marked increase in density over a ten year period	(Cole *et al.*, 1990)
Seasonal Closures	Annual six month closure of *P. elephas* fishery in Spanish Mediterranean	Abundance significantly higher following closed period	(Goñi *et al.*, 2001)

4 DATA REQUIREMENTS TO ENABLE ASSESSMENT OF WELSH CRAWFISH POPULATION(S)

The Marine Strategy Framework Directive (MSFD) sets out three key attributes in order to determine Good Environmental Status (GES) for commercially exploited species which should:

1) Be exploited sustainably consistent with high long term yield

2) Have full reproductive capacity

3) Have a healthy age and size distribution

GES can only be attained if all three criteria are fulfilled. Two approaches to assessing these three attributes are set out which differ in their data requirements (Piet *et al.*, 2010). Where there is sufficient data for analytical assessments reference levels can be set as indicators of GES. These would include calculations of fishing effort relative to maximum sustainable yield ($F > F_{MSY}$) and determination of what the spawning stock biomass (SSB) should be in order to avoid any risks of impairment of recruitment. A review of analytical stock assessment methods for crustacean fisheries has been carried out by Smith and Addison (2003) which compares analytical methods that model stock and/or fishery dynamics using commercial fisheries data and in some cases fisheries independent data. Smith and Addison (2003) provide information on the data requirements for each method along with their advantages and disadvantages. They also provide examples of where the different assessment methods have been used for spiny lobster fisheries.

Where there is insufficient data to carry out analytical stock assessments and in the absence of set reference points, it is suggested by Piet *et al.* (2010) that analysis and observations of data trends can be used to assess GES. This second option would be the most appropriate for the Welsh crawfish fishery which has significant identified data deficiencies. The data requirements of this approach are a measure of abundance or biomass based on surveys or commercial catches, and data on the length frequency distribution.

The data required to fulfil the criteria using the less robust methodology as set out by Piet *et al.* (2010) is: a ratio of catch to biomass which can be obtained from a time series of CPUE data preferably obtained by survey; log-transformed population abundance, and the 95^{th} percentile of the population distribution. For GES to be attained there should be no degradation gradient in these indicators. It is therefore suggested that as a minimum, in order to assess the Welsh crawfish population within the context of GES, length frequency and CPUE data should be collected using targeted surveys to supplement the catch and effort data currently available. These surveys should be "sufficiently representative i.e. in terms of the area covered as well as the sampling method" and "capable of delivering appropriate data, i.e. recorded numbers at length" (Piet *et al.*, 2010).

The collection of length frequency data can be useful for observing changes to the population which could be caused by fishing pressure, or indeed changes which were indicative of a period of recovery within the population. Changes in the length frequency distribution which are driven by fisheries typically show a reduction in the mean size of the population as larger individuals are removed (Galhardo *et al.*, 2006). Goñi *et al.* (2003b) carried out a study on a population of *P. elephas* which had been protected for almost ten years through a marine reserve. They suggested that the size structure of the population of crawfish in the area would have approached that of the virgin, un-fished population in this time, which represented half of the maximum life span for *P. elephas* as suggested by Mercer (1973).

Length frequency data is not only valuable in terms of a biological descriptor relative to GES, but would also help to inform management decisions such as changes in landing sizes. Information on the size, sex and numbers of individuals in the population would also allow interpretation of management measures to be carried out; for example, it would be possible to calculate potential egg production from various components of the population. Other data which should be collected would include information on the reproductive cycle, such as the proportion of berried females within the population; at what time of year they are present and their geographical distribution. These data would inform the potential use of measures such as prohibition of landing berried females, changes in landing size, and area or seasonal closures.

Differences in the biology and behaviour of various components of the population could substantially alter the length frequency distribution of the population at different times of the year and it is therefore important to record data, representative of the population, in the form of a continuous time series where possible. There may also be a significant spatial element to the data which would also need to be considered and sampled accordingly. A seasonal reproductive migration in a Mediterranean population of crawfish resulted in changes in the abundance of females, but not their length frequency distribution; however the length frequency distribution for males showed marked seasonal changes (Goñi *et al.*, 2001). The methodology for data collection should also be considered when looking at length frequency as a population descriptor. Hepper (1977) looked at the length frequency distributions of the catch from different fishing methods and reported that while the distributions were similar, the catch from pots was slightly smaller than that caught in tangle nets and by divers. In addition tangle nets tend to be indiscriminate in the individuals they capture while pot fisheries can be more selective (e.g. Goñi *et al.*, 2003b).

Catch per unit effort (CPUE) and landings per unit effort (LPUE) data can both be used as an index of abundance within a fishery. CPUE represents the total catch including that which is discarded (e.g. undersized, soft), while LPUE includes only the retained portion of the catch. Fishermen's catch and effort data, if collected throughout the year, can be used as a proxy indicator as to the status of the stocks. Observations and analysis on LPUE within each fishery can provide a useful indicator of abundance and can also be used to determine real time changes in the fishery. A time series of data is required to analyse trends in LPUE and an understanding of the biology of crawfish is important in interpretation of any trends in LPUE. Care should be taken in the recording of CPUE and LPUE data so that any changes in fishing practice are incorporated in the analysis. For pot fisheries this would incorporate data from four different kinds of pots fished (Davies, 1999), each of which will have different levels of efficiency at catching crawfish. In the case of net fisheries, for example, the increased landings reported for Wales in the period around 1997 (where fishermen discovered a migration route and preferentially exploited it) would have resulted in an increase in LPUE. This increase in LPUE would not have been representative of any change in the abundance of crawfish, but rather represents changes in fisher's behaviour. The context of the data collected is important to its interpretation.

The introduction of technical conservation measures can also affect LPUE data from the fishery through increased discarding of individuals e.g. through the introduction of MLS or MaxLS or through prohibition of landing berried females. The value of observer trips in recording information on the entire catch (both that landed and discarded) is evident here.

The data requirements set out above are key in assessing GES under the MSFD, however, in order to determine the most appropriate management measures in order to facilitate recovery of Welsh crawfish populations the collection of further biological and fisheries data will be required. The collection of this data could also form the basis of analytical stock assessments in order to provide a more robust methodology for the determination of GES.

More detailed information on the behaviour and movements of Welsh crawfish would also be extremely beneficial in assessing the potential value of management measures, such as area or seasonal closures. It has been shown that net fisheries in particular can target migration routes of crawfish and increase catch rates and landings. This type of fishing is very efficient and has the potential to significantly reduce crawfish numbers over a relatively short period of time. It is important therefore to identify migratory routes which could inform area or seasonal closures to protect crawfish at a stage in their life cycle where they are particularly vulnerable to fishing effort.

One of the main limiting factors in assessing the potential for recovery of crawfish populations, via management measures which increase the reproductive potential of the population, is data on recruitment. While it is thought that populations of *P. elephas* can occur in areas where there is larval retention through gyres (M. Robinson, pers. comm.), the source of larvae for Welsh populations is not clear and the available information on larval behaviour and prevailing currents does not permit identification of larval source and sink dynamics. Mark-recapture and genetic studies could provide useful information in determining the connectivity of crawfish populations in Welsh waters with those in other areas. This would allow an informed assessment of whether or not those measures which increase the reproductive output of the population would benefit recovery of Welsh populations or not. Information on larval source and sink dynamics overall would help inform the management of crawfish populations and their recovery at the most appropriate geographical scale: Wales, regional sea, or European level.

Fisheries data is currently collected through permit schemes, and while this provides a useful record of catch and effort there are inconsistencies in the spatial resolution of the data recorded by fishermen (P. Coates, pers. comm.). Standardised collection of spatial fisheries data would be extremely valuable in determining which management measures would be most appropriate and in determining the relevant legislative framework with regards to the geographic scale of management measure required.

5 DISCUSSION

Populations of *Palinurus elephas* within Welsh waters are generally accepted to be in a depleted state due to changes in fishing practice in the 1960s and 1970s. This report has set out the potential for both existing and possible management measures to aid the self-propagated recovery of crawfish. Although it is not the purpose of this report to make recommendations on the future management of crawfish within Welsh waters, conclusions can be drawn about the relative suitability of different management options. The potential for recovery is assessed within the broad context of achieving Good Environmental Status (GES) as defined in the Marine Strategy Framework Directive (MSFD) Task Group Report on Commercially Exploited Fish and Shellfish (Piet *et al.*, 2010).

It is accepted that current data deficiencies on the biology and exploitation of crawfish in Welsh waters mean that it is not possible to carry out analytical stock assessments; however, historical LPUE data has been identified as a benchmark on which recovery can be assessed (see Section 2.2). There are limitations to the use of such data however; as it is only available from late 1980 onwards it can only provide an insight into a recovering population rather than one which has recovered. Lack of historical data also produces difficulties in determining what GES actually represents in relation to crawfish population abundance and length frequency distribution prior to the commencement of fishing. Interpretation of LPUE data, while useful in assessing initial recovery, will need to be supplemented by additional data collection in order to determine if the population is moving towards a level which represents GES, as set out in Section 4.

5.1 Existing management measures

Assessment of the existing management measures within Welsh waters indicated that there was limited potential for aiding recovery of crawfish populations. There have been no significant changes in LPUE from the fishery following the introduction of the 110 mm CL MLS in 1997 in south Wales, the European 95 mm CL MLS in 1997, through the existence of marine SACs for over a decade, or via the non-commercial catch limits. Although the increased MLS introduced in south Wales is more conservative than the EU limit of 95 mm CL it is limited by the geographical extent of the bylaw which extends to six nautical miles. Length frequency data also indicate that the 110 mm CL MLS may be too small with regards to the size frequency of individuals and size at 50% maturity (see Table 1.2) within the population (Hunter *et al.*, 1996). In addition to the possible disparity between the length frequency and SOM of the population and MLS, the continued removal of larger individuals through on-going exploitation could disproportionately affect the reproductive output of the population as larger females contribute a greater proportion of eggs (Goñi *et al.*, 2003a, Galhardo *et al.*, 2006), see also Section 3.2.1. In isolation the use of MLS to aid recovery of crawfish may well be limited for these reasons and it is likely that both an appropriate MLS and $M_{ax}LS$ would be required to produce greater gains in reproductive output.

While this report does not consider the socio-economic implications of management, a significant increase in MLS could have a considerable impact on existing fisheries through reduction in catches, and this can result in non-compliance (Galhardo *et al.*, 2006). Although catches of crawfish in Wales are relatively low, it is a high value species and as such can make up an important part of fishers income (P. Coates, pers. comm.) so non-compliance could be a consideration.

The management strategies for Pembrokeshire Marine and the Pen Llŷn a’r Sarnau Marine Special Areas of Conservation do not currently provide any specific measures which would encourage the self-propagated recovery of crawfish, while in the Skomer Marine Nature Reserve a voluntary ban on net fishing and voluntary recreational diver no-take, could have potential to aid recovery. The management structures for these designated sites do provide a mechanism through which potential conservation measures (voluntary and statutory) could be discussed and agreed.

Within the context of attaining GES for Welsh crawfish populations under the Marine Strategy Framework Directive, the current management measures in place in Welsh waters are not effective in facilitating recovery, nor are they resulting in recovery towards historical levels of LPUE.

5.2 Possible Management Measures

Of the potential management measures outlined in this report, those which regulate fishing activity are likely to have the most positive impact on the recovery of crawfish in Welsh waters. The establishment of HPMCZs may well provide refuges for crawfish where areas of protection include suitable habitats. However, as their main function is to protect ecosystem function and resilience, as opposed to specifically facilitating crawfish recovery, their potential impacts for this species are likely to be limited. The potential direct benefits of each management measure are summarised in Table 5.1, along with possible combinations of measures which could enhance the potential to aid crawfish recovery. When considering changes to fisheries management it is also important to take into consideration displacement of effort and diversification into alternative fishing methods, both of which can have implications for the success of any management measure in ensuring the recovery of *P. elephas* populations in Welsh waters.

There are several management measures which have the potential to increase the reproductive output of the population while placing no limits on effort or restrictions on the area fished. Of these the introduction of a prohibition of landing berried females could be an appropriate initial or interim management measure, should fishing activity during the winter months when females area berried, be identified as a concern. This measure would also apply to all sectors of the fishing fleet and would not require the collection of additional biological or fisheries data. This would protect a portion of the Welsh crawfish population from fishing and also increase the reproductive potential of the population, while additional data collection was carried out to inform further management measures. V-notching is a further method by which the reproductive potential of the population could be increased and legislation is in place to prohibit the landing of notched individuals. However, given the potentially high mortality rates associated with this technique for crawfish, it is not considered to be a viable option for aiding in the recovery of this species.

The introduction of an appropriate MLS and $M_{ax}LS$ for crawfish also has the potential to increase the reproductive output of the population. Given the greater reproductive potential of larger individuals and the current depleted status of the stocks, the introduction of both measures simultaneously would provide greater potential gains in terms of egg production and would also help to promote a length frequency distribution that better reflected GES. Introducing appropriate limits would, however, depend on the collection of appropriate length frequency data from the fishery and further biological information on the size at maturity of Welsh stocks. It is possible that a revised MLS could be introduced based on existing data (see Table 1.2) as an interim measure while data was collected to provide the most appropriate landing sizes based on the current length distribution of the population.

Technical conservation measures such as gear modifications can be beneficial in reducing catch rates and also preventing the capture of juveniles. Given the current depleted status of Welsh crawfish populations, and the relatively low levels of landings, it is unlikely that gear modifications would have any impact on the recovery of the population. The application of such measures is more likely to be beneficial in areas where recovery has been facilitated, as they can provide a degree of protection to populations which may be subjected to renewed fisheries interest.

Prohibiting individual fishing methods in discrete areas, while reducing removals from the population, may be limited in terms of facilitating recovery and attaining GES for crawfish populations. If a prohibition is implemented for only one gear type fishing can be continued using other methods, and this would reduce any potential benefits with respect to changes in the length frequency distribution, and any gains in terms of increased abundance or reproductive output. Prohibitions on specific gear types may be more relevant to management within a recovering population. For example, where numbers of crawfish were shown to be increasing this may make them more attractive to fishing by divers and a prohibition would prevent recovery from being inhibited by increased fishing effort.

Prohibitions on landing crawfish may be more effective in eliciting recovery than prohibitions of fishing with certain gear types, particularly as crawfish are a bycatch species. Given the current low levels of UK landings of crawfish by foreign vessels it is likely that prohibitions on landing *P. elephas* implemented through a Welsh Statutory Instrument would be appropriate in facilitating recovery of crawfish. However, mechanisms by which to gauge any increase in fishing by EU vessels within the Welsh Zone would be advisable in order to make sure that any recovery gains made through domestic legislation were not being undermined by increased fishing effort from non-UK vessels. A reduction in the catch limits or a zero catch limit for recreational fisheries may also be appropriate alongside a prohibition on landings, particularly as there is little information about the level of non-commercial activity carried out. These measures together would ensure reduced removals from the population from both commercial and recreational effort. It is possible that a prohibition on landing crawfish could still result in some fisheries related mortalities, particularly in net fisheries. Investigations into the mortality rates of live returns from net fisheries should be carried out in order to determine if prohibitions on net fishing in areas of high crawfish catch rates would also be required alongside a landing prohibition in order to gain the greatest potential for recovery.

Area closures have been shown to be effective for populations of *P. elephas* in the Mediterranean, and also for other species of spiny lobster. Care should be taken in the interpretation of the effectiveness of such measures as the environmental conditions and level of fisheries is different from that observed in Welsh waters. The scale and speed of recovery achievable within depleted Welsh populations of crawfish may not be comparable to studies carried out in the Mediterranean. The implementation of any area closures in Welsh waters would need to be based on detailed information on the current extent of crawfish populations. This would facilitate selection of the most appropriate areas for closure in order to produce the best possible gains in terms of recovery.

Where management measures are intended to increase the reproductive output of the population it is very difficult to determine if this will result directly in increased recruitment. This is largely due to the long pelagic phase of the larvae during which time they could be transported large distances. During this time the larvae are not passive but will undergo movements within the water column, and this makes it very difficult to determine connectivity between populations via larval transport. There are also other factors such as predation and density dependence which can have a significant effect on the survival of juvenile crawfish when they settle out of the water column and during their subsequent growth prior to entering the fishery. These factors mean that it is very difficult to determine the link between increased reproductive output and increased recruitment from within the same population.

Time scales for recovery based on increased recruitment to the population give an estimate of a minimum of four to five years for recovery to be observed in the fishery, based on age data presented by Mercer (1973). The interpretation of this data should be approached with great care as pointed out by the author (Table 1.1), and also with regards to the growth data presented in

Section 1.1.2, which showed that *P. elephas* can show zero growth in terms of length following the moult. It may be the case that any recovery resulting from increases in the reproductive output of the population could take many more years than this to have a significant impact on CPUE. Measures to determine levels of recruitment to the population (i.e. individuals below the MLS) would allow assessment of recovery over shorter timescales.

The implementation of suitable management measures will be affected by the legislative framework and jurisdiction of relevant legislation with respect to both the area covered and the nationality of vessels affected. Should the identification of management measures for the recovery of crawfish extend beyond 6 nm then legislation which applies at the Welsh and UK level may not be sufficient to facilitate recovery of crawfish due to fishing by vessels from outside the UK which would only be bound by EU legislation. Information on the level of fishing being carried out by such vessels would help to determine the potential impact on any management measures applied beyond 6 nm.

The presence of juveniles within surveyed areas in the south of Wales indicates that some recovery of populations may already be occurring, though this cannot be evidenced quantitatively and any reasons behind it are not clear. It is important that recovery itself is taken into consideration when planning any fisheries based measures. Once population levels are seen to increase there could be renewed interest in the fishery. Both tangle netting and dive fisheries have been shown to be efficient at reducing populations of crawfish and this would suggest that the reintroduction of sustained fishing effort could quickly reduce the effects of any existing crawfish recovery.

It is important that data collection is carried out on the current status of crawfish populations. This will provide a baseline from which recovery towards GES can be determined and would also provide a mechanism by which the effectiveness of individual management measures can be assessed and kept under review.

Table 5.1 The potential **direct** effects for each management measure, if implemented effectively, to contribute to the recovery of *Palinurus elephas* in Welsh waters. The capability for increased reproductive output does not necessarily infer increased recruitment. Increased abundance refers directly to the management measure reducing removals from the fishery, rather than through increases in recruitment brought about by the resultant increased reproductive output (though these may also be possible). Potential combinations of measures refer to the potential measures set out in this report.

Management Measure	Increased Reproductive Output	Increased Abundance	Potential Combinations of Measures
Maximum landing size	Yes – protection of larger and more fecund individuals	Possibly in the long term if individuals are permitted to reach the minimum landing size without being caught by the fishery	Benefits in terms of reproductive output could be increased if combined with an appropriate MLS
Landing Prohibition	Yes – protection of reproductively active individuals	Yes – removal of fishing mortality (although mortalities through net fishing should be monitored).	Implementation alongside a zero non-commercial catch rate would provide the maximum potential gains in both reproductive output and increased abundance
Gear restrictions	No	Yes - localised	Gear restrictions along with prohibitions could reduce the potential for net related mortalities of crawfish in areas with a high catch rate Prohibitions of diver collection could safeguard any recovery facilitated by other management measures
Catch Limits	No – high grading may reduce reproductive output by preferential removal of larger and more fecund individuals which would attain a better price	Yes – although this would be limited	Could be used as a measure to protect a recovering stock where the removal of individuals had previously been prohibited
V-notching	Potentially, although there are concerns with mortality rates	Only temporary – individuals will become available to the fishery again	
Prohibiting the landing of Berried females	Yes – although could be limited as peak fishery may not overlap with berried	Only temporary – individuals will be available to the fishery when not berried	

	season		
Area Restrictions	Yes – localised	Yes - localised	
Seasonal Restrictions	Possibly if restrictions allowed reproduction in females	Only temporary – could result in increased effort following closures	
HPMCZ in Wales	No – designations not specific to crawfish	Unlikely	
MCZ - England	No – designations not specific to crawfish	Unlikely	

5.3 Conclusions

Historical fishing records and data indicate that at present Welsh populations of the crawfish *Palinurus elephas* are depleted. Current management measures in force within Welsh waters; minimum landing sizes, non-commercial catch limits and marine SACs do not appear to be facilitating the self-propagated recovery of this species as LPUE remains at a low level. Of the potential management measures set out in this report, those with the greatest capacity to facilitate recovery are those which manage fishing activity, as opposed to nature conservation measures. It may be necessary for these measures to be introduced at the EU or inter-country level in order to incorporate fishing carried out by vessels from outside the UK inside Welsh waters. Although at present fishing by non-UK vessels is not thought to be significant and the establishment of measures at the Welsh level may be appropriate in the interim.

Where management measures result in the potential for increased reproductive output of the population it is not clear if this would result in a direct increase in the population, as the recruitment mechanisms for Welsh populations are unclear. Given the current lack of information in this regard it is likely that management measures such as landing prohibitions which both reduce removals from the population and increase the reproductive output of the population are likely to be the most effective in supporting recovery of Welsh crawfish populations (see Table 5.1). The introduction of Highly Protected Marine Conservation Zones (HPMCZ) in Welsh waters and Marine Conservation Zones (MCZ) in English waters do not appear to provide an effective mechanism for facilitating crawfish recovery. This is due to their focus on the protection of habitats and also their relatively small size.

The potential rate of recovery which could be achieved from a depleted population level is not clear. Indications are that any increase in recruitment would take at least four to five years to be seen in the fished population. The MSFD aims to achieve GES by 2020, so even if appropriate management measures were implemented immediately, it is highly unlikely that GES for Welsh crawfish populations will be achieved in this time-frame. It is, however, possible that some indications of recovery towards the LPUE values recorded in the 1980s could be achieved.

Fisheries data are collected providing a time series of crawfish LPUE data since the 1980s and this can be used as a proxy indicator of stock status and a benchmark by which recovery can be assessed. A more extensive data collection programme will also be required in order to assess individual management measures within the context of GES as set out in the MSFD and to inform future reviews of management. The data required will include length frequency distributions, information on the reproductive biology of crawfish in Welsh waters and information on the geographical distribution of the current population. Not only will this additional information provide an essential background on which to base management decisions, it could also facilitate the future analytical assessment of the stocks using numerical modelling techniques.

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Appendix 1: Data archive appendix

Data outputs associated with this project are archived as Project No. 353 and Media No. 1332 on server–based storage at the Countryside Council for Wales.

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats.

- CCW Science Report No. 989 - Management measures for self-propagated future recovery of crawfish, *Palinurus elephas*, in Welsh waters.doc
- CCW Science Report No. 989 - Management measures for self-propagated future recovery of crawfish, *Palinurus elephas*, in Welsh waters.pdf

Metadata for this project is publicly accessible through Countryside Council for Wales' Library Catalogue http://www-library.ccw.gov.uk/olibcgi/w24.cgi by searching 'Dataset Titles'. The metadata is held as record no 114818.

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