# The Brown Crab (Cancer pagurus L.) Fishery: Analysis of the resource in 2004-2005 

Oliver Tully, Martin Robinson, Ronan Cosgrove, Eimear O'Keeffe, Owen Doyle, Bridget Lehane


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## Preface

The Management Framework for Shellfisheries was established in 2005 to oversee the sustainable development and management of the shellfisheries sector in Ireland. The Framework is a co-operative management model between state and industry centred around 4 Species Advisory Groups (SAGs). In June of 2005 the Crab Advisory Group requested that a report on the status of crab stocks and fisheries in Ireland be prepared prior to development of a Management Plan for the fishery. This report has been compiled for the Crab Advisory Group and its constituent Local Advisory Committees (LACs) and outlines the current status of crab stocks and fisheries in Ireland at the end of the 2004 fishing season. The document is a work in progress, which will be developed periodically as the appropriate data and assessment methods become available. It specifically points to areas where data and research programmes are required in order to do this. The report makes specific conclusions relevant to management in order to assist and encourage the Crab Advisory Group to develop a management plan for the fishery that is based on the best available scientific advice.


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## Summary

1. Brown crab (Cancer pagurus) off the northwest coast of Ireland and west of Scotland can be regarded as a single stock. The stock boundaries elsewhere are unknown but in this report 3 other fisheries between North Mayo and Shannon, Shannon and Cork and from Cork to Rosslare, respectively, are regarded separately.
2. Brown crab fisheries in Ireland developed during the 1970s and 1980s. Landings increased exponentially between 1992-2004 and amounted to over 13000 tonnes in 2004. Landings, in 2004, from the northwest stock into Ireland, Northern Ireland and Scotland were 7800, 1064 and 970 tonnes respectively.
3. Crab stocks off the southwest and southeast coasts are exploited only by Irish vessels $<12 \mathrm{~m}$ in length, although the French vivier fleet from Roscoff fishes crabs in ICES VIIg which may constitute part of the southeast stock.
4. The Irish fleet can conveniently be divided into $<12 \mathrm{~m}$ vessels, which land crab mostly on a daily basis, and an $>18 \mathrm{~m}$ vivier fleet which is more mobile, can carry crab alive onboard and undertake trips of 5-6 days. The $>18 \mathrm{~m}$ fleet fishes off the northwest coast. The $<12 \mathrm{~m}$ fleet has, as a result of modernisation, increased its geographic range in recent years and often fishes outside the 12 nm national territorial limit.
5. Approximately 60 Irish registered vessels targeted crab off the northwest coast in 2005 compared to over 130 vessels in 1997. In some areas of Donegal the decline in the number of vessels was $80 \%$. The number of vessels targeting crab elsewhere is not accurately known but in the southwest and southeast many such vessels also target lobster for periods of the year.
6. Although the number of vessels declined in the northwest the fishing effort potential expanded from approximately 41000 pots in 1997 to over 55000 pots in 2005. The increase in effective effort (pot hauls $x$ soak time) may be less than the increase in effort potential (pots owned) because of an increase in soak time from 24 to 48 hrs , in the inshore fishery, and a resultant decline in hauling frequency.
7. Landings per unit effort (LPUE) in the northwest offshore fishery declined by 50\% between 19902004. This pattern was probably similar inshore although the data are less complete and come from a variety of sources. The majority of this decline occurred between 1990-1994 during a fishery development phase. Between 1994-2000 LPUE was stable but declined by a further $15 \%$ in 2001. LPUE was stable between 2001-2004.
8. LPUE in different components of the offshore fishery, including the edge of the continental shelf, Malin Shelf and Stanton Bank showed variable patterns although the overall trend was one of decline. This decline was observed in the raw data and in statistically standardised indices of the data, which removed potential bias due to change in soak times, seasonal and spatial distribution of fishing and competition between gear.
9. A significant proportion of the catch is returned alive to the sea in both inshore and offshore fishery. This practice affects the value of the LPUE index to an unknown degree.
10. LPUE trends in the southwest and southeast fisheries are unclear because of poor data. The resilience of these fisheries may depend on the proportion of the stock that is distributed offshore and which is subject to low fishing mortality.
11. The size composition of the landings in the northwest fishery remained remarkably constant between 1997-2001, and possibly since 1985, despite the dramatic change in effort and landings during that time. The modal landing size in the inshore and offshore fisheries varied between $155-175 \mathrm{~mm}$ carapace width. Few crabs smaller than 140 mm are landed although the minimum legal size (MLS) is 130 mm . Although the reasons are unclear, the apparent lack of response in the size distribution of crab to increases in landings and effort limits how these data can be used to estimate fishing mortality and exploitation rate.
12. Mean size at maturity is 120 mm carapace width.
13. Egg per recruit (EPR) assessment for the northwest stock indicates that more than $20 \%$ of the reproductive potential of the stock may be protected even at high levels of fishing mortality because of the small size at maturity relative to the effective, and market driven, MLS of 140 mm and the mean landing size of 165 mm . The target EPR of $30 \%$ is attained at low to moderate levels of fishing mortality and depending on the effective MLS. EPR in other stocks may be lower because the effective MLS is lower.
14. The stocks and fisheries are subject to various risks including interactions with other fisheries
a. By-catch rates of crab in the lobster fishery are 20-30\% of targeted crab LPUE.
b. Crab are used extensively as bait in the south Irish Sea and Malin Hd. whelk fishery. This increases fishing mortality on crab that would normally be discarded and reduces the yield per recruit.
c. By-catch of crab by trawlers and netters may be significant although it remains unquantified.
d. There is a high, although variable, prevalence of the lethal and highly infectious bitter crab disease in all stocks that contributes to as yet unknown level of mortality of crab.
e. Economically, crab fisheries are at increased risks because LPUE has declined, fishing costs have increased and continued escalation of effort may have a further negative effect on LPUE.
15. The observed LPUE in the northwest fishery, although real, can be interpreted in a number of ways. The stock biomass may have declined in proportion to the observed decline in LPUE although trends in grading and live return of poor quality crab to the sea from vivier vessels may have contributed to the observed pattern in LPUE.
16. The decline in LPUE in the northwest fishery is unlikely to be due to recruitment overfishing given the protection afforded to EPR.
17. LPUE in the northwest fishery is highly correlated with the total number of pots hauled in the fishery each year. Further declines in biomass and LPUE are expected if effort increases. LPUE should be stable if effort is stabilised. LPUE should increase quickly following any reduction in effort if the cause of the decline in LPUE is not due to recruitment overfishing. If the latter is the case recovery will be slower.

## Introduction

Just over 13000 tonnes of brown crab (Cancer pagurus) were landed into Ireland in 2004. This catch had an approximate value of €23 million. Economically, brown crab is the third most important species of fish landed into Ireland. Landings increased by approximately 500 tonnes per year between 1990-2004 although the increase was higher in the period 1997-2004 and particularly from 2001 in some areas. A significant number of vessels depend on crab fishing, particularly in the northwest where 60 vessels target this species. On all coasts, hundreds of vessels rely to some degree on brown crab in the mixed lobster and crab fisheries.

This report is the first attempt to draw together all relevant information on crab stocks and fisheries that is available in Ireland. The ultimate objective is to provide robust fisheries management advice that will assist in the sustainable development of the fishery. In this context the report is produced for the national Crab Management Advisory Group, which is a constituent committee of a co-management advisory framework that provides recommendations to the licensing authority (The Department of Communications, Marine and Natural Resources) on matters relevant to the management of shellfisheries. Crab fisheries are not subject to any particular management regime. The fishery is in open access and there is no limit on catch although days at sea regulations came into force in 2005. Effort and catch are both increasing.

No national monitoring programme for crab or crab fisheries was in place in Ireland prior to 2005. Typically the data that was collected, and presented in this report
was project based. This results in data for a particular limited duration of time and for certain geographic areas and is usually collected as part of a university postgraduate project or to service short term national or EU funded projects. This project based work extends back to the 1970s and 1980s during the development of the fishery in Ireland (Edwards, 1971, Fox and Bates 1986, Cosgrove 1998, Tully et al. 2002).

The main body of data presented in this report is landings and effort for the offshore vivier fleet in Donegal. Equivalent data for the inshore fishery and for other stocks on the west and south coasts are generally not available to the same extent or have been collected, as mentioned above, opportunistically on particular projects, surveys etc. Data are reported for different geographic regions, reflecting the probable distribution of the main stocks off the Irish coast. Trends in landings per unit effort (LPUE) are provided for the period 19902004 for the northwest stock. Biological information on maturity and fecundity is used in an egg production per recruit analysis and in relation to target and limit reference points for spawning potential. In addition to the biological analysis the fishery is profiled and changes in participation, effort and the geographic distribution of effort are described. Although it has not been possible to provide an analytical assessment, in the traditional sense, and there are no estimates of stock size, exploitation rate or sustainable yield the report does provide information, analysis and conclusions sufficient to progress the management of crab stocks in Ireland.

## The Biology of Crabs

## 1. Commercial distribution

Brown crab (Cancer pagurus) is exploited commercially throughout Britain and Ireland, north to the mid west coast of Norway, Sweden and south to northern France. Landings are increasing in Ireland, Britain and Norway and are stable in France. There have been no instances to date of stock collapse or depletion below commercially viable levels in any region. The fishery is traditional in Britain where commercial landings were made off the Norfolk coast in the early part of the 18th century (Edwards 1966). The fishery was well developed off the Yorkshire coast by the early 1960s although restricted to coastal waters out to two miles (Edwards 1967). The fishery in Norway has, until recently, been mainly a recreational fishery but is now commercially very significant (Anon 2005). In England and Wales and Ireland brown crab is now one of the most important commercial fish species.

## 2. Biology

The brown crab is a long-lived large decapod crustacean. Crabs live for at least 15 years and recruit to the fishery probably between the ages of 4-6 years. Moulting may occur each year in smaller crabs but less often as size increases (Edwards 1971). Tag return data indicates that the intermoult period may be as long as 4 years. The percentage increase in size at moult in juvenile crab is approximately 18-25\% (Edwards 1971). Mating takes place when the female crab is soft (after moulting) and the male guards the female for a period of time prior to the female moult. Eggs are spawned onto the pleopods where they are carried over winter. The hatching season is protracted and larvae may be found during spring, summer and autumn depending on latitude and water temperatures. Fecundity is very high and each female crab may hatch between 1-4 million eggs. Post larvae are known to settle inshore (Robinson 1999) and juvenile crabs are more common in shallow than in deep water. Adult crabs undertake extensive migrations, which may be associated with the reproductive cycle.

## 3. Biology and Management

The fecundity of crab is extremely high compared to lobster, for example. Crab, therefore, have a different reproductive strategy and larval and juvenile biology, which may rely on sheer numbers to offset high mortalities during early life history. As such, crab recruitment may be more constrained by environmental conditions during the larval and juvenile phase than by the spawning stock biomass and the stock recruitment relationship may be quite variable and difficult to detect. High larval densities and settlement suggests that crab populations are regulated by density dependent events after settlement to the seabed.

Crabs are migratory and hatching of larvae occurs over wide areas in shallow and deepwater as evidenced by the widespread distribution of first stage larvae. Crabs, therefore, have open population structures compared to lobster. Stocks in Ireland are probably regional (>100 kms) in scale and extend to varying extent from the coast to offshore waters.

## Crab fishing in Ireland: The historical context

Targeted fisheries for brown crab in Ireland developed during the 1960s (Fig. 1). Various surveys were commissioned by BIM between 1965 and 1992 to identify the distribution of commercial quantities of crab around the Irish coast (Fox and Bates 1986). These included evaluations of the Malin Hd. fishery, surveys of Donegal Bay (Anon 1979) and work on meat content and condition off the southeast and southwest coasts. The fishery developed off Malin Hd. in Donegal and along the Donegal coast and, to a lesser extent, on the south coast during the 1970s. The Malin Hd. fishery accounted for $25 \%$ of national landings during the 1980s. The offshore fishery developed in 1990 and by the mid 1990s had fully explored the distribution of brown crab on the Malin Shelf. This stock, which extends from Donegal to the edge of the continental shelf, is the largest stock fished by Irish vessels. However, about $40 \%$ of Irish landings originate from stocks off the west, southwest and southeast coasts.

The first processing plants were developed in Donegal in 1968-1969 although landings at that time were small compared to today. A large proportion of the catch is currently exported live to France although processing technology in Ireland has advanced significantly in recent years.
The present day fishery has no parallel in the past in terms of production, investment and economic significance. Landings are well outside the historic range as is the level of fishing effort. The fishery is now one of the main fisheries off the northwest coast supporting a modern fleet or vessels and processing plants ashore. It is, increasingly, an intensive and highly capitalised industry.


Figure 1. National landings of brown crab between 1952 and 2004.

## Management Measures

The crab fishery in Ireland, at the time of writing, is regulated by the following measures:

1. Each vessel must hold a polyvalent or pot fishing licence. Such vessels, if they are over 10 m in length, must declare landings in a EU logbook.
2. The MLS is 130 mm carapace width between $48-56^{\circ} \mathrm{N}$ and 140 mm north of $56^{\circ} \mathrm{N}$
3. Fishing effort by Irish vessels, over 15 m in length in ICES area VI and VII, is limited to 465000 and 40960 kilowatt days per annum respectively (Council Regulation (EC) $1415 / 2004$ ). Activity by vessels over 10 m is length is limited to 63198 kw days in the Biological Sensitive Area (1954/2003) of Area VII.
4. Landing of crab claws greater than $1 \%$ of the total weight of the catch on board is illegal
5. Crabs cannot be captured in either the commercial or recreational fishery by SCUBA.

Crabs can be captured recreationally without licence. No effort cap or bag limit applies to this catch but it cannot be sold commercially.

## Research and Monitoring Activity

Very little work on brown crab was undertaken in Ireland prior to 1995. Since then, however, considerable momentum has been gained in acquiring information relevant to the sustainable management of this fishery. The monitoring and research programs that have been completed or that are ongoing are summarised below. A number of issues or themes are dealt with in these projects including catch and effort data, measurement of recruitment, size at maturity, tagging to identify stock structure, quality assessment and live shipment. The catch and effort dataset from offshore vivier vessels is of high quality and extends back to 1990. Methods to monitor recruitment are important and various types of data are currently being generated including larval distribution, coastal seabed maps, and distribution of pre-recruit crab in order to develop methods to measure recruitment of crab prior to entry into the fishery. Quality of crab going to the market continues to be a significant issue. One project has built a seasonal profile of stock quality, using blood protein as an indicator, to identify times of year when high proportions of crab have poor meat yield in addition to research on the effects of various types of live shipment on survival of crab. Important data on movement of crab and the stock structure have been obtained from tagging studies, the largest of which was undertaken in 2001 off Malin Hd.. The following is a, non-exhaustive, list of projects that have been undertaken.

1. Marine Institute funded project in 1996-1998 to compile catch rates in the offshore and inshore fishery (TCD, BIM)
2. EU funded project (1999-2002) on evaluation of assessment data for key European edible crab stocks (TCD, BIM, CEFAS)
3. NDP funded project (2002-2006) on development of recruitment indices for brown crab (TCD, BIM, Seabed Surveys International)
4. NDP funded project (2002-2004) on optimising post harvest survival of edible crab during transport (TCD, BIM, University Hull, OceanWest Ltd.)
5. Tagging and assessment of stocks (2001-2002) at Malin Hd. (TCD, BIM)
6. Survey and tagging of crab off west Galway (2002) (BIM)
7. Expansion of offshore fishing grounds for brown crab (2002) (TCD,BIM)
8. NDP funded project (2002-2005) on the regional variation in size at maturity and the implication for technical conservation measures (TCD, GMIT, BIM).
9. BIM inshore Fishing Activity Record (FAR) scheme to record catch and effort in lobster and crab fisheries

Despite the amount of work that has been completed assessment of crab remains a difficult problem as it does for European crab stocks generally. Having considered and interpreted the available data the authors of this report identify priority areas for fisheries monitoring and research that will contribute towards sustainable exploitation and management of the fishery.

## Data Sources

## 1. Landings

The Department of Communications, Marine and Natural Resources (DCMNR) compiled landings data from EU logbooks and from purchase records of companies and co-operatives trading in crab. Landings data for Northern Ireland and Scotland were obtained from The Department of Agriculture and Rural Development (DARD) and the Fisheries Research Services (FRS) Aberdeen respectively.

## 2. Stock structure

## Larval distribution

Larval surveys were undertaken during July 2001 on the Malin Shelf. These data indicate the area over which larvae of brown crab are distributed. In particular, the distribution of stage I larvae can be used as an indicator of the distribution of recent spawning.

## Tag returns

Over 8000 crabs were tagged and released in September 2001 north of Malin Hd.. Although the tag used is lost at moult, hundreds of recaptures were reported which showed the rates and directions of migrations of crab on the Malin Shelf. Approximately 4000 crabs were released in 5 locations off the southwest coast in 2004. Recaptures from this release have not been compiled for this report.

## Fishing activity

The distribution of fishing activity of the Irish, Northern Irish and Scottish fleets on the Malin Shelf indicates the distribution of commercial quantities of crabs in the area.

The above 3 sources of information were used to determine the geographic area over which crab are distributed and to infer their population structure.

## 3. Landings per unit effort (LPUE)

The main body of data on LPUE originated from the private diaries of 3-4 vivier vessels fishing in the northwest offshore fishery.

The quality of the catch and effort data is known to be very high. The data were recorded in private diaries by the skippers and were voluntarily given to BIM.

The catch rate data has a number of characteristics that make it particularly reliable as a monitoring tool. The fine
spatial resolution of the data, in particular, allows the distribution of fishing and LPUE to be mapped and the behaviour of the fleet to be monitored. Changes in LPUE can, therefore, be associated with shifts in the geographic location of fishing. Efforts by the fleet to maintain LPUE by expanding the area fished or shifting to previously unfished areas can be monitored.

LPUE data were compiled for the inshore sector in Donegal for the period 1990-1997 by Cosgrove (1998) by correlating the daily consignments delivered by each vessel owner to crab buyers in the northwest with the numbers of pots used by the vessel. This is likely to be more error prone than vessel diary information. Meredith and Fahy (2005) undertook a similar process and updated the index to 2005.

In 2002 BIM promoted a voluntary Fishing Activity Record (FAR) scheme for crab and lobster fishermen in the inshore sector. Returns were generally poor although useful data has resulted in some areas on daily catch and effort or more specific data on catch and effort for each string of pots and the associated geographic position of fishing.

Surveys for crab were commissioned by BIM at various stages and in various areas between 1992-2004. Although these are not strictly comparable with commercial catch rate data they are an index of the distribution of commercial quantities of crab. These include surveys off Malin Hd. in 1985, Donegal Bay in 1979 and 2002, offshore along the west and south coasts 1992, west of Galway in 2002, west of Baera and Dingle peninsulas in 1999 and 2004 and offshore to the south of Wexford in 2002 and 2004.

## 4. Size distribution data

The size distribution of the catch was collected during 1996-1997 (Cosgrove 1998) in the northwest fishery. Additional data were collected on board offshore vessels periodically in 2000-2001. In the southeast annual sampling of size composition was undertaken between 2001-2004. The sources of the data and sample sizes vary widely in this programme. As discussed above no national programme for the collection of these data existed and the strategic sampling strategies necessary for such data collection were generally not in place. The available size composition data are presented to indicate if changes in average size or in the distribution of size have accompanied the increase in fishing effort that occurred.

## The Northwest Fishery

## 1. Landings

## Landings into Ireland

Landings into Mayo and Donegal fluctuated between 3000-4000 tonnes between 1990-2000. This increased significantly to approximately 6500 tonnes in 2001 and reached a historic high of 7800 tonnes in 2004 (Fig. 2).


Figure 2. Annual landings of crab into Donegal and Mayo between 1990-2004

## Landings into Ireland by ICES rectangle

The geographic origin (statistical rectangle) of the Irish landings in 2004 was derived from the vessel diary information submitted by 4 of 5 of the vivier vessels active in 2005 and raising the landings by 700 tonnes for the 5th vessel for which there were no data and applying the same spatial fishing pattern to that vessel. Inshore landings by port compiled by the DCMNR were allocated to the known distribution of fishing derived through interviews with the skippers of all inshore vessels in 2005 (see below).

Over 1800 tonnes were taken by inshore vessels north of Malin Hd. in statistical rectangle 39E2. Over 1500 tonnes were taken by the Mayo $<12 \mathrm{~m}$ fleet west of Donegal Bay in area 38E0 and a further 500 tonnes were taken west of this in 38D9. Over 400 tonnes were taken off northwest Donegal in 39E1 (Fig. 3). Landings by statistical rectangle by all vessels are shown in Figure 4.


Figure 3. Landings of crab by statistical rectangle by the Mayo and Donegal < 12m fleets in 2004

## Overlap between Irish, Northern Irish and Scottish fleets

The northwest crab stock is fished by fleets from Northern Ireland, Scotland and the Republic of Ireland (Fig. 4). Northern Irish vessels have access inside the national 12 nm territorial limit of the Republic of Ireland. This access entitlement, under a voisinage agreement between the Republic of Ireland and Northern Ireland, is reciprocal, giving access to the $0-12 \mathrm{~nm}$ territory of Northern Ireland to vessels registered in the Republic. Republic of Ireland vessels do not have access to Scottish territorial waters inside of 12 nm . Scottish vessels are also excluded from Republic of Ireland territorial waters inside 12 nm . Vessels from each of the 3 jurisdictions may and do land their catch in ports in any of the 3 jurisdictions. Vessels 10 m in length and over must record catch in the official EU logbook. This is included in the statistics of the jurisdiction in which the vessel is registered. However, these same landings may also be recorded in the country where the landing is made depending on the method by which the landings statistics are collected. It is not possible to exclude possible duplicate entries of landings, and, therefore, to obtain the total landings from the stock without access to landings by each vessel in the 3 jurisdictions. Errors of this type are likely to occur mainly due to vessels registered in Northern Ireland landing into ports of the Republic of Ireland. Landings by vessels under 10 m in length are recorded through buyers records and compiled by DCMNR.

Republic of Ireland landings originate mainly from north of Malin Hd. (1837 tonnes) and north to Stanton Bank ( 872 tonnes) and west from Malin Hd. to the Shelf edge and south to the west of Donegal Bay (1926 tonnes). Allocation of landings to some of the ICES rectangles fished by the inshore fleet may be prone to error as the landings are not referenced in many cases to a particular rectangle. The origin of these landings was deduced through interviews with the skippers regarding the location in which they generally fished. Landings into Ireland from the northwest stock were approximately 8000 tonnes in 2004.

Northern Ireland landings originate from north and east of the Inishowen peninsula towards the Scottish coast and south to the North Channel and the northern Irish Sea. Landings into Northern Ireland from the stock, including the North Channel, were 1064 tonnes in 2004.

The Scottish fleet fishes all along the west coast of Scotland but more intensively offshore along the north coast of Scotland west of Orkney. Scottish activity south of $56.5^{\circ} \mathrm{N}$, possibly the northern limit of the Malin Shelf stock, was mainly along the Scottish coast west of Islay and the Clyde in 2004. Landings into Scotland, originating south of $56.5^{\circ} \mathrm{N}$, were approximately 970 tonnes in 2004. An increase in Scottish fishing activity south of $56.5^{\circ} \mathrm{N}$ may have occurred during 2005 as an offshore vessel, previously fishing north of Scotland, began fishing west of Islay. One vivier vessel 24 m in length, fishing for the entire year in this area, would account for an additional 700 tonnes.
The landings of crab from the Malin Shelf stock by the Irish, Northern Irish and Scottish fleets were, therefore, 8000 ( $80 \%$ ), 1064 ( $11 \%$ ) and 970 ( $9 \%$ ) tonnes respectively in 2004. Geographic overlap in the distribution of fishing of the 3 fleets occurred mainly off the north coast of Donegal north to Stanton. A maximum of 2 of the 3 fleets fished in any particular ICES rectangle in 2004.


Figure 4. Landings of brown crab into Ireland, Scotland and Northern Ireland by ICES statistical rectangle in 2004. Data sources: Dept. Agriculture and Rural Development (DARD) Northern Ireland, Fisheries Research Services (FRS) Scotland, Dept Communications Marine and Natural Resources (DCMNR) Dublin (landings by port) and private diary data from the Irish vivier vessels. ICES sub-divisions are shown in red.

## 2. Stock structure

Crabs on the northwest coast, from north Mayo to the Inishowen peninsula and west and northwest to the edge of the continental shelf, are part of a single stock. Its northern limits are not well known but the stock is contiguous with crab fisheries off the west coast of Scotland and Hebrides. Crabs distributed between $54.50^{\circ} \mathrm{N}$ and $57.0^{\circ} \mathrm{N}$ and from $6.0^{\circ} \mathrm{W}$ to $11.5^{\circ} \mathrm{W}$ can be regarded as a single biological or functional unit. Evidence for this comes from 3 sources:

1. Larval distribution
2. Migration of adult crab
3. Spatial distribution of fishing

## Larval distribution

Crab larvae hatch mainly during the early summer and can be found in the water column throughout the summer months. There are 5 larval stages followed by the decapodid, which is the stage that settles to the seabed. The distribution of the first larval stage may be taken as a proxy for the distribution of spawning although this will depend on dispersal dynamics in the area. The first larval stage occurs throughout the Malin Shelf from the coast to the edge of the continental shelf although abundance in July 2001 was higher closer to shore and particularly north of Inishowen. This suggests that crabs spawn throughout the area (Fig. 5).


Figure 5. Distribution of the first larval stage of brown crab over the Malin Shelf in July 2001.

## Migration of adult crab

Crabs migrate from the Irish coast in a westerly, northwesterly and southerly direction in Autumn. There is also, however, a counter migration and easterly and north easterly migrations have been recorded. Crabs released at the edge of the continental shelf have been recaptured on the shelf and close to the Irish coast (easterly migration) and crabs that have migrated south to Area VIlb undertake return migrations north into Area VI (Fig. 6).


Figure 6. Distribution of tag returns, over a 3 year period, from a release of 8000 crabs north of Malin Hd. in September 2001.

## Distribution of fishing

Fishing occurs throughout the Malin Shelf to the 200m depth contour and east to the Irish and Scottish coasts. The distribution of fishing is shown above for Irish, Northern Irish and Scottish fleets. Landings are taken throughout the area between $54-58^{\circ} \mathrm{N}$ and from 11-6 W (Fig. 4).

## Distribution of the stock

Combining information on larval distribution, tag returns and the distribution of fishing indicates that crab off the northwest coast are distributed over an area of approximately $45000 \mathrm{~km}^{2}$ between $54.50^{\circ} \mathrm{N}$ and $57.0^{\circ} \mathrm{N}$ and from $6.0^{\circ} \mathrm{W}$ to $11.5^{\circ} \mathrm{W}$ (Fig. 7).


Figure 7. Probable distribution of the northwest crab stock derived from information on the migration of adult crabs, the distribution of early larval stages (and probable spawning) and the distribution of commercial fishing.

## 3. Analysis of landings per unit effort (LPUE) data

## General Linear Modelling (GLM)

The use of LPUE data to monitor fisheries assumes that changes in the data are proportional to changes in the actual abundance of the stock. This might not be the case for a multitude of reasons some of which can be removed or controlled for by statistical methods. Bias in the LPUE data could be inherent in a time series of such data for the following, non-exhaustive, list of reasons.

1. Vessel performance: The performance of a vessel can vary over time due to crew or skipper effects.
2. Grading practice: Generally a high percentage (10$50 \%$ ) of legal sized crab are returned alive to the sea because they have recently moulted and are in poor condition. As this grading is subjective the ability of the crew to grade successfully, and the market demand, will affect live return rates and, therefore, the amount of crab landed for each trap hauled.
3. Soak time: Changes in the frequency of hauling traps will affect the LPUE index as LPUE is related to the frequency at which gear is hauled at least for frequencies between 2 and 4 days.
4. Fishing area: Vessels may change the location of fishing due to local depletion of crab, due to fishing, or to follow the migration of crab.
5. Fishing season: If LPUE varies seasonally and the proportion of effort in each season changes over time then the time series of annual estimates will be biased
6. Environmental effects: The catchability of crab may change due to tidal and weather conditions. Changes in fishing strategy to concentrate on conditions that give better catches will bias the catch rate upwards.
7. Gear competition: Pots placed close together compete to attract crab. The area of influence or the distance over which this could operate depends on the trap soak time or at least the duration of time over which bait is effective and the rate at which crab move past the gear. If the amount of gear increases over time the LPUE time series could be biased downwards.

Differences between years and vessels in the spatial and temporal coverage of fishing and the likely effects of soak time and other factors, mentioned above, on LPUE infers that it would be hazardous to interpret the data in terms of stock trends without first accounting for known sources of potential bias in the data. Generalized linear modelling (GLM) was, therefore, used to derive standardized LPUE indices, which isolated the components of variation due to long-term, seasonal or spatial trends or due to soak time or gear competition effects. This analysis did not standardise for any changes in the level of grading of the catch that might have occurred during the period and which would affect the catch rate index used here.

Trap soak times are likely to be very important in determining LPUE, but there is unlikely to be a linear relationship between LPUE and soak time at the scale of days, i.e. trap-days is probably not a good measure of fishing effort. Recorded soak times in the northwest fishery varied up to 85 days, but almost half of all records were for soak times of 2 days or less, and $98 \%$ of records were for 10 days or less. Average soak times varied two-fold between years. For the purposes of analysis, data were restricted to records of soak times of 10 days or less. Over this time-scale it is reasonable to suppose that LPUE has an asymptotic relationship with soak time, whereas LPUE potentially could decline over longer soak times owing to escapement and cannibalism. The relationship was modelled as:

1 n (LPUE) $=\alpha-\beta \frac{1}{\text { soak time }}$,
where $\alpha$ is the value of $\operatorname{In}($ LPUE $)$ after infinite soak time (effectively an asymptote) and $\beta$ is related to the rate
of trap entry. This approximates to a truly asymptotic relationship, but can be used within a GLM framework without the need for non-linear regression techniques.
In the analysis catch locations were simplified to ICES statistical rectangles and dates were simplified to months. LPUE data were transformed by $\ln (x+0.1)$, and GLM models were fitted to the data assuming a Normal distribution of errors, using the R statistical package. Year, month, ICES rectangle and vessel were included as factors (categorical effects) in the models, and $1 /$ soak time was included as a continuous variable. The final model used the entire data set, using year, month, vessel, rectangle and soak time effects, with month * rectangle interaction to account for seasonal changes in the distribution of crabs (i.e. possible migration over the ground) and month * soak time interaction to account for seasonal variation in the rate at which crabs enter traps. Based on this analysis a separate model including year, soak time and gear competition was fitted to all the data.

Further analyses were undertaken on sub-sets of the data from the northwest offshore fishery in order to avoid the need to include time * area interactions in the analysis and to provide standardised indices for specific areas and times of year. The fleet tends to target specific areas at different times of year. This pattern may be related to the migratory behaviour of crab, which are more abundant on specific grounds on a seasonal basis.

## 4. Sources of variation in landings per unit effort (LPUE)

## Analysis of variance in LPUE

Analysis of variance of the offshore crab LPUE data showed that soak time, year and month were more important factors contributing to variability in LPUE compared to geographic location or the vessel from which the data originated (Table 1). However, all of these factors combined account for only $28 \%$ of the variance in the data.

Table 1. Analysis of variance of catch rate data in the offshore fishery showing the important effects of soak time, year and time of year

| Factor | df | SS | MS | F |
| :--- | :---: | :---: | :---: | :---: |
| Year | 14 | 324 | 23 | 132 |
| Month | 11 | 234 | 21 | 121 |
| Vessel | 4 | 16 | 4 | 23 |
| ICES area | 15 | 105 | 3 | 20 |
| Inverse soak time | 1 | 51 | 105 | 602 |
| Month*ICES | 129 | 170 | 2 | 7 |
| Residuals | 19,275 | 3,379 |  |  |

## Soak time

Results of GLM demonstrated the clearly non-linear relationship of LPUE with soak time (Fig. 8). For the example given, LPUE after 2 days was only $44 \%$ higher than that after 1 day, and after 10 days was still only $92 \%$ higher. The slope of the soak time effect ( $\beta$ in Eq. 1) varied almost three-fold between months (Fig. 9). This would be expected if the rate of trap entry were related to temperature, moulting and other seasonal patterns. The slope might also be expected to vary in relation to stock abundance - higher rates of trap entry at greater crab density - which offers the possibility that $\beta$ is potentially useful as an index of stock abundance. The trend of $\beta$ over years (Fig. 10) does not resemble that of LPUE, although if 1990 and 1992 are excluded from Fig. 10 there is the same suggestion of an overall decline.


Figure 8. GLM estimates of the effects of soak time on LPUE, scaled to 1 vessel, January, 2003 in ICES rectangle 39E0. Dotted lines are $95 \%$ confidence limits


Figure 9. Slope of soak time effect ( $\beta$ in Eq. 1) in each month estimated by GLM. Dotted lines are 95\% confidence limits


Figure 10. Slope of soak time effect ( $\beta$ in Eq. 1) in each year estimated by GLM

## LPUE by vessel

Variability in LPUE due to vessel effects was low compared to month, year and soak time effects (Table 1). LPUE for different vessels standardised to January 2003 and a two day soak time in statistical rectangle 39E0 varied by about 10\% (Fig. 11)


Figure 11. Monthly LPUE standardised to January 2003 and a 2 day soak in ICES rectangle 39E0.

## Monthly LPUE offshore

Seasonal variability in LPUE was highly pronounced up to 1994. Peak LPUE generally occurred in the autumn and winter during this period. This pattern changed in 19952000. For instance in 1997 peak LPUE occurred in June and declined during the year until February of 1998. The original pattern was somewhat restored in 2001 when peak LPUE occurred at the end of the year. During the period 2001-2004 seasonal variability in LPUE was low and the average LPUE was approximately 1.5 kgs per pot (Fig. 12).

The maximum daily landings taken in each month between May 1990 and Dec 2004 showed strong peaks up to 1999. Between 2000-2004 peaks in maximum daily landings were largely non-existent although a peak occurred in December 2004 (Fig. 13).


Figure 12. Average non-standardised monthly LPUE (kgs per pot) in the offshore fishery between 1990-2004.


Figure 13. Maximum daily non-standardised LPUE (kgs per pot) in the offshore fishery in each month between 1990-2004.

## Month and ICES area

Examples of the month, area and month*area effect on the LPUE are shown in Fig. 14. LPUE tended to be higher in autumn but not in all areas and generally the level of variability in LPUE between months was quite low relative to the long term trend or the effect of soak time.


Rectangle 40E0


Rectangle 39E1


## Rectangle 40E1



Figure 14. Monthly LPUE, scaled to a 2-day soak time, Vessel 1, and 2003 for selected ICES rectangles. GLM estimates ( $\pm 95 \%$ C.I.) are shown together with unadjusted data averages, scaled to the same mean and standard deviation.

Overall month effects standardised to statistical rectangle E039, 2003, 2 day soak time for Vessel 1 and excluding any statistical interaction term for month and area indicated that higher LPUE generally occurred in October-December (Fig. 15).


Figure 15. Monthly LPUE ( $\pm 95 \%$ C.I.) standardised to 2003, statistical rectangle E039, a 2 day soak time and to vessel 1.

## 5. Annual trends in offshore LPUE

## All areas

LPUE varied between 2.6-2.8kgs per pot in 1990-1992. A decline occurred in 1993 and 1994 to 1.8 kgs per pot. LPUE was stable between $1.6-1.8 \mathrm{kgs}$ per pot between 1994-2000, declined in 2001 and was stable between 1.4-1.5kgs per pot between 2001-2004 (Fig. 16, Table 2). The trends in the raw data and GLM standardised index were similar (Fig. 17).


Figure 16. Annual average ( $\pm 95 \%$ C.I.) LPUE in the offshore crab fishery.

Table 2. Annual LPUE in the offshore crab fishery. The number of fishing days ( N ) and pot hauls on which the data are based is shown.

| Year | $\mathbf{N}$ | Mean | S.d. | Max | Pot hauls |
| :--- | :---: | :---: | :---: | :---: | :---: |
| 1990 | 55 | 2.79 | 1.43 | 7.11 | 28000 |
| 1991 | 348 | 2.82 | 1.26 | 6.80 | 155700 |
| 1992 | 637 | 2.66 | 1.38 | 13.45 | 214700 |
| 1993 | 1,181 | 2.29 | 1.05 | 9.94 | 471614 |
| 1994 | 1,338 | 1.81 | 0.92 | 9.92 | 664520 |
| 1995 | 1,432 | 1.93 | 0.94 | 7.48 | 666288 |
| 1996 | 5,013 | 1.83 | 0.98 | 14.20 | 586668 |
| 1997 | 1,214 | 1.85 | 0.75 | 9.20 | 665240 |
| 1998 | 1,416 | 1.64 | 0.79 | 19.20 | 812150 |
| 1999 | 1,121 | 1.84 | 0.84 | 19.20 | 629175 |
| 2000 | 1,275 | 1.88 | 0.84 | 5.86 | 703470 |
| 2001 | 1,213 | 1.41 | 0.57 | 3.87 | 928375 |
| 2002 | 1,432 | 1.58 | 0.54 | 4.00 | 1213350 |
| 2003 | 1,100 | 1.43 | 0.51 | 4.60 | 837925 |
| 2004 | 1,533 | 1.42 | 0.54 | 6.33 | 1305100 |



Figure 17. GLM of offshore LPUE data standardised to September, a 2 day soak and to 1 vessel and scaled to the long term mean. The dotted lines are $95 \%$ confidence limits for the model. Scaled data points are also shown.

## LPUE by geographic area in the offshore

 fisheryThe offshore fleet is a highly mobile fleet that can follow the migration of crabs on the Malin Shelf. The landings data reported by these vessels to some degree reflects the success with which the vessels can track seasonal crab movements. Although fishing occurs throughout the region particular areas are fished seasonally. For instance the Stanton Bank area north of Inishowen is targeted in autumn and winter while the shelf edge between $9.5-10^{\circ} \mathrm{W}$ along the 200 m contour is targeted in late spring and summer. In latter years the pattern varied as competition for fishing grounds intensified resulting, to some degree, in fishing in most areas throughout the year.

Because of the seasonal fishing pattern six area by season combinations were identified for further analysis. These were the Stanton Bank (ICES statistical rectangles 40E2, 41E2) autumn (Sept-Dec) and spring (Jan-Apr) fisheries, the spring and summer (May-Aug) shelf edge (39E0, 40E0) fisheries and the spring and summer Malin Shelf (39E1, 40E1) fisheries. The annual observed and standardised LPUE index is reported below for these fisheries.

Autumn (September-December) fishery in
Stanton Bank area (40E2, 41E2)
The annual LPUE in the autumn fishery in the Stanton Bank area fell from 3.4 kgs per pot in 1991-1992 to 1.8 kgs per pot in 1994. LPUE fluctuated between 2.5 and 1.6 kgs per pot during the period 1993-2002 and was the lowest on record at 1.4 and 1.35 kgs per pot in 2003 and 2004 respectively (Fig. 18, Table 3).

The GLM standardised LPUE index for the Stanton Bank autumn fishery shows a similar trend to the raw data (Fig. 19). The rate of decline in LPUE over the period 19962004 was slightly higher in the standardised index.


Figure 18. Annual average ( $\pm 95 \%$ C.I.) LPUE in the Stanton Bank autumn fishery.


Figure 19. GLM standardised and observed LPUE in the Stanton Bank autumn fishery standardised to September, a 2 days soak and to 1 vessel. The dotted lines are $95 \%$ confidence limits for the model. Scaled data points are shown.

Table 3. Annual LPUE for the Stanton Bank autumn fishery. The number of fishing days ( N ) and pot hauls on which the data are based is shown.

| Year | $\mathbf{N}$ | Mean | s.d. | Pots hauled |
| :---: | :---: | :---: | :---: | :---: |
| 1991 | 102 | 3.43 | 1.41 | 36200 |
| 1992 | 166 | 3.53 | 1.77 | 50100 |
| 1993 | 330 | 2.84 | 1.15 | 127464 |
| 1994 | 345 | 1.85 | 0.78 | 168395 |
| 1995 | 339 | 2.24 | 1.03 | 155225 |
| 1996 | 1,449 | 2.52 | 1.03 | 167611 |
| 1997 | 272 | 1.85 | 0.69 | 178256 |
| 1998 | 186 | 1.85 | 0.53 | 112150 |
| 1999 | 128 | 1.71 | 0.40 | 82375 |
| 2000 | 319 | 2.41 | 0.97 | 163585 |
| 2001 | 248 | 1.59 | 0.61 | 179600 |
| 2002 | 329 | 1.62 | 0.55 | 282100 |
| 2003 | 164 | 1.40 | 0.43 | 101875 |
| 2004 | 206 | 1.35 | 0.38 | 207000 |

In season LPUE in the Stanton Bank autumn fishery
In the Stanton Bank autumn fishery, during 20012004, LPUE was highest in October and declined by approximately 0.2 kgs per pot haul during the season to the end of December (Fig. 20).


Figure 20. Monthly changes in the average crab LPUE ( $\pm 95 \%$ C.I.) in the Stanton Bank autumn fishery during 2001-2004.

Spring (January-April) fishery in the Stanton Bank area (40E2, 41E2)
The annual LPUE index fell from 3.2 in 1991 to 1.27 kgs per pot in 1996 and fluctuated between $1.6-1.8 \mathrm{kgs}$ per pot during 1997-2001. There was a linear decline in the index between 2001-2004 from 1.77 to 1.33 kgs per pot (Fig. 21, Table 4).

The GLM standardised LPUE index for the Stanton Bank spring fishery showed a similar trend to the raw data (Fig. 22). The index declined annually during the period 1999-2004.


Figure 21. Annual average ( $\pm 95 \%$ C.I.) LPUE in the Stanton Bank spring fishery.

Table 4. Annual LPUE for the Stanton Bank spring fishery. The number of fishing days ( N ) and pot hauls on which the data are based is shown.

| Year | N | Mean | s.d. | Pots <br> hauled |
| :---: | :---: | :---: | :---: | :---: |
| 1991 | 45 | 3.09 | 1.02 | 23200 |
| 1992 | 127 | 2.48 | 0.97 | 46800 |
| 1993 | 248 | 1.98 | 0.91 | 97775 |
| 1994 | 271 | 2.38 | 1.22 | 115100 |
| 1995 | 359 | 1.89 | 0.93 | 165600 |
| 1996 | 819 | 1.27 | 0.93 | 96250 |
| 1997 | 304 | 1.80 | 0.68 | 135881 |
| 1998 | 428 | 1.58 | 0.67 | 247750 |
| 1999 | 365 | 1.94 | 0.75 | 201250 |
| 2000 | 159 | 1.58 | 0.73 | 84905 |
| 2001 | 66 | 1.77 | 0.74 | 38850 |
| 2002 | 97 | 1.52 | 0.43 | 76550 |
| 2003 | 51 | 1.42 | 0.43 | 39000 |
| 2004 | 128 | 1.33 | 0.36 | 105800 |



Figure 22. GLM standardised and observed LPUE in the Stanton Bank spring fishery standardised to September a 2 days soak and to 1 vessel. The dotted lines are $95 \%$ confidence limits for the model. Scaled data points are shown.

## In season LPUE in the Stanton Bank spring

fishery
Monthly LPUE in the Stanton Bank spring fishery was higher in January and February compared to March and April in the period 2001-2004 (Fig. 23).


Figure 23. Monthly changes in the average ( $\pm 95 \%$ C.I.) LPUE in the Stanton Bank spring fishery during 2001-2004

Spring (January-April) shelf edge fishery (E040, E039)
The annual LPUE in the shelf edge spring fishery declined from 2.0 to 1.6 kgs per pot between 1993 and 1996. Very little fishing occurred in this area prior to 1993. LPUE fluctuated between 1.5 and 1.9 kgs per pot during the period 1996-2002, declined to a historic low of 1.25 in 2003 and recovered to 1.6 kgs per pot in 2004 (Fig. 24, Table 6).

The GLM standardised and observed LPUE in the shelf edge spring fishery showed similar trends. The standardised index declined from 1997-2001. Both data and model estimates reached their lowest level in 2003 but increased in 2004 (Fig. 25).


Figure 24. Annual average ( $\pm 95 \%$ C.I.) LPUE in the shelf edge spring fishery.

Table 6. Annual LPUE for the shelf edge spring fishery. The number of fishing days ( N ) and pot hauls on which the data are based is shown.

| Year | N | Mean | S.d. | Pots <br> hauled |
| :---: | :---: | :---: | :---: | :---: |
| 1993 | 46 | 2.03 | 1.23 | 21125 |
| 1994 | 26 | 1.94 | 0.38 | 15250 |
| 1995 | 53 | 1.72 | 0.74 | 30950 |
| 1996 | 522 | 1.59 | 0.73 | 60800 |
| 1997 | 94 | 1.84 | 0.85 | 50625 |
| 1998 | 333 | 1.60 | 0.66 | 167000 |
| 1999 | 307 | 1.74 | 0.70 | 156175 |
| 2000 | 134 | 1.72 | 0.82 | 67615 |
| 2001 | 173 | 1.48 | 0.47 | 106500 |
| 2002 | 310 | 1.85 | 0.62 | 213925 |
| 2003 | 108 | 1.25 | 0.45 | 94100 |
| 2004 | 262 | 1.61 | 0.60 | 209550 |



Figure 25. GLM standardised and observed LPUE in the shelf edge spring fishery standardised to January, 1 day soak time and to 1 vessel. The dotted lines are $95 \%$ confidence limits for the model. Scaled data points are shown.

In season LPUE in the spring shelf edge fishery Monthly average LPUE in the shelf edge spring fishery declined between February and April in the period 20012004 (Fig. 26)


Figure 26. Changes in the monthly average LPUE ( $\pm 95 \%$ C.I.) in the shelf edge spring fishery in the period 2001-2004.

The summer (May-August) shelf edge fishery (40E0, 39E0)
The annual LPUE in the shelf edge summer fishery increased between 1993 and 2000 fluctuating between highs and lows on alternate years. A significant and persistent reduction, to 1.4 kgs per pot, occurred in 2001 (Fig. 27, Table 7).

The GLM standardised and observed LPUE in the shelf edge summer fishery generally corresponded although the GLM model explained only $17 \%$ of the variance in the data (Fig. 28). Raw and standardised estimates in 1999 differed but the 1999 data was based on only 18 fishing days. Standardised LPUE was higher in 2001-2004 but showed the same stable pattern as the observed data.


Figure 27. Annual average ( $\pm 95 \%$ C.I.) LPUE in the shelf edge summer fishery.

Table 7. Annual LPUE for the shelf edge summer fishery. The number of fishing days ( N ) and pot hauls on which the data are based is shown.

| Year | $\mathbf{N}$ | mean | S.d. | Pots <br> hauled |
| :---: | :---: | :---: | :---: | :---: |
| 1993 | 216 | 1.93 | 0.70 | 89675 |
| 1994 | 268 | 1.60 | 0.66 | 147700 |
| 1995 | 244 | 2.01 | 0.82 | 119000 |
| 1996 | 759 | 1.73 | 0.66 | 86100 |
| 1997 | 189 | 2.25 | 0.90 | 106141 |
| 1998 | 94 | 1.94 | 1.88 | 49750 |
| 1999 | 18 | 2.38 | 4.22 | 14375 |
| 2000 | 108 | 1.96 | 0.69 | 62430 |
| 2001 | 178 | 1.40 | 0.49 | 148975 |
| 2002 | 201 | 1.31 | 0.33 | 177100 |
| 2003 | 83 | 1.51 | 0.44 | 72100 |
| 2004 | 162 | 1.38 | 0.57 | 143650 |



Figure 28. GLM standardised and observed LPUE in the shelf edge summer fishery standardised to May, a 1 day soak time and 1 vessel. The dotted lines are $95 \%$ confidence limits for the model. Scaled data points are shown.

## In season LPUE in the summer shelf edge

 fisheryMonthly average LPUE in the shelf edge summer fishery was similar in May, June and July but significantly lower in August in the period 2001-2004. The August data, however, was based on only 7 fishing days (Fig. 29).


Figure 29. Monthly changes in the average ( $\pm 95 \%$ C.I.) LPUE in the shelf edge summer fishery in 2001-2004.

The Malin Shelf (39E1, 40E1) summer (MayAugust) fishery
The annual LPUE in the Malin Shelf summer fishery declined from 2.8 to 1.2 kgs per pot between 1990-1994. Following a recovery in 1995 to over 2.2 kgs per pot the index declined until 2001. Between 2001-2004 LPUE increased from 1.3 to 1.7 kgs per pot (Fig. 30, Table 8).


Figure 30. Annual average ( $\pm 95 \%$ C.I.) LPUE in the Malin Shelf summer fishery.

The GLM standardised and observed LPUE in the Malin Shelf summer fishery were similar. The GLM model explained approximately $20 \%$ of the variance in the data. The steep fall in LPUE in 1994 seems to have been a reality as this is also indicated in the standardised estimate (Fig. 31).

Table 8. Annual LPUE in the Malin Shelf summer fishery. The number of fishing days (N) and pot hauls on which the data are based is shown.

| Year | N | mean | S.d. | Pots <br> hauled |
| :---: | :---: | :---: | :---: | :---: |
| 1990 | 22 | 2.75 | 1.14 | 11000 |
| 1991 | 61 | 2.18 | 0.90 | 27200 |
| 1992 | 68 | 1.91 | 0.91 | 24500 |
| 1993 | 150 | 2.17 | 0.74 | 62100 |
| 1994 | 99 | 1.30 | 0.67 | 49325 |
| 1995 | 50 | 2.22 | 0.94 | 26125 |
| 1996 | 351 | 1.56 | 0.63 | 43523 |
| 1997 | 88 | 1.93 | 0.73 | 48675 |
| 1998 | 43 | 1.86 | 0.54 | 26875 |
| 1999 | 17 | 1.75 | 0.61 | 9250 |
| 2000 | 252 | 1.61 | 0.55 | 147990 |
| 2001 | 61 | 1.34 | 0.36 | 58325 |
| 2002 | 128 | 1.50 | 0.45 | 124325 |
| 2003 | 95 | 1.43 | 0.46 | 74925 |
| 2004 | 92 | 1.73 | 0.43 | 85200 |



Figure 31. GLM standardised and observed LPUE in the Malin Shelf summer fishery. The dotted lines are $95 \%$ confidence limits for the model. Scaled data points are shown.

In season LPUE in the summer Malin Shelf fishery
Monthly average LPUE in the Malin Shelf summer fishery were on average lower in August than during May, June or July in the period 2001-2004 (Fig. 32).


Figure 32. Monthly changes in the average ( $\pm 95 \%$ C.I.) LPUE in the Malin Shelf summer fishery in 2001-2004.

## The Malin Shelf (39E1, 40E1) spring (Jan-Apr)

 fisheryThe annual LPUE in the Malin Shelf spring fishery declined from 2.4 to 1.0 kgs per pot between 1991 and 1995-1996. It recovered during the period 1997-1999 to between 1.5 and 2.2 and declined again in 20002001 to 1.0 kgs per pot. Between 2001-2004 it averaged between 1.4-1.5kgs per pot (Fig. 33, Table 9).


Figure 33. Annual average ( $\pm 95 \%$ C.I.) LPUE in the Malin Shelf spring fishery.

Table 9. Annual LPUE in the Malin Shelf spring fishery. The number of fishing days ( N ) and pot hauls on which the data are based is shown.

| Year | N | Mean | s.d. | 95\%cl | Pots <br> hauled |
| :--- | :---: | :---: | :---: | :---: | :---: |
| 1991 | 10 | 2.42 | 1.18 | 0.37 | 4400 |
| 1992 | 26 | 2.25 | 1.30 | 0.26 | 9800 |
| 1993 | 19 | 1.74 | 0.50 | 0.11 | 8500 |
| 1994 | 66 | 1.46 | 0.68 | 0.08 | 39550 |
| 1995 | 12 | 1.06 | 0.27 | 0.08 | 5250 |
| 1996 | 32 | 1.07 | 0.51 | 0.09 | 4000 |
| 1997 | 6 | 1.61 | 0.96 | 0.39 | 2500 |
| 1998 | 38 | 1.53 | 0.85 | 0.14 | 25500 |
| 1999 | 155 | 2.02 | 0.57 | 0.05 | 88875 |
| 2000 | 37 | 1.14 | 0.40 | 0.07 | 20685 |
| 2001 | 16 | 0.99 | 0.39 | 0.10 | 9900 |
| 2002 | 113 | 1.42 | 0.43 | 0.04 | 97600 |
| 2003 | 69 | 1.54 | 0.56 | 0.07 | 56900 |
| 2004 | 83 | 1.42 | 0.45 | 0.05 | 79500 |

The GLM standardised and observed LPUE in the Malin Shelf spring fishery showed similar trends. Sample sizes were low resulting in wider confidence limits. The observed and modelled estimates in this fishery were more variable that in other areas showing periodic declines followed by increases (Fig. 34).


Figure 34. GLM standardised and observed LPUE in the Malin Shelf spring fishery. The dotted lines are $95 \%$ confidence limits for the model. Scaled data points are shown.

## In season LPUE in the spring Malin Shelf

## fishery

Monthly average LPUE in the Malin Shelf spring fishery, in the period 2001-2004, was higher in January and April compared to February or March (Fig. 35)


Figure 35. Monthly average ( $\pm 95 \%$ C.I.) LPUE in the Malin Shelf spring fishery in 2001-2004.
6. Preliminary estimates of the effects of gear competition on the LPUE index

## Introduction

The LPUE index is calculated from the total number of crabs captured in a given string of pots (the index gear) in an area. It is presumed that changes in the value of this index, after standardising for soak time and other effects, are directly proportional to changes in the number of crab on the seabed that come within the area of influence of the trap. However, the number of crab coming within this area of influence may be related to fishing effort elsewhere if crab are migrating or moving through the area. Tag return data indicates that the rate of migration or directional movement of crab may be in the region of $1-1.5 \mathrm{~km}^{\text {. day }}{ }^{-1}$. Interception of crab by gear close to an index string of pots could, therefore, reduce the LPUE in that string of pots. If the level of interception or competition between gear units increases over time, because of an increase in the number of pots being fished, then the LPUE index will be biased downwards and indicate a decline in the stock size when, in fact, this may not be the case. In the northwest fishery the amount of gear in the fishery expanded annually between 1990 and 2004. The annual LPUE also declined linearly in relation to the number of pots hauled annually in the fishery (Fig. 36). This correlation could be interpreted as a gear competition effect.


Figure 36. Relationship between LPUE and the annual numbers of pots hauled by index vessels in the northwest offshore crab fishery 1990-2004.

## Methods

To detect and standardise for possible gear competition effects a data query was developed in ArcGIS to calculate the total number of pots within 5 km of each index set of gear for the 3 days prior to the date on which the index gear was hauled (Fig. 37). At average rates of movement of $1-1.5 \mathrm{~km}^{2}$ day ${ }^{-1}$ these conditions allow for the possible catch of a crab within 5 km of a pot if the pot is soaked for 3 days. The total number of pots within 5 km of each index set of gear for the 3 days prior to hauling that gear was calculated for all gears fished by the 3-4 offshore vessels for which data were available from 1990-2004.

To account for possible gear competition effects the LPUE data was standardised using the GLM method described above and which included the number of pots, classified into groups of 250, within 5 km of index fishing positions as a factor in the model. Year and soak time were also included as these were the dominant factors or variables in the original analysis (Table 1).

## Results

The annual unstandardised LPUE index was very similar to LPUE data calculated for all pots within a 5 km radius of this index gear calculated as described above (Fig. 38). This suggests that fine scale variability in LPUE, less than 5 km in radius, was not important or that strings of traps separated by less than 5 km are expected to catch, on average, similar numbers of crab.

The average number of pots within 5 km of an index set of traps fluctuated during the period 1990-2004 (Fig. 39). This statistic indicates, on average, the number of pots a crab vessel could expect to be within 5 km of its own position on a daily basis in each year during the period. During 1990 the average number of pots, at just over 800, was higher than in 1991 or 1992. Although effort in 1990 was low it was concentrated in a small area. This area expanded in 1991 and 1992. The numbers remained stable between 1993-1997, as the fishery consolidated, declined in 1998 and increased from 2001-2004. Although the overall effort increased year on year this did not result in year on year increases in gear competition (defined as fishing within 5 km ). This, presumably, was due to avoidance of such competition by the vessels by increasing the geographic area fished rather than increasing the intensity of fishing in any one location.


Figure 37. Graphic depiction of ArcGIS query to estimate the total number of pots, within 5 km of a given fishing position (point X ), that were fishing 3 days prior to hauling gear at point $X$.


Figure 38. The relationship between the annual LPUE index and the LPUE in pots within 5 km of gear used to calculate the index.


Figure 39. The average number of pots within 5 km of index gear each year between 1990 and 2004 in the offshore fishery.

Pots, which were within 5 km of index gear, contributed significantly to the variability in catch (Table 10) although this effect was weak compared to soak time or the year effect. Gear competition was negatively correlated with the annual LPUE index affirming the presence of gear competition (Fig. 40).

The effect of gear competition on the LPUE index is expected to vary through the year and to be stronger during periods of time when crab are migrating. This appears to be the case (Fig. 41). For instance the slope of the regression line of LPUE on the number of pots within 5 km was steeper in autumn when crab are migrating, compared to mid summer.


Figure 40. Relationship between annual average LPUE and the number of pots within 5 km of fishing positions used to calculate the LPUE.




Figure 41. Relationship between the seasonal average LPUE index and the number of pots within 5 km of fishing positions used to calculate the index.

Table 10. Analysis of variance of the effect of year, gear competition and soak time on LPUE.

|  | df | SS | MS | F |  |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Year | 14 | 365 | 26 | 128 | $\mathrm{P}<0.0001$ |
| Pots | 10 | 13 | 1 | 7 | $\mathrm{P}<0.0001$ |
| Soak | 1 | 110 | 110 | 110 | $\mathrm{P}<0.0001$ |
| Residuals | 18,227 |  |  |  |  |

## Annual LPUE standardised for gear competition

The observed LPUE and LPUE standardised for year, soak time and gear competition effects were similar (Fig. 42). Therefore, although competition between gear was apparent (Fig. 40, 41) there was no trend in competition between gear over the 15 year series.


Figure 42. Comparison of observed LPUE and LPUE standardised for gear competition, soak time and year effects in the offshore crab fishery between 1990 and 2004.

## 7. LPUE in the <12m vessel fishery

LPUE of crab for vessels $<12 \mathrm{~m}$ in length were sourced in a variety of ways as described earlier. The data by Meredith and Fahy (2005), shown below, was re-scaled by 1.25 under the assumption that the differences in methodologies, whatever they may have been, led to the observed $25 \%$ difference in LPUE in that series and Cosgrove's (1998) index, for years in which they overlapped.

There was a significant decline from 1990-1991 in the index derived by Cosgrove (1998) (Fig. 43). This decline was also observed in the offshore data where it continued until 1994. Both indices declined by approximately 0.08 kgs per pot haul per annum between 1992 and 1999. Meredith and Fahy's re-scaled index declined to approximately 1.25 kgs per pot haul in 2000 and 2001
but subsequently increased from 2001 to 2004 by 0.24 kgs per year. This trend is different to the offshore index which was stable during this time.

Other LPUE data, available from various times and locations in Donegal, suggest that a decline had already occurred in the inshore fishery by 1990. LPUE for the Malin Hd. fleet in 1985 averaged 5.3 kgs per pot. In Donegal Bay in 1979 it ranged from 2.5-4.3kgs per pot and in Donegal Bay in 2002 it was 1.6 kgs per pot. Logbook data from northwest Donegal in 2003 indicated an index value of 1.0 kgs per pot.


Figure 43. Comparison of 2 LPUE indices for the inshore crab fishery in Donegal 19902004.

## 8. Discussion of LPUE data

The observed and GLM standardised estimates of annual LPUE in the offshore fishery, and for all areas combined, showed a virtually identical pattern, demonstrating, that at the spatial scale of the fishery, differences in the spatial and seasonal coverage of catch records did not introduce any significant bias in the estimated trend in LPUE between 1990 and 2004. The annual trends, therefore, are not due to changes in soak times, gear competition, areas fished, times of year fished or to vessel effects. Both observed and GLM standardised estimates showed that LPUE fell by $50 \%$ over the period 1990-2003. The majority of this decline occurred in the period 1990-1994 (range 2.79-1.81). A second, smaller decline, occurred in 2001.

Trends in LPUE for different geographic areas of the fishery varied. LPUE in the shelf edge summer fishery increased from 1993-1998 when LPUE, in other areas, was in decline. The Malin Shelf summer fishery in 2004 was significantly better than the average for the fishery overall. The Malin Shelf spring fishery recovered in 2002-2004 from low points in 2000 and 2001 and fluctuated periodically during the previous 10 years. Spatial variability in the long-term trend was probably caused by variation in the direction, rate and timing of crab migration into and out of these areas.

There were no strong seasonal patterns in LPUE, although there was a slight tendency for higher values to occur in late summer and early winter in more easterly rectangles (40E2-41E2) compared with higher values earlier in the year in westerly rectangles (39EO-40EO) and overall, ignoring the area effect, for catches to be higher in October-November. Again, trends in the unadjusted data averages compare well with the GLM estimates for monthly LPUE by area although the match was not so strong as for the annual indices.

Data on LPUE for the inshore fishery indicated a similar trend to that offshore up to 1999. Evidence from Fox and Bates (1986) also suggests that LPUE had declined prior to 1990. The grading practice and the pot designs used in the 1980s, however, were probably quite different to those used in the 1990s. LPUE off Malin Hd., derived from buyers records, were relatively stable during the period 1992-1999, declined significantly in 2001-2002 and then recovered to 1999 levels. Data from northwest Donegal, however, suggested that LPUE may be lower than indicated by the time series of data derived from buyers records. The differences, however, could also be due to geographic variation in the abundance of crab. Limited data from the Donegal Bay area in 1979 and 2001-2002 also indicated a decline in LPUE similar to that observed in other areas. Generally, in both inshore and offshore sectors, LPUE ranged between $1.4-2.0 \mathrm{~kg}$ per pot haul in 2004. These estimates are very similar to those in other European crab stocks that have been fished for an equivalent or longer period of time and which are regarded as stable (Anon 2005).

The scale and rate of migration of crab over the fishing area, as demonstrated by tagging, suggests that spatial variability and differences in LPUE between vessels, whether these are inshore or offshore vessels, are not expected to differ greatly. The GLM analysis supports this view; area and vessel effects explained a relatively small proportion of total variance compared to year and soak time effects. The annual trends in LPUE observed in the extensive offshore data set should, therefore, be representative of the pattern throughout the inshore and offshore fishery. The limited data available from inshore certainly does not contradict this view and indeed supports it to a remarkable degree considering the different methods by which the data were derived.

Using LPUE data to monitor the status of crab stocks assumes that changes in this index reflect, proportionally, changes in the abundance and size of the stock. The relationship between the index and crab abundance may be affected by many environmental and biological factors. In the case of lobster, there is a direct proportional change in the catch rate of $v$-notched lobsters and the
numbers of v -notched lobsters known to be in the stock (Tully, unpublished data). In this case at least, therefore, LPUE is directly proportional to actual abundance.

Fishing strategies may significantly affect the relationship between catch rate indices and stock abundance. If fishing effort only occurs at times and locations of relatively high crab availability, then LPUE may be only weakly sensitive to trends in stock abundance i.e. there is targeted fishing at areas and times of year when a certain catch rate is expected and fishing is curtailed when LPUE falls below an economically determined limit. The mobile offshore fleet certainly has the capacity to play the 'cat and mouse' and find locations and times where LPUE might be more optimal. However, the GLM area*month interaction term removes this potential bias which may arise due to changes in fishing behaviour over time. The intensity of fishing activity offshore, however, limits the capacity of the vessels to be 'strategic' in where and when they fish particularly in more recent years. Fishing occurs throughout the year and increasingly, as effort increased, in all areas for extended seasons. Strategic fishing would positively bias the catch rate relative to the real abundance of the stock. Increased effort and competition for space, however, would negatively bias the catch rate as vessels were 'forced' to fish in what they regarded 'strategically' as sub-optimal areas. Competition for ground in the offshore crab fishery is high to the extent that vessels may periodically leave the area and fish elsewhere and this has increased in more recent years. The extent to which there are optimal areas and times to fish seems to be limited; spatial and within year variability in the data sets was not high. The catch rate data, therefore, would not seem to be unduly biased because of fishing strategy.

Although the LPUE for crab at a given location may be an unbiased estimate of crab abundance at that location it is not an indicator of the abundance of the stock at other locations. Each catch rate record is, therefore, a local estimator. The important issue here is whether these local estimators are independent of fishing effort at other locations. In sedentary species eg scallops the catch at a given location does not depend on fishing effort at another location as there is no re-distribution of fish following each of the catches at each location. At the other extreme, such as a pelagic fishery, the catch rate, theoretically at any rate, depends on all catches at all locations as the fish have a significant capacity to re-distribute spatially following a given catch. Given the rate of migration of crab $\left(1.5 \mathrm{~km}^{2}\right.$.day ${ }^{-1}$ ) the LPUE at a given location could well be influenced by catches and effort at other locations up to a certain distance from that location. This spatial autocorrelation of LPUE with
respect to fishing effort would infer that the local LPUE estimates may not be directly related to the abundance of the stock but to the level of fishing effort (and catch) at distances up to a certain range from a given fishing location and overall to the total amount of effort in the fishable area. This effect is known to occur at very fine spatial scales and can be observed in individual strings of traps where LPUE at the ends of the string are higher than in the middle. Crabs at the middle of the string have a higher number of traps to choose from than at the edge. Anecdotally reports from the industry suggest that local LPUE declines as additional fishing effort is introduced to an area. The LPUE index in this case could be reflecting the competition among ever increasing pot numbers for the same stock of crabs rather than a decline in the size of the stock. The analysis presented in this report showed that competition between pots is important and has a bearing on the LPUE index. As expected, because of crab migration patterns, this effect was stronger at certain times of year. During periods of crab migration the LPUE local estimators may not, therefore, be independent of surrounding fishing effort. Although such gear competition effects were apparent there was no trend in the intensity of that competitive effect in the period 1990-2004. This presumably was due to a strategic spacing out of effort as overall effort increased. This competition for space in fact led to one vessel leaving the area in 2004. Standardising the LPUE data for gear competition effects did not, therefore, alter the trends seen in the data series.

Not all legal sized crab are retained on board the vessels. These crabs are returned alive to the sea for various reasons but usually because they are in poor condition due to recent moulting and have low meat content. The grading of crabs on board the vessels may vary over time due to changing market demands. The LPUE index in this report was not corrected for any potential bias due to changes in grading on board the vessels as no independent data or index that would indicate changes in grading practice existed by which this bias could be removed.

Although conclusions, with respect to the impact of onboard grading and its effect on LPUE, must await further analysis certain features of the LPUE data series suggest that such an analysis will not change the overall trend. Firstly, the time series from 1994-2004 was stable but for a reduction of $10-15 \%$ in 2001 . There is no reason to believe that grading increased by 10$15 \%$ in 2001 . There was also a very high correlation between the annual number of pots hauled and the LPUE index indicating that the level of grading would need to be highly correlated with annual effort in order
to significantly affect the shape of the LPUE time series. Nevertheless, vessel owners indicated that levels of grading and return of crab live to the sea were higher in more recent years. Data from processors on the quantities of poor quality crab in the landings may be an indicator of grading practice on board the vessels and could be used as a proxy to standardise the LPUE index for this effect.

## 9. Size composition data

Offshore: crabs returned to the sea alive The majority of crabs returned alive in 1997 in the offshore sector were above the minimum landing size and measured between $140-180 \mathrm{~mm}$ in carapace width (Fig. 44).


Figure 44. Size composition of female crab returned alive from the vessels in 1997

In the offshore fishery the proportion of the catch returned varied during the year. The annual average percentage returned was $28 \%$ in 1996 - 1997. This reached a minimum of $10 \%$ in early spring and a maximum of $50 \%$ in November 1997. The reasons why these crabs were not retained on board were as follows; $38 \%$ were undersized ( $26 \%$ male and $12 \%$ female), $14 \%$ had shell necrosis, $11 \%$ were white faced, $2 \%$ had no claws, $1 \%$ were berried and $1.5 \%$ were either dead, dying or damaged when captured. The remaining $32 \%$ were returned due to poor sorting by size and quality.

## Landings offshore

Crabs landed from the offshore fishery were sampled in 1996,1998 and 2001 on board the vessels. Mean monthly size of female crab varied from 162 mm carapace width in March to 176 mm in July. Male crab varied in size from 157 mm in October to 173 mm in July. The size compositions did not change between 1996-2001 (Figs. 45, 46). In fact the mean size was also similar to earlier data collected north of Malin Hd. by Fox and Bates (1986). Approximately $87 \%$ of crabs landed in the offshore fishery were female.


Figure 45. Size composition of female crab landed in the offshore fishery in 1996, 1998 and 2001.




Figure 46. Size composition of male crab landed in the offshore fishery in 1996, 1998 and 2001.

Size composition of the landings inshore
The monthy average size of female crabs landed in the inshore fishery in 1996 and 1997 varied between 160166 mm carapace width. Male crabs varied in size from $158-167 \mathrm{~mm}$ (Fig. 47). Between 80-90\% of crabs landed were female.


Figure 47. Size composition of male and female crab in the inshore landings in 1996 and 1997.

## Discussion

The size composition of crabs in the offshore and inshore fishery remained constant between 1997-2001, and possibly back to 1985 , during a period of significant increase in fishing effort, increased landings and, presumably, increased fishing mortality. The reason for this is unclear as the fishery high grades for large crabs well above the MLS. In addition the growth rate of crabs over 160 mm , which is the average size of crab landed in the fishery, is slow. Tag return data shows that the intermoult period may be as long as 4 years. With heavy and size selective fishing pressure the abundance of these large crabs would be expected to decline but there is no evidence that this has occurred. The explanation may lie to some degree in the sampling strategy and in the way in which samples are aggregated and requires further investigation.

The data shows that the current legal MLS of 130 mm is of little significance as a conservation measure. The market based 'limit' is approximately 140 mm and the modal landing size is $155-165 \mathrm{~mm}$.

The size composition of the crabs not retained on board the vessels also shows that few, legally undersized, crabs are captured in the offshore fishery and the dominant reason for returning these crabs to the sea is quality related. This supports the theory that there is a general pattern of crab migration into deeper water as their size increases and that recruitment to the population and the fishery probably occurs in inshore waters.

## 10. Egg production per recruit (EPR)

Egg production by each crab recruiting to the fishery (egg per recruit, EPR) can be estimated, for a range of fishing mortalities, using growth and maturity data. EPR reference points are used in a number of crustacean fisheries worldwide and can be useful when the stock recruitment relationship is unknown and even, as in the present case when current level of fishing mortality is unknown. The EPR output compares the reproductive capacity of a crab exposed to various levels of fishing mortality with its reproductive potential when it is only subject to natural mortality.

## Size at maturity

The size at maturity of northwest crab was estimated by Cosgrove (1998) from samples taken in 1997. More recent and repeated estimates were made by Robinson (unpublished data). There are a number of difficulties in estimating maturity. Not all mature crabs spawn every year. For instance crabs, which are $180-190 \mathrm{~mm}$ carapace width, may have undeveloped gonads in autumn when they would be expected to spawn. The interpretation in this case is difficult as these, apparently immature crab, may have spawned in the previous year and should therefore be classified as mature. Correctly identifying the maturity status of these crab can only be made if evidence of previous spawning is found. This usually requires histological preparation of the gonad.

The size at maturity ogive produced by Cosgrove (1998) for northwest crabs is shown in Fig. 48. Mean size at maturity is approximately 120 mm carapace width and all crabs appear to be mature at about 140 mm . This ogive concurs with more recent, histologically validated, data by Robinson.

Figure 48. Size at maturity of female crabs from Cosgrove (1998) and the cumulative size distributions of the landings.


## Fecundity and spawning frequency

Brown crabs have a high fecundity producing up to 4 million eggs at each spawning. Fig. 49 is a composite of all data available for this species including Cosgrove's (1998) estimate for the northwest stock.


Figure 49. The size-fecundity relationship for brown crab. The function was derived from all available information on the fecundity of this species including 1997 data for the northwest stock.

The frequency of spawning is poorly known but given the current information on maturity and the presence of undeveloped gonads in large crabs it is certain that not all commercial sized crabs spawn every year. However, this is likely to be size related and as the probability of moulting decreases with increasing size so the probability of annual spawning may increase with size as these two cycles are antagonistic.

Accurate information on size at maturity, size and fecundity and spawning frequency are required for Egg Per Recruit (EPR) modelling.

## Egg per recruit (EPR) analysis

An EPR model, which included features from the Length Cohort Analysis (LCA) model described by Jones (1974) and Sparre and Venema (1992), which is usually used to calculate yield per recruit, was developed for crab using the information on maturity and fecundity shown above. The model was seeded with 1000 crabs recruiting at a size equivalent to the minimum onset of maturity (about 100 mm carapace width) and exposed to an exponential decay in numbers according to various input values of $F$ between 0-2.2 and $M$ of 0.1 . Growth parameters were used to control the amount of time each crab spent in a particular size group. However, there were no data on moult increments or frequency to estimate the vonBertalanfy growth parameters directly. Values for the parameters, $K$ and $L_{\infty}$, used in the model were therefore adjusted such that the length of time crabs spent in each length group corresponded to what is known about the minimum moult frequency in the stock from tag return data for commercial sized crab over 140 mm . Values for $K$ and $L_{\infty}$ used were 0.13 and 230 respectively. $A$ maturity ogive, derived from data in Cosgrove (1998), which indicated a mean size at maturity of female crab of 120 mm carapace width was used to identify the proportion of crab in each size class in the model that were mature. The probability of annual spawning
was assumed to be the inverse of the moult frequency. The annual moult probability was set at 1 for crabs less than 120 mm and 0.5 for crabs greater than this size.
The EPR model was run under 2 different combinations of MLS of 130 mm carapace width, which is the legal size limit, and 140 mm , which is the market driven MLS. The output was set in the context of reference points for EPR regarded as appropriate, although unproven, for the northwest crab stock.

## EPR results

EPR declined monotonically with increasing F (Fig. 50) and was less than $50 \%$ at relatively low values of F . Values of $F$ between 1-2 had a limited effect on EPR because at these high levels of mortality few crabs survive to larger size groups. Smaller mature crabs, below the MLS, contributed proportionally more EPR than larger crabs at high F. Lower MLS exposes smaller crabs to fishing and results in lower EPR in relation to $F$.


Figure 50. Egg per recruit (relative to EPR at $F_{0}$ ) in relation to fishing mortality and MLS of 130 and 140 mm . Limit and target reference points are indicated by the horizontal red lines.

## EPR Reference points

In order to avoid recruitment overfishing the ratio of the EPR when there is no fishing ( $F_{0}$ ) to the EPR at current fishing mortality ( $\mathrm{F}_{\text {current }}$ ) should not fall below a given value. This reference point value is unknown for crab and will depend on the parameters of the stock recruitment ( $S-R$ ) relationship and more precisely on the slope at the origin of the relationship. Species that are resilient to high fishing pressure have a higher slope at the origin of S-R i.e they produce a higher number of recruits per spawning unit. Mace and Sissenwine (1993) estimated the appropriate EPR ratio for 91 stocks of fish in Europe and North America where the S-R relationship was known. Resilience was positively related to body size, which is a proxy for fecundity, longevity and low $M$. These species require a lower EPR ratio to maintain their populations than small sized short lived
species. On average the lower limit for the EPR ratio was 0.2. Mace and Sissinwine (1993), Clark (1991) and Goodyear (1989) variously recommended precautionary default values for EPR of $0.2-0.35$ when the $S-R$ is unknown.

In the northwest crab fishery values of relative EPR do not fall below the lower limit of 0.2 even at high values of $F$. The 'safe zone' for EPR may lie between 0.2-0.35. The value of 0.35 could be used as a target for management as it is at the upper limit of the precautionary range identified for other stocks, may define the point at which recruitment is not compromised and may be a proxy for MSY or fishing mortality that will result in maximum long term yield ( $\mathrm{F}_{\mathrm{MSY}}$ ). This target is met if the MLS is 140 mm , mean size at maturity is 120 mm and if $F$ is less than or equal to 1.0.

## 11. Effort and Participation in the Fishery

## Introduction

The northwest crab fishery developed during the 1970s on a small scale, relative to more recent years. Further development occurred during the 1980s and from 1990, with the introduction of the offshore vivier fleet, and incremental modernisation of the inshore fleet, landings increased exponentially. Since the 1980s, the fishery has been an important source of income and employment in Donegal both at sea and in processing facilities ashore.

Cosgrove (1998) collated data, by interviewing boat owners, on the distribution of fishing and fishing effort in 1997. This exercise was repeated in the summer of 2005 in order to show changes in

- The total number of vessels targeting the fishery
- The geographic distribution of fishing
- The total potential effort in the fishery and
- The effort potential of individual vessels

Earlier reports also make reference to effort and vessel numbers in specific sectors such as the Malin Hd. fishery (Fox and Bates 1986).

Fleet profile in 1997 and 2005
In 1997 effort by vessels <12m in length was concentrated north of Malin Hd. and in west Donegal from the ports of Malin, Leenan Keel, Maheraroarty, Bunbeg, Burtonport and Teelin. In 2005 the main centres of fishing activity were in northwest Mayo and north Donegal (Figs. 51 and 52) and activity from Bunbeg, Burtonport and Teelin had declined dramatically.

An estimated 129 vessels targeted crab in Donegal in 1997 and a further 24 fished out of north Mayo. The total number of vessels targeting the fishery out of north Mayo and Donegal combined in 2005 was 60 including those in the offshore vivier sector. Vessels included in the 2005 data were those relying almost $100 \%$ on crab but with varying contributions from whelk and lobster. The vessels included in this list typically fished more than 300 pots per day. Some of the vessels in the 1997 list may be mixed crab and lobster boats as the number of pots owned typically was less than 600 . Some of these may have targeted the lobster fishery. The number of vessels targeting crab, however, seems to have declined by $50 \%$ between 1997 and 2005. The examples below support this view.

In the early 1980s 15 vessels fished from the Inishowen peninsula. By 1985 this had increased to 33 vessels each fishing approximately 300 pots. From 1985 there was a gradual decline in the number of vessels and by 2005 just 17 remained. This was close to the number of vessels in the fishery in the early 1980s and represented a $50 \%$ reduction in the number of crab vessels in Inishowen between 1985 and 2005. Employment on vessels in 1985 was 4-5 men per boat (Fox and Bates 1986) or up to 105 fishermen. In 2005 vessel crew size was 2-3 representing a maximum of 51 fishermen.

In the Burtonport and Bunbeg region the reduction in the number of vessels targeting the fishery was more dramatic than in Inishowen. In 199751 vessels fished the northwest and west of Donegal south to Teelin. By 2005 this number had declined to 9 representing a reduction of $80 \%$ in the participation of vessels $<12 \mathrm{~m}$ in length in the crab fishery in northwest and west Donegal. However, in addition to those boats which specifically targeted crab and which numbered 60 in 2005, vessels which target lobster also rely to varying degrees on a bycatch of brown crab. These vessels are typically smaller, varying in length from 6-9m, and fish less than 300 pots per day. No data exists on the importance of crab bycatch for these lobster boats. The number of such vessels off the Donegal coast in 2005 was at least 131 with a further 32 off north Mayo.

The change in the distribution of fishing and the location of the main centres of activity with respect to landings is shown very clearly in Figs. 51 and 52. The reduction in the crab fleet off west Donegal and the expansion of activity from north Mayo are obvious features. The relatively small area fished by the Malin Hd. fleet disguises its importance as a major producer of crab at over 1800 tonnes per annum.


Figure 51. Distribution of fishing in the $<12 \mathrm{~m}$ and vivier crab fisheries in 1997. Each rectangle, colour coded by Malin, Northwest Donegal and west Donegal is the approximate extent of fishing by one vessel. Mayo fishing effort is not included but was mainly distributed along the north and northwest of Mayo in 1997.

The interpolated LPUE data for the offshore fleet reveals their annual distribution of fishing (Fig. 53). The expansion of the Fishery between 1990-1994 is clearly evident. From 1995 the geographic area fished was stable although these were periods of exploration, e.g. 2001, followed by consolidation.


Figure 52. Distribution of fishing in the $<12 \mathrm{~m}$ and vivier crab fisheries in 2004-2005. Each rectangle, colour coded by Malin, Northwest Donegal and north Mayo is the approximate extent of fishing by one vessel


Figure 53. Annual distribution of fishing and interpolated LPUE by the $>18 \mathrm{~m}$ Irish registered vivier crab fleet off the northwest coast of Ireland

## Effort profile in 1997 and 2005

Although the number of vessels targeting the fishery declined, very significantly, between 1997 and 2005 the number of pots and, therefore, the potential effort increased substantially. Data for 46 vessels, under 12 m in length, showed that they owned an average of 375 pots each. This average was applied to all other vessels resulting in an estimated 26000 pots in the $<12 \mathrm{~m}$ fleet in 1997. In 2005 estimates of the total number of pots, obtained by interviewing the skippers, was 41795 in the inshore fleet or 60\% higher than in 1997. In the offshore fleet total effort potential in 1997 was, approximately, 6000 pots and in 2005 was 15200 pots or an increase of $153 \%$ in the 8 year period. The proportion of the total effort potential in the vivier sector was $26 \%$. The reduction in the number of vessels in the fishery and the parallel increase in effort potential was obviously due to an increase in the number of pots owned per vessel. The distribution of pots among vessels in 1997 and 2005 clearly shows this change. The modal number of pots for 46 vessels in 1997, for which there was data, was 250-500. In 2005 the modal number was 500-750. In 200514 vessels had between 750-1000 pots compared to 1 in 1997 (Fig. 54). Pot numbers in the offshore sector increased from approximately 1200 per vessel in 1997 to 3000 in 2005.


Figure 54. The distribution of pots in the crab fleet in Donegal in 1997 and 2005. The 1997 data is not a complete census of the fleet.

The implication of the increase in effort potential (the number of pots fished by each vessel) depends on how these pots are utilised in the fishery. The effective or realised unit of effort is a combination of a number of factors but is essentially related to the number of days fished, the time of year the pot is fished and the soak times used. The soak time effect was clearly shown in the GLM analysis of catch rate data. Furthermore, the slope of the relationship between catch rate and soak time also varied by month implying that soaking a pot for different periods of time has different effects in each month because of changes in the catchability of crab due to various environmental and biological factors.
The relationship between effort potential and realised effort in the offshore fishery in 2004 was the same as in 1997 as neither the soak time distribution or the seasonal pattern of fishing changed (Fig. 55). The increase in effort was due to increase in pot hauls over all values of soak time and in all months of the year. In the inshore sector in 2005 an estimated $75 \%$ of pots were soaked for 48 hrs and $25 \%$ for 24 hrs . The soak time profile in 1997 was unknown although 24 hr soaks were most common particularly when LPUE was high (Cosgrove 1998). The pot ownership profile in Fig. 54 also suggests that a 24 hr soak time was the norm as only 1 vessel owned over 750 pots and it is logistically feasible to fish up to 700 pots per day from these vessels. The increase in effective effort was less than that expected from the $60 \%$ increase in pot ownership, therefore, because of a change from 24 hr to 48 hr soak times. However, without detailed fishing activity records it is not possible to track changes in the profile of effective effort in the $<12 \mathrm{~m}$ sector.


Figure 55. Distribution of soak times in the offshore fishery in 1997 and 2004. Soak times longer than 7 days are not shown

## Discussion

Very significant changes occurred in the level of fishing effort, the geographic distribution of that effort and the individual vessel effort between 1997 and 2005 in the northwest crab fishery. Effort potential was progressively aggregated into fewer vessels in the 8 year period and by 2005 the main centres of activity were Malin Hd., the offshore vivier sector and north Mayo. Vessels, which operated out of Burtonport and Bunbeg and other ports in west Donegal in 1997, were not fishing in 2005. This change in effort profile occurred during a period of relative stability in LPUE at least in the offshore sector but also in Malin Hd.. The main reduction in LPUE offshore occurred in the period 1990-1994 with a further reduction of $10-15 \%$ in 2001. However, there is likely to be a lag period between declines in LPUE and decisions by fishermen to leave the fishery. Although the factors responsible for the change in effort profile are probably complex and related to overall opportunities in the economy falling LPUE may have precipitated decisions to leave the fishery. In addition, however, prices for crab fell in real terms during the period and a number of other fisheries, and in particular salmon, also declined during this time. The profile of the surviving vessels may tell the true story and reflect the economic reality. To survive in the fishery at a time when LPUE was declining and prices were not keeping pace with this decline, or with inflation, the options were to increase fishing effort or to stop fishing. The increase occurred through vessel modernisation and increased vessel power all of which increased the capacity to haul more pots per day.

## The Southeast Fishery

## 1. Landings

Annual landings of crab into Waterford and Wexford fluctuated around 100 tonnes between 1990-1995. Between 1995 and 2002 there was a linear increase in annual landings, resulting in landings of 937 tonnes in 2002. Landings in 2004 reached a historic high of 986 tonnes (Fig. 56).


Figure 56. Annual landings of crab into Waterford and Wexford 1990-2004.
2. LPUE

## Inshore

LPUE data, from voluntary fishing activity records, were available only for 2002 and 2003. LPUE inshore was $1.08 \pm 0.58 \mathrm{kgs}$ per pot haul in 2002 and $1.01 \pm 0.49 \mathrm{kgs}$ per pot in 2003. Seasonal variation in LPUE was low (Table 9). LPUE was higher in May and June than in July and August. LPUE in Oct-Nov was similar to that in early summer.

Table 9. Monthly commercial LPUE in the inshore fishery off Wexford and Waterford in 2002 and 2003

| Month | N | Mean | S.d. |
| :--- | :---: | :---: | :---: |
| Mar | 3 | 0.73 | 0.18 |
| Apr | 9 | 0.62 | 0.32 |
| May | 14 | 1.14 | 0.53 |
| Jun | 24 | 1.25 | 0.50 |
| Jul | 105 | 1.08 | 0.55 |
| Aug | 186 | 0.99 | 0.46 |
| Sep | 203 | 1.04 | 0.59 |
| Oct | 156 | 1.17 | 0.65 |
| Nov | 70 | 1.15 | 0.49 |
| Dec | 16 | 1.03 | 0.51 |

## Offshore

The Irish fleet do not, in general, fish in offshore waters south of Wexford although they took part in surveys in this area in 2002 and 2005 (Fig. 57).

In 2002 average LPUE was 0.94 kgs per pot in June south of $51^{\circ} \mathrm{N}$ and 0.47 kgs per pot in July north of $51^{\circ} \mathrm{N}$ in ICES rectangles 31 E 3 and 31E2. This LPUE was lower than in inshore waters. LPUE offshore south of Wexford (ICES $32 \mathrm{E} 3,32 \mathrm{E} 2$ ) in September 2005 was $1.7 \pm 0.5 \mathrm{kgs}$ per pot. Live return rates in September 2005 were $0.3 \pm 0.2 \mathrm{kgs}$ per pot.

The French Roscoff vivier fleet fished in ICES VIIg since, at least, 1987. Effort in recent years in this area has declined however. LPUE of the French fleet, which usually operates on a 24 hr soak time, was stable between 1.41.6 kgs per pot between 1990-2002 (data shown in Fahy et al. 2004).


Figure 57. Brown crab survey positions by two Irish vessels in 2002 and 2005.

## 3. Size composition

Size sampling of the landings and live returns was undertaken during the summer and early autumn months of 2001-2004 in the southeast fishery. These data were collected on board fishing vessels and ashore in buyers premises. Sea and shore based size composition samples, above the MLS, taken in 2002 were similar (Fig. 58). Crabs, below the MLS, ranged in size from $70-130 \mathrm{~mm}$ carapace width. Shore based samples in 2001 and 2002 had modal sizes of $140-150 \mathrm{~mm}$ and $150-160 \mathrm{~mm}$ respectively.


Figure 58. Comparison of size distributions of female crab in Wexford from shore and sea based sampling.

The average size of crabs was higher in the fishery in autumn compared to summer. This was probably due to the combined effects of moulting and migration. The average sizes and size frequency distribution of the landings in the southeast inshore fishery was largely similar to that in the northwest especially in the autumn fishery.

Table 10. Monthly size of female crabs sampled ashore in 2001 and 2002

| Month | N | Mean | S.d. |
| :--- | :---: | :---: | :---: |
| June | 283 | 154.49 | 12.90 |
| July | 559 | 155.43 | 14.17 |
| Aug | 468 | 151.62 | 14.39 |
| Sep | 792 | 161.32 | 16.11 |
| Oct | 169 | 160.37 | 16.46 |

## 4. Fishing effort

The effort potential in the Wexford lobster-crab fishery increased from 5000 pots in 1965 to over 22000 pots in 2002. The number of pots doubled between 1997 and 2002 (Fig. 59). These pots were distributed in the lobster and crab fisheries unlike those in the northwest, which primarily target crab. Calculation of effective effort is, therefore, more difficult and in the absence of fishing activity records it was not possible to distinguish between effort potential and realised effort. Nevertheless the increase in potential effort is obvious and consistent with the observed increase in landings in recent years.


Figure 59. Number of pots in the Wexford fishery between 1965 and 2002.

The number of vessels fishing pots in Wexford in 2001 (Rosslare to Duncannon) was 67. Twelve of these fished less than 100 pots. The number of vessels fishing more than 100 pots in 2005 was 50 representing a decrease of 5 over the number in 2001.

## 5. Fishery interactions

## Whelk

The southeast crab fishery has important interactions with the whelk fishery in particular that need to be taken into account in assessment and management of crab in the area. The interaction occurs mainly due to the use of crab as bait in the whelk fishery. The implications for management are

- Crab used as bait are not necessarily included in the landings data if there is direct transfer of crab for bait between vessels or if crab and whelk are fished by the same vessel
- Crab used in the bait fishery are usually in early post moult (soft or white), are in poor condition and have low weights. This will depress the yield per recruit or at least lead to higher uncertainty in yield per recruit estimates
- Undersized crab may be used as bait. Again this depresses the yield per recruit and if not incorporated will lead to less conservative management advice.

Fahy (2001) assessed the level of interaction between crab and whelk fisheries in Wexford and concluded that the weight of crab used in the whelk fishery corresponded to $7.2 \%$ of the landed weight of whelk. This amounts to approximately 200 tonnes of crab. The proportion of this that is incorporated into the landings is unclear.

Lobster
Fishing activity records between 2002-2004, submitted voluntarily by a number of vessels in the lobster fishery, identified by-catch LPUE of crab in the lobster fishery. Data for 2002-2004 indicated that crab by-catch in the lobster fishery varied from $0.28-0.46 \mathrm{kgs}$ per lobster pot haul (Table 11). On average, over the 3 year period 20022004, by-catch LPUE of crab in the lobster fishery was $34 \%$ of the LPUE in the targeted crab fishery.

Table 11. By-catch of crab (LPUE in kgs per pot haul) in the Wexford targeted lobster fishery in 2002-2004

| Year | $\mathbf{N}$ | Mean | s.d. |
| :---: | :---: | :---: | :---: |
| 2002 | 1,368 | 0.31 | 0.43 |
| 2003 | 1,285 | 0.28 | 0.38 |
| 2004 | 500 | 0.46 | 0.38 |

## The Southwest Fishery

## 1. Landings

Landings of crab into Cork and Kerry was less than 500 tonnes per annum between 1990-1996 (Fig. 60). This increased to 1200 tonnes in 1997 and 2000 tonnes in 1998. In 2004 landings were 3570 tonnes.


Figure 60. Annual landings of crab into Cork and Kerry 1990-2004

## 2. Distribution of fishing

Crab fishing off the southwest coast occurs predominantly inside the 12 nm limit and generally within 6 nm of the coast. Survey data from 1992, 1999 and 2004, and anecdotal information on the by-catch of crab by offshore trawlers, indicated that crab are widely distributed inshore and offshore although the distribution of commercial densities is unclear (Fig. 61). Vessels target crab from the Shannon estuary along the Kerry coast and east of Mizen Hd. to Cork. The eastern boundary of the south coast stock is unknown and it may be contiguous and linked to the stock off the southeast. Crabs migrate from Wexford in a south and southwest direction (Fahy et al. 2004).

## 3. LPUE

## Kerry

LPUE of crab off Kerry were available from voluntary fishing activity records and from dedicated surveys in areas not generally fished commercially. Commercial catch rate data off Kerry yielded an annual average LPUE of $1.88-2.13 \mathrm{kgs}$ per pot haul (Table 12). Catches were highest in the period May-July in this inshore fishery (Table 13) varying from $2.1-2.4 \mathrm{kgs}$ per pot compared to $1.7-1.8 \mathrm{kgs}$ per pot in spring and autumn.

Table 12. Commercial LPUE data for crab off the Kerry coast in 2002-2004

| Year | $\mathbf{N}$ | Mean | S.d. |
| :---: | :---: | :---: | :---: |
| 2002 | 170 | 1.94 | 0.64 |
| 2003 | 195 | 1.88 | 0.99 |
| 2004 | 60 | 2.13 | 1.00 |

Table 13. Monthly LPUE of crab off the Kerry coast in 2002-2004.

| Month | N | Mean | S.d. |
| :--- | :---: | :---: | :---: |
| Apr | 11 | 1.77 | 0.93 |
| May | 28 | 2.40 | 0.89 |
| Jun | 47 | 2.44 | 0.78 |
| Jul | 88 | 2.11 | 0.89 |
| Aug | 106 | 1.79 | 0.89 |
| Sep | 95 | 1.68 | 0.72 |
| Oct | 50 | 1.74 | 0.81 |

Surveys undertaken in the Skelligs area and west of Valentia in 1999 returned an average LPUE of $1.49 \pm 0.7 \mathrm{kgs}$ per pot. This varied from 1.19 in July to 1.85 in September (Table 14). This seasonal pattern was opposite to that shown in the commercial data from the inshore fishery and may result from a migration of crab inshore during summer followed by a migration offshore to deeper water in Autumn. LPUE was generally lower in the survey data. This is expected, as the objective of the survey was to identify the distribution of crab rather than to target only areas yielding the highest LPUE.

Table 14. Monthly LPUE off the coast of Cork/Kerry during survey in 1999.

| Month | N | Mean | S.d. |
| :--- | :---: | :---: | :---: |
| May | 10 | 1.78 | 0.75 |
| Jun | 217 | 1.41 | 0.65 |
| Jul | 37 | 1.19 | 0.40 |
| Sep | 29 | 1.85 | 0.75 |
| Oct | 80 | 1.69 | 0.80 |



Figure 61. Areas off the southwest coast surveyed in 1999 and 2004 including indications of areas fished by the commercial inshore fleet. Fishable areas may be potential crab ground.

## Cork

Few data on LPUE, from commercial sources, were available for county Cork. Average annual LPUE from limited data for the July-Sept season, in 2002 and 2003, was $1.32 \pm 0.52$ and $2.39 \pm 0.69 \mathrm{kgs}$ per pot respectively. LPUE based on survey data in 2004 (Fig. 61) was $0.91 \pm 0.46 \mathrm{kgs}$ per pot. Monthly LPUE was highest in July and August and lowest in Sept-Nov. This seasonal pattern was consistent with the 1999 surveys (Table 15).

Table 15. Monthly LPUE from surveys in 2004

| Month | N | Mean | S.d. |
| :--- | :---: | :---: | :---: |
| July | 161 | 0.91 | 0.46 |
| Aug | 126 | 1.09 | 0.49 |
| Sept | 28 | 0.54 | 0.19 |
| Oct | 112 | 0.63 | 0.17 |
| Nov | 420 | 0.96 | 0.47 |

## 4. Size composition

Crab carapace width during the 2004 survey varied from $85-200 \mathrm{~mm}$ (Fig. 62). The mean size of all female crabs and legal sized female crabs was 146 mm and 151 mm respectively. Male crabs were smaller averaging 130 mm carapace width and 145 mm for all crabs and legal sized crabs respectively. Eleven percent of all crab were under the MLS. Most of these were male. These average sizes were smaller than in the southeast or northwest fisheries.


Figure 62. Size composition of crab caught during survey in 2004.

## 5. Fishery interactions

Crab by-catch is an important component of the lobster fishery in Cork and Kerry. By-catch LPUE of crab in the lobster fishery varied from 0.22-0.44kgs per pot in Kerry, in 2002-2004, and $0.11-0.22 \mathrm{kgs}$ per pot in the Cork lobster fishery. This may indicate a higher abundance of crab in the Kerry area compared to that in west Cork. Bycatch rates of crab in the lobster fishery were between $11-20 \%$ and $15-20 \%$ of targeted crab LPUE in Kerry and Cork respectively.

Table 16. By-catch of crab (LPUE in kgs per pot haul) in the Cork and Kerry targeted lobster fishery in 2002-2004

| Year | N | Mean | s.d. |
| :---: | :---: | :---: | :---: |
| Kerry |  |  |  |
| 2002 | 643 | 0.28 | 0.31 |
| 2003 | 796 | 0.22 | 0.35 |
| 2004 | 287 | 0.44 | 0.28 |
| Cork |  |  |  |
| 2002 | 172 | 0.19 | 0.22 |
| 2003 | 136 | 0.17 | 0.12 |
| 2004 | 102 | 0.15 | 0.11 |

## The Midwest Fishery

## 1. Landings

Landings of crab into counties Galway and Clare increased significantly in 1994 to 580 tonnes from just over 100 tonnes in 1990-1992. Annual landings ranged between 300-500 tonnes during the period 1995-2002 but increased to 631 tonnes in 2003 (Fig. 63).


Figure 63. Annual landings of crab into Galway and Clare between 1990 and 2004.

## 2. LPUE

Mean annual LPUE in 2002, from limited data, was $0.74 \pm 0.26 \mathrm{kgs}$ per pot. LPUE from survey data in 2002 off west Galway was $1.21 \pm 0.72 \mathrm{kgs}$ per pot.

By-catch of crab in the lobster fishery in Clare averaged $0.25 \pm 0.32$ and $0.19 \pm 0.23 \mathrm{kgs}$ per lobster pot haul in 2002 and 2003 respectively.

# A Regional Comparison of the Status of Crab Stocks and Fisheries 

## 1. Stock structure

The structure of crab stocks off the coast of Ireland has not been completely identified. Information from a variety of sources indicates that a single stock occurs in the area from North Mayo to Inishowen in Donegal. South of Erris Head crab fishing is much less extensive than in Donegal and is restricted to inshore areas. Surveys offshore in 1992 (not reported here) confirmed that the abundance of crab in deeper water off the west coast was very limited. Fishing activity and abundance of crab in both inshore and offshore waters increases again south of the Shannon estuary. The stock boundaries off the southwest coast are less well known. In this report the southwest stock was assumed to occur from Shannon to Cork. The stock and fishery between Cork and Rosslare was regarded as a fourth stock. The extent to which crab occurs offshore in the southwest and southeast is unclear but is very important. The resilience of inshore crab fisheries, in the face of increasing fishing pressure, will depend on how much of the stock occurs offshore during the inshore fishing season and which is, therefore, not subjected to fishing.

Information on stock boundaries will be enhanced in the future through hydrodynamic modelling and prediction of larval dispersal and also by tagging programmes to monitor the migration of adult crab.

## 2. Landings, effort and biomass

The northwest fishery
Landings and effort increased in the northwest between 1990-2004 and in 2004 were the highest on record.

Aggregation of fishing effort into a smaller number of vessels, which fish both inside and outside the 12 nm limit, occurred between 1997 and 2005. Vessels from Scotland, Northern Ireland and Republic of Ireland fish the same stock.

Some conclusions regarding the current status of the northwest stock can be drawn from analysis of the data. LPUE in the offshore fishery declined by approximately $50 \%$ between 1990-2004. The reduction occurred at two points in time between 1990 and 1994 and again in 2001. Changes in LPUE were not due to changes in location or season of fishing, changes in soak time, gear
competition or to variation between vessels but were highly correlated with the annual number of pots hauled. This correlation may be due to in season fishing mortality i.e. the rate of crab removal during periods of intensive fishing was higher than could be replaced by growth of juvenile crab. More seriously it may be caused by a reduction in recruitment brought about by over fishing of spawning stock. Estimates of EPR, although crude and using poor information on growth, do not support this view and although the current level of fishing mortality is unknown the EPR limit of $20 \%$ of spawning potential is, essentially, protected at all reasonable values of $F$ because of the substantial difference between the average size at maturity $(120 \mathrm{~mm})$ and the average size of crab landed in the fishery $(160-165 \mathrm{~mm})$. The reduction in LPUE may also be partly accounted for by higher grading at sea but the effect of this is currently unknown. Taking the trend in the LPUE index at face value and, therefore, that the index reflects proportional changes in the stock biomass and given the caveats discussed above, the following conclusions may be drawn

1. The long term sustainable yield (landings) is unknown although the current rate of annual increase in landings is obviously not sustainable
2. Recruitment is above the precautionary reference point of $20 \%$ of unexploited egg production
3. The current biomass is $50 \%$ of the 1990 biomass which was close to the unexploited biomass
4. Further declines in biomass and LPUE are expected if effort increases
5. LPUE should stabilise if effort is stabilised
6. LPUE should increase quickly following any reduction in effort if the cause of the decline in LPUE is not due to recruitment overfishing. If the latter is the case recovery will be slower.

Although the reasons for and implications of the observed declines in LPUE in the northwest stock and in other areas is open to interpretation the reality is that the current LPUE is 1.4 kgs per pot lift. The response of the fleet to date to falling LPUE has been to aggregate effort into a smaller number of larger or more efficient vessels, to increase the number of pots fished and to increase the soak time so the catch rate in each pot is optimised. Vessel operating costs and gear costs have
increased and a significant amount of capital is now invested in the industry. There is an economic and social (employment) risk because of escalating costs and falling LPUE. This increasing imbalance between LPUE and effort is seen in the overall relationship between landings and effort. Landings are not increasing in proportion to effort suggesting that further investment in effort is likely to reap little reward and may possibly be counterproductive. The industry would be more profitable and less at risk if LPUE was higher. Given that the annual effort and annual average LPUE are highly correlated, and recruitment does not seem to be limited, it may be possible to achieve this in the short term.

For economic and social reasons and for precautionary biological reasons, given the uncertainty with respect to the status of the stock, management should attempt to stabilise and subsequently reduce effort in the fishery.

## South and west coast fisheries

Data on trends in effort and participation in the crab fisheries in the south and west coast fisheries is weak. Effort in the southeast mixed lobster and crab fishery has increased and perhaps at a rate equivalent to or higher than that in the northwest. Vessel numbers are, however, relatively stable in the southeast having declined from 55 to 50 between 2001 and 2005.

Catch rate indicators in the southeast (this report and Fahy et al. 2002, 2004) suggest that LPUE has declined. Generally LPUE in the northwest, west and southwest seems to have fluctuated around $1.4-2.0 \mathrm{kgs}$ per pot lift since 2002. LPUE in the southeast may be lower. Off the southeast coast (ICES VIIg) French fishing effort has declined since 2001. This area yielded stable catches of $1.4-1.6 \mathrm{kgs}$ per pot between 1987 and 2002 for the French fleet. These LPUE are equivalent to those in the northwest fishery although the fishing strategy and soak times differ.

## 3. Bitter Crab Disease (BCD, Haematodinium)

The dinoflagellate, Hematodinium, is a microscopic parasite that has been shown to infect a number of crab, lobster and shrimp species. Although it had been reported from the Channel Islands, France, the English Channel and the North Sea in brown crab, velvet crab and Nephrops (Dublin Bay prawn), prior to autumn 2004 it had not been detected in Irish fisheries. A number of fishermen began to notice a number of discoloured, weak brown crabs in their pots at this time, however, and subsequent investigations revealed the parasite to be the cause. The shell of crab in the late, terminal stage of infection turns a light pinkish colour, while internally their organs turn a pale yellow colour, lose shape and become very difficult to distinguish from one another. The blood also turns a pale yellow or pinkish colour that is easily recognisable from the usual healthy clear or opaque condition. It is not possible to detect early stages of infection without scientific examination as there are no symptoms externally or internally visible to the eye. Although it is not yet clear exactly how the parasite enters the host crab or lobster, or how long it takes from first infection to death monitoring is continuing. Studies on other species around the globe have indicated that although crabs/lobsters may be infected by the parasite, some stocks either have a stronger resistance to the effects or environmental conditions are such that the late, terminal stages are not reached. In effect the animals may become carriers of the parasite without suffering ill effect. Initial indications suggest that the parasite may occur in all brown crab stocks around the Irish coast, but late terminal stage infections have only been seen on the south coast (Table 17).

Table 17. Seasonal sampling to monitor Hematodinium infection

| Location | Date | Crab examined | Crab infected | \% infected |
| :--- | :---: | :---: | :---: | :---: |
| Wexford | Nov-04 | 45 | 8 | 18 |
|  | Dec-04 | 50 | 2 | 4 |
|  | Mar-05 | 47 | 7 | 15 |
|  | Jun-05 | 89 | 1 | 1 |
| Cork | Aug-05 | 60 | 11 | 18 |
|  | Nov-04 | 59 | 7 | 12 |
|  | Jun-05 | 50 | 5 | 10 |
|  | Aug-05 | 49 | 7 | 14 |
|  | Oct-05 | 50 | 30 | 60 |
|  | Nov-04 | 48 | 0 | 0 |
|  | Apr-05 | 59 | 7 | 12 |
|  | May-05 | 50 | 11 | 22 |
|  | Aug-05 | 50 | 14 | 28 |

There is some indication that the parasite affects undersized (<130mm carapace width) brown crab more readily, that it occurs more commonly in shallow water (although this could be because smaller crab are more common there) and that areas where clawing has commonly taken place are more likely to be affected. Initial results suggest that the parasite is spread to healthy individuals by the consumption of infected crab meat and die within 14 days. If infected individuals are clawed and the body discarded, other crabs may become infected by cannibalism of the weak/dead carcass as brown crab will readily consume fresh meat from other dead brown crab.

Studies into the effect of the parasite are ongoing, and have the ultimate aim of developing management measures to minimise the impact of parasite outbreaks. Initially, it is important that fishermen report suspected outbreaks so that the incidence of the parasite can be confirmed. The use of infected animals for bait either in crab or other fisheries or leaving dead/dying individuals in re-baited pots is not recommended. These should be removed from fished areas if an outbreak has been confirmed. Marketing infected claws is also poor practice, as although the meat does not pose a threat to human health, it tastes bitter (hence it is called 'Bitter crab disease in the U.S.A. and Canada where it affects blue crab and snow crab) and may reduce consumer confidence in the product. Overland transportation of infected crab/bodies/products should be curtailed if there is any risk of introducing the parasite to other wild stocks. Even when a host has died it may contain living encapsulated (hibernating) parasites that can become active if introduced to seawater again. Further guidelines for the control of the parasite are required and will be developed for the Irish crab fishery by researchers in conjunction with the crab advisory group.

## 4. Fishery Interactions

A number of fisheries for crab and other species significantly interact and impact on crab stocks and fisheries in Ireland

1. Whelk: the use of crab as whelk bait encourages and provides a market for poorly conditioned crab that reduces the potential yield from the crab fishery and may impact on spawning potential. This interaction occurs mostly in the southeast but also in recent years in the Malin Hd. fishery
2. Lobster: crab by-catch in the lobster fishery is approximately $20-30 \%$ of the catch rate of crab in the target crab fishery. This interaction occurs inshore within 1-2 miles of the coast and along the shore. This is the area where smaller crabs just above the MLS are likely to be encountered and where prerecruit crabs will be captured and discarded. There may be a mortality associated with this discarding.
3. Trawling: Although no data are presented in this report, by-catch of crab by trawlers is known to be significant in some areas off the south and southwest coasts in particular.

## Research and Monitoring Priorities

This report has reviewed all of the available information on Irish crab stocks. Considering the findings a number of priorities for future research and monitoring are listed below. These are directly applicable to the stock assessment process and do not extend to research on other issues currently of importance in the industry.

- Landings data: Accurate landings data are essential for the calculation of total annual removals from the stock and extension of the analysis of catch and effort into sustainable yield estimates. The methods by which the landings data are compiled should be described and if necessary reviewed.
- Catch rate data: The majority of data reported relate only to landings per unit effort. The quality and quantity of these data from the offshore fishery is very high but should be extended to include the numbers of crab in the catch that are graded and return alive to the sea. The inshore sector does not, as yet, report an adequate amount of data in the voluntary fishing activity record scheme that is sufficiently representative of the fishery. Although all vessels over 10 m are required to submit details of catch in the EU logbook the format and content of the data reported in the EU logbook is not suitable for crab fisheries. The options for catch and effort data collection would seem to be
- Re-design the EU logbook so that appropriate data can be reported under the existing mandatory reporting system.
- Rely on the existing voluntary fishing activity record scheme and apply additional resources to encourage reporting. This is the approach being taken in 2005 in the northwest fishery
- Develop a second mandatory reporting system for all Irish registered crab fishing vessels or vessels fishing crab in Irish waters
- The choice of reporting medium should be either paper or electronic. An electronic system for reporting data has recently been developed for Irish vessels
- Biological parameters: Information on growth rate and size at maturity, which are input parameters to almost all stock assessment models, is still weak. A number of projects are ongoing which will improve this situation
- Size sampling of the landings: A national sampling programme should be put in place to sample the size composition of the landings. Although there is some doubt as to whether these data can be useful in length based analytical models or if the size composition is a useful indicator of fishing mortality a strategic sampling programme would allow these options to be explored


## - Fishery independent indices

- Recruitment: Given that population regulation in brown crab is likely to occur shortly after settlement to the seabed direct monitoring of recruitment at this point in the life cycle would be a valuable index of the health of the stock and over time could be used to forecast recruitment to the fishery. This is a long term objective.
- Economic data: Data on costs, earnings, participation and employment in the fishery are necessary to make informed management decisions. The current monitoring and research emphasis is almost entirely biological (stock) in focus. Although protection of the stock from collapse or depletion below agreed reference points is a listed priority under national and international guidelines on sustainable management research on economic and social aspects of the fishery and its fleet should receive more attention.


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