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REPORT OF THE STUDY GROUP ON THE BIOLOGY AND LIFE HISTORY OF CRABS (SGCRAB)

9-11 MAY 2005

GALWAY, IRELAND

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

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1 Introduction

1.1 Background of the Study Group

The first meeting of the Study Group on the Biology and Life History of Crabs (SGCRAB) met in Jersey, UK, in 1993 to review progress on the research and fishery management of two commercially important Majidae species, the spider crab (*Maja squinado*) and the snow crab (*Chionoecetes opilio*), fished on the two sides of the Atlantic and in the Pacific, as reported in C.M. 1993/K:3. The Study Group recognised the need for more intensive coverage of the life history characteristics of the two species, and a better geographic representation of carcinologists. This lead to a second meeting at La Coruna, Spain, which reviewed new information available on the life history and fishery management of the Spider crab and *Chionoecetes* species (*opilio, bairdii, tanneri*), as reported in C.M. 1996/K:1. It was recommended that the SGCRAB should meet on a three years basis and that the remit be enlarged to include other commercially important crab families (notably portunid and cancrid crabs which are not covered by ICES assessment working groups or study groups. The third, fourth and fifth meetings of SGCRAB was convened in Brest, France (4–7 May, 1998) and in Copenhagen 25–29 March 2001 and Tromsø (Norway) 2-4 June 2003 respectively. This document reports on the sixth meeting of the group in Galway, Ireland from 9–11 May 2005.

1.2 Terms of Reference

The **Study Group on Biology and Life History of Crabs** (Chair: Oliver Tully, Ireland) met in Galway, Ireland from 9–11 May 2005 to:

a) compile data on landings, discards, effort and catch rates (CPUE) for the important crab fisheries in the ICES area;

b) standardise methods for the acquisition, analysis and interpretation of CPUE, size frequency and research survey data;

c) define stock structure / management units for crab stocks;

d) assess environmental effects including diseases on crab fisheries

e) assess the interaction between net/dredge fisheries other anthropogenic activities and crab stocks

f) assess the effects of fishing on the biological characteristics of crab stocks

g) review the methods for estimating recruitment in crab stock

1.3 Participants at the Study Group meeting

Tully, O. (Chair)	Ireland
Fahy, E.	Ireland
Robinson, M.	Ireland
Addison, J.	United Kingdom
Eaton, D.	United Kingdom
Bossy, S.	Jersey
Henderson, S.	Scotland (Shetland)
Kinnear, J.	Scotland
Latrouite, D.	France
Wohl, A.	Norway
Ungfors, A	Sweden
Taylor, D.	Canada

Other members were contacted by e-mail and asked for submissions to this report.

2 Progress in relation to the Terms of Reference

2.1 ToR A): Compile existing data on landings, discards, effort and catch rates (CPUE) for the important crab fisheries in the ICES area

2.1.1 Official landings and catch rates (2001-2004) in the Norwegian fishery for *Cancer pagurus.* (Astrid K. Woll)

The fishery for Brown crab *Cancer pagurus* in Norway is an inshore coastal fishery. Annual catch is 5,236 tonnes (Table 1) which was worth approximately €7m in 2004. The landings are reported through different fish sales organisations. Largest is Norges Råfisklag which controls the fishery from N63° to the Russian border. About 80% of the Norwegian official landings of Brown crab are sold through this organisation. Norges Råfisklag is separated in smaller regional zones (Figure 1). In Skagerrak, the most southern part of Norway, crabs can be sold without reporting to a sales organisation (Skagerakfisk), hence no official landings are presented for Skagerrak (Table 1).

Table 1: Norwegian landings (tonnes) of Brown crab (*Cancer pagurus*) from 1995 to 2004 reported to the different sales organisations. In italic are landings in the local zones of Norges Råfisklag, percent females of the landed crab in 2004 in brackets.

Sale organisastion	N latitude	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	
Norges Råfisklag	63°- 69°	1 157	1 161	1 362	2 134	1 963	2 187	2 714	3 311	3 780	4 030	
Vesterålen								*0*	*14*	*14*	*0*	*-*
Salten										*134*	*391*	*(74.7)*
Helgeland								*600*	*597*	*791*	*1 112*	*(71.2)*
Nord-Trøndelag								*276*	*355*	*434*	*289*	*(73.1)*
Sør-Trøndelag								*1 698*	*2 174*	*2 122*	*2 015*	*(53.2)*
Nordmøre								*140*	*170*	*282*	*223*	*(69.3)*
Sunnmøre&Romsdal	62°-63°	51	62	45	52	35	29	87	160	95	28	
Vest-Norges	60°-62°	258	281	323	408	352	306	300	435	621	669	
Rogaland	58.30°-60°	338	279	389	401	556	382	334	395	434	506	
Skagerakfisk	58.30°	-	-	-	1	-	-	-	-	2	3	
Sum (tonn)		1 804	1 783	2 119	2 996	2 906	2 904	3 434	4 301	4 932	5 236	

The peak season in the crab fishery north from 62°N is from August to November. Vessels 10-15 m in length fish with traps and deliver the live catch to one of few processing plants. The largest of these has an annual turnover from 2000-2500 tonnes. The crab fishery has expanded northwards. In Helgeland and Salten the landings have increased in the last 4 to 5 years as transport and handling problems to the processing plants further south have been solved.

Smaller, but important regional coastal crab fisheries extend south of 62°N (Figure 1). As far south as Rogaland the fishing season starts in April and lasts until November. The crabs are sold at the local markets and to processing plants in the region.

a)

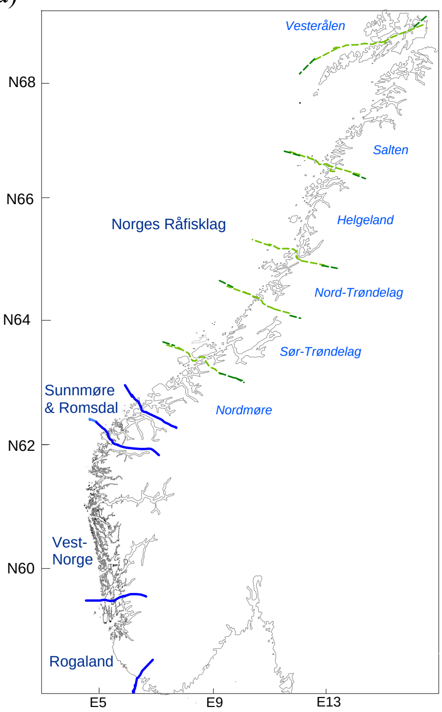


Figure 1: The location of the different fish sale organisations where crab fishery is conducted. Norges Råfisklag is separated in several local zones.

There has been no systematic description of the population structure of the crab stock in Norwegian waters and no estimate of the abundance of the crab stock. The fish sales organisations give information about the landings but no biological information. The fishery is regulated by a minimum legal size (MLS) of 130mm carapace width. In the 1950's the MLS south of N60° was changed to 110mm carapace width. The change was based on a general opinion that the crab was of a smaller size in these regions than further north. It is illegal to land berried and soft shelled crabs in all regions.

A logbook programme, which aimed to establish routine registration of biological parameters in the crab fishery, started in 2001. The logbooks are maintained by commercial fishermen (a reference fleet) and provide data for annual indices in selected geographic regions of catch data, sex ratio and size distribution (Table 2). Each fisher reported the catch from 4 standardised trial traps set in between their own traps.

Table 2: Mean catch rates (kg traphaul^{-1}) in the Norwegian fishery for Brown crab in September (October for Vesterålen). N=no. of boats in reference fleet. MLS = 11 cm CW for Rogaland and 13 cm for the other regions.

	Vesterålen			Helgeland			Trøndelag			Rogaland		
Year	N	LPUE	DPUE	N	LPUE	DPUE	N	LPUE	DPUE	N	LPUE	DPUE
2001	1	1.22	0.80	5	3.57	0.31	13	2.51	0.99			
2002	3	1.13	0.56	5	3.66	0.82	13	2.83	1.59	4	1.69	2.15
2003	3	1.30	0.35	5	3.08	0.63	13	2.55	1.22	3	2.84	1.45
2004	1	2.23	0.27	5	3.25	0.79	10	2.95	1.34	3	2.46	2.87

The average catch rates for 2001 to 2004 (LPUE) varied between the regions as shown in Table 2. LPUE was highest for Helgeland (3.4 kg × trap haul^{-1}), Midt-Norge somewhat lower

(2.7 kg · trap haul^{-1}), then Rogaland (2.0 kg × trap haul^{-1}) and Vesterålen (1.3 kg ×trap haul^{-1}). To allow comparison between Rogaland and the other regions, LPUE for Rogaland was calculated according to a MLS = 130mm CW resulting in a smaller LPUE (1.7 kg × trap haul^{-1} ± 0.10).

Catch rates expressed as number of crabs.trap haul^{-1} (CPUE) from 2001 to 2004 varied between all regions, for Midt-Norge (8.6), Helgeland (7.6) and Vesterålen (3.6). In Rogaland the average number was higher than in the other region with on average 13.4 crabs × trap haul^{-1} (Figure 2). Catches in Helgeland had the lowest portion of discarded crabs with 22% compared to 42% in Midt-Norge. Of the discards, the portion of soft and pale crabs was highest in the southern region Rogaland (33%), and higher for Midt-Norge (14%) than for Helgeland (5%) indicating that moulting occurs later in season farther north along the coast. The data from Vesterålen is from October *vs*. September for the other regions, and a direct comparison is not reliable.

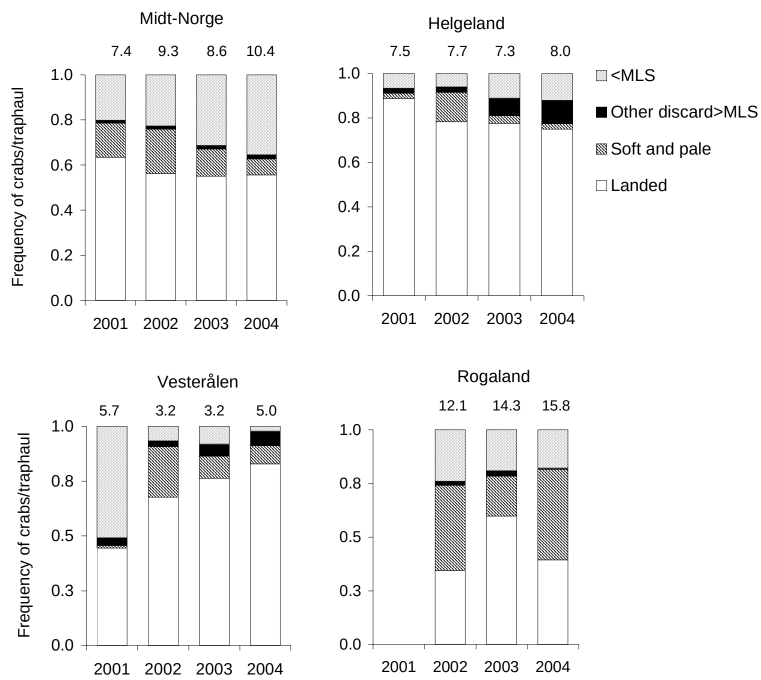


Figure 2: Catch composition (%) in September (October for Vesterålen) for region and year. The average number of crabs · traphaul^{-1} above columns. Minimum legal size for Rogaland is 11 cm carapace width, for the other regions 13 cm.

2.1.2 An LPUE series for the Irish north west brown crab stock, compiled from easily available data (Ed Fahy and David Meredith)

Fishers of inshore vessels less than 10m in length in Ireland are not required to keep logbooks and the majority of them do not do so. LPUE series for inshore fisheries for a variety of species have been constructed from the purchase records of commercial buyers who purchase on a daily basis. It is possible to compile an index of catch rate per vessel per day from these data by combining it with information on the number of pots owned (and presumably fished) by each vessel. Daily landings of brown crab from the northern stock for the period 1978 – 2004 were made available by a factory which purchases crab from the Malin Head area in the months of July – December. Details of the amount of gear used over the period were obtained from the fishing community in Malin (Figure 3).

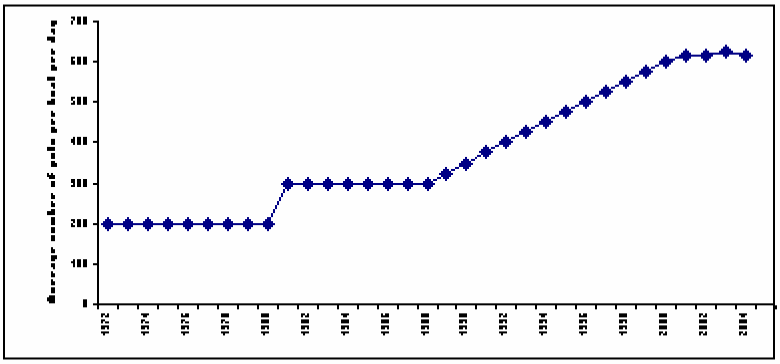


Figure 3: Reconstruction of pot numbers per boat in the Malin Head fleet.

Between 1978 and 2004 the inshore crabbing fleet based between Greencastle and Malin Head underwent considerable changes accompanying technical improvements in navigational aids and hauling gear and better vessel design and construction materials. The introduction of an offshore vivier supercrabber fleet in the 1990s was a stimulus to improve inshore boats. In recent years the territorial ranges of the two fleets have overlapped. Inshore vessels now fish out to 20 nm and supercrabbers in to within 6 nm.

In 1985 an estimated 35 boats in this small inshore fleet fished 10,000 creels; in 2004 the number of boats had fallen by 51% to 17 vessels fishing 12,900 creels, an increase in fishing gear of 29%. In terms of creels per boat, there was an increase of approximately 165% on average. The maximum number of creels a 12 m vessel can currently handle daily is about 700. Beginning in 2000 about one third of the Malin inshore fleet used two sets of fishing gear, which increased their effective effort because of longer soak times.

Throughout the period for which data were made available, the average daily landings per month remained fairly stable (Figure 4). Mean daily landings per annum trended upwards from 750 to 850 kg between 1991 and 2004, the time of greatest change in the inshore fleet (Figure 5).

The data on which the LPUE series are constructed are shown in Figure 6, together with the series itself. This series is compared with those from the offshore sector collated from logbook data (this report) and with an earlier series collected using similar methods for the inshore Donegal fleet for 1990-1997 (Tully et al 1997). Although the three LPUE series are not strictly comparable, being constructed from different fleets and/or times of year, the availability of the other two provided a context in which ours, compiled from easily available data, could be evaluated (Figure 7)

Trends in the three series are expressed as logarithmic curves for the period 1990 - 2004 in Figure 8. A fourth data series, compiled from our complete data set (1980 - 2004) is not included here. Its regression is described as: $y = -0.04x + 80.289$. $N=24$, $R2=0.5275$ and $P<0.0001$. Although differences would be expected in LPUE data from different fleets exploiting a fishery, the three time series of LPUE from 1990 – 2004 indicated similar trends in LPUE although the offshore fleet and inshore Malin curves compare more closely. Appropriately, the more recent data in our investigation are based on a more detailed account of gear in use in this fishery and it is then that convergence is greatest.

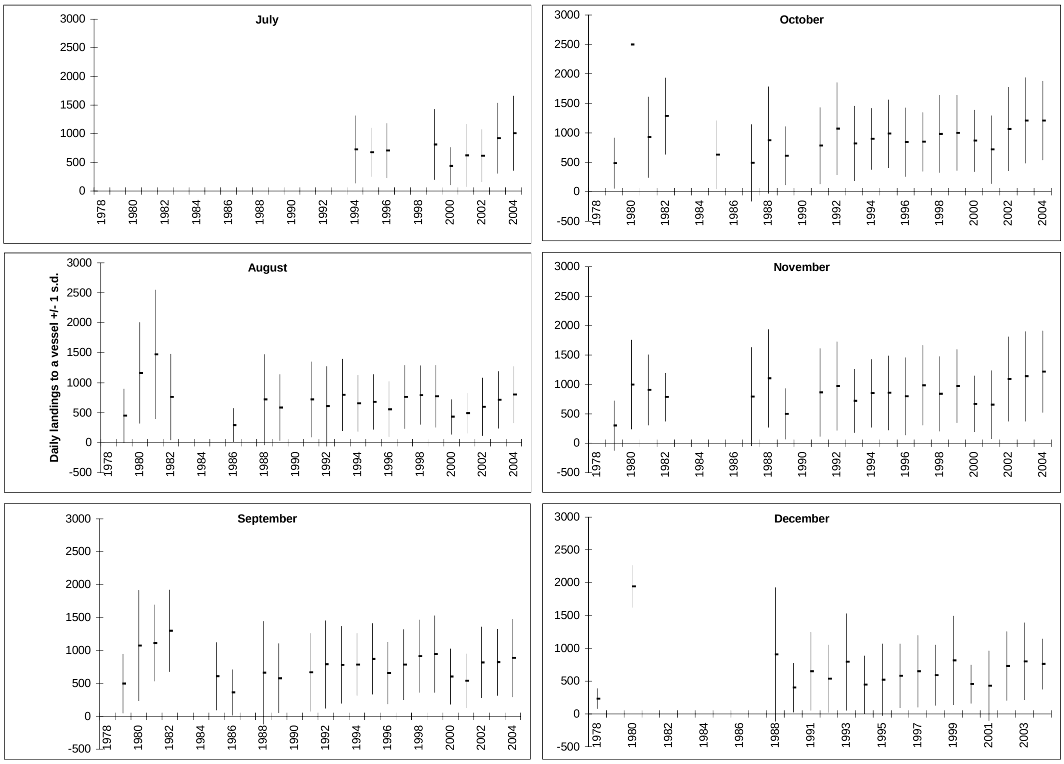


Figure 4: Variation in consignment size (kg) of brown crab landed from the Malin Head inshore fishery in each month in the series 1978 – 2004 inclusive.

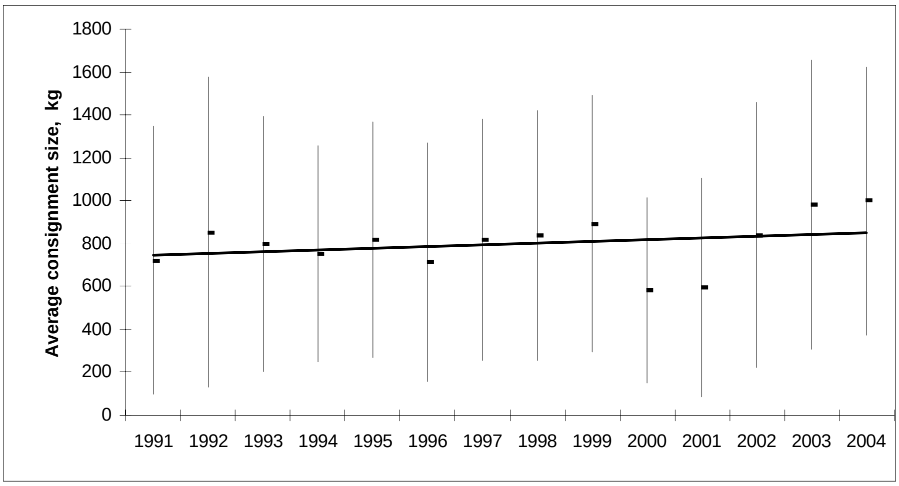


Figure 5: Annual consignment weight (mean +/- 1 s.d.) from 1991 to 2004 inclusive

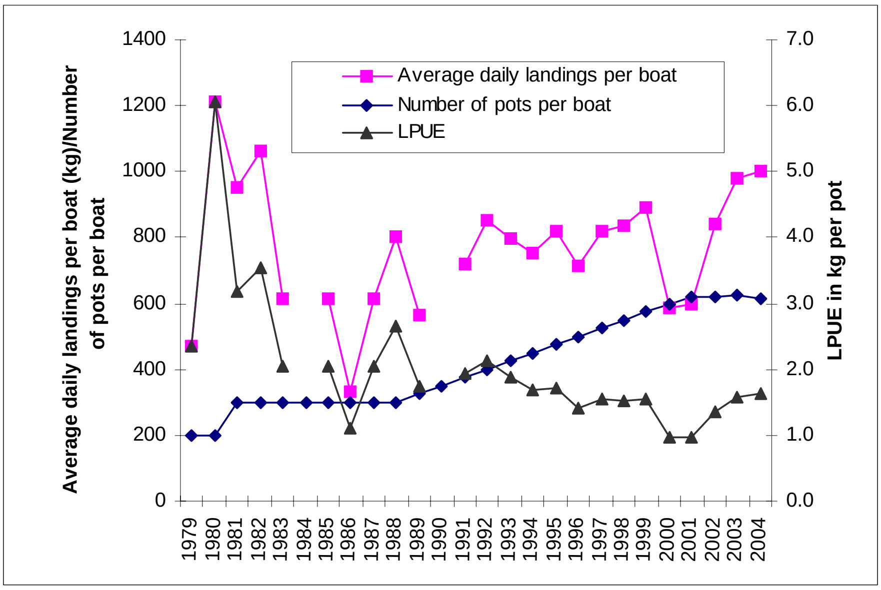


Figure 6: Annual consignment size, average creel number and derived LPUE series for the Malin inshore fishery from 1979 to 2004.

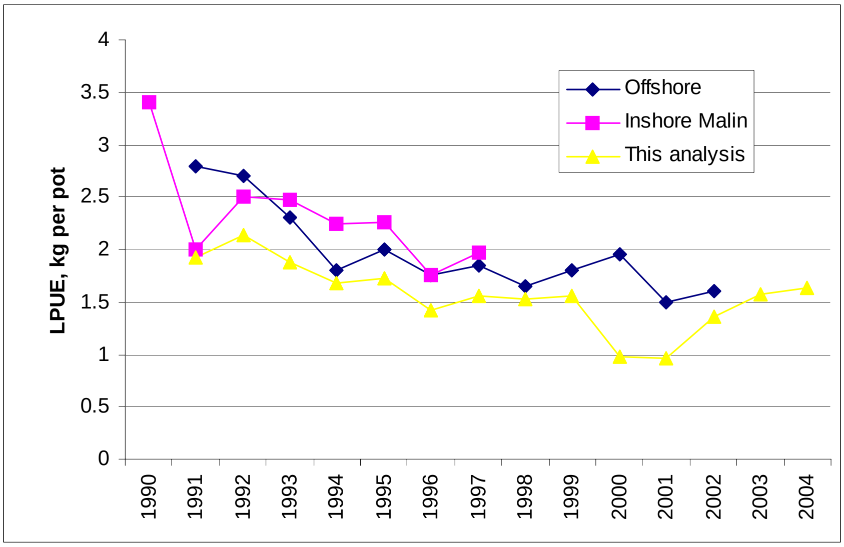


Figure 7: Three LPUE series for the Irish north west crab stock compared.

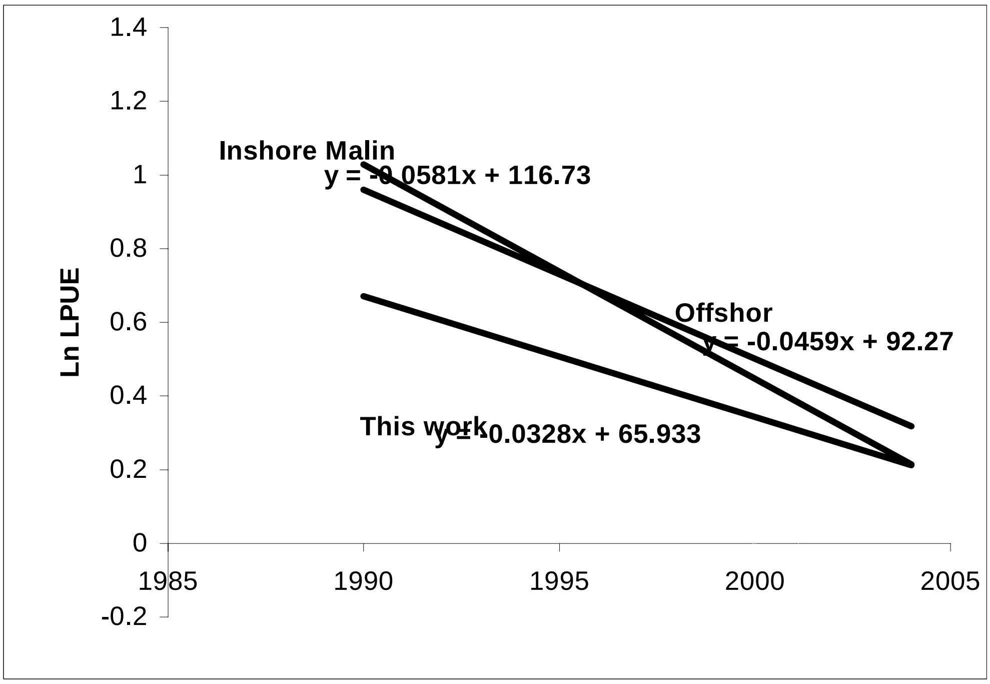


Figure 8: Logarithmic curves fitted to the three data series and extended over the period 1990 – 2004.

The percentage decline in LPUE from the four data series is summarised below. The offshore series compares most closely with our results when the decline is calculated from the full data series from 1980 to 2004.

	1990 - 2004 Inshore Malin	1990 - 2004 Offshore	1990 - 2004 This study	1980-2004 This study
LPUE in 1980	3.0	2.5	1.9	2.0
LPUE in 2004	1.3	1.3	1.2	1.1
% loss	57	48	37	45

The new data series presented here were relatively inexpensive to obtain and indicates a 50% decline in CPUE over a 15 year time series. A long time series of similar approximate data may provide a workable monitoring mechanism for crab for which many other methods of stock assessment are currently inappropriate.

References

Tully, O, R Cosgrove, Fergal Nolan, R McCormick, E Hannigan, G Breslin, C O'Donnell, A O'Donnell, G Gallagher (1998) MRM project reference number A14. Marine Institute. Development of computerised systems for visualisation and mapping of shellfisheries data: a case study using the Donegal crab fishery

2.1.3 *Cancer pagurus* offshore fishery in France (Daniel Latrouite)

Fifteen offshore potters, most of which are from the Morlaix district (Roscoff offshore potters), operated in 2003. Their fishing zones cover more than 25 different ICES statistical rectangles in divisions 7E 7F, 7G, 7H, 8A, 8B and 8D but 43% of their landings come from 8A, 34% from 7E and 11% from 7H. Catch rates are stable or increasing in all areas (Table 3, Figure 9).

Table 3: Mean annual LPUE by ICES division for Roscoff offshore potters, 1986-2003. LPUE is expressed in kg per pot and refer to May-November

year	7E	7H	8A	All area
1 986	1.42	1.26	1.45	1.42
1 987	1.40	1.30	1.44	1.46
1 988	1.38	1.26	1.84	1.45
1 989	1.20	1.15	1.54	1.27
1 990	1.38	1.43	1.41	1.44
1 991	1.30	1.29	1.49	1.41
1 992	1.28	1.23	1.86	1.42
1 993	1.29	1.32	1.83	1.47
1 994	1.29	1.51	1.89	1.44
1 995	1.53	1.38	1.69	1.54
1 996	1.53	1.41	2.07	1.65
1 997	1.23	1.22	1.80	1.52
1 998	1.57	1.52	1.87	1.64
1 999	1.39	1.48	1.73	1.59
2 000	1.37	1.23	1.61	1.50
2 001	1.36	1.27	1.67	1.52
2 002	1.30	1.39	1.66	1.49
2 003	1.60	1.38	1.76	1.64

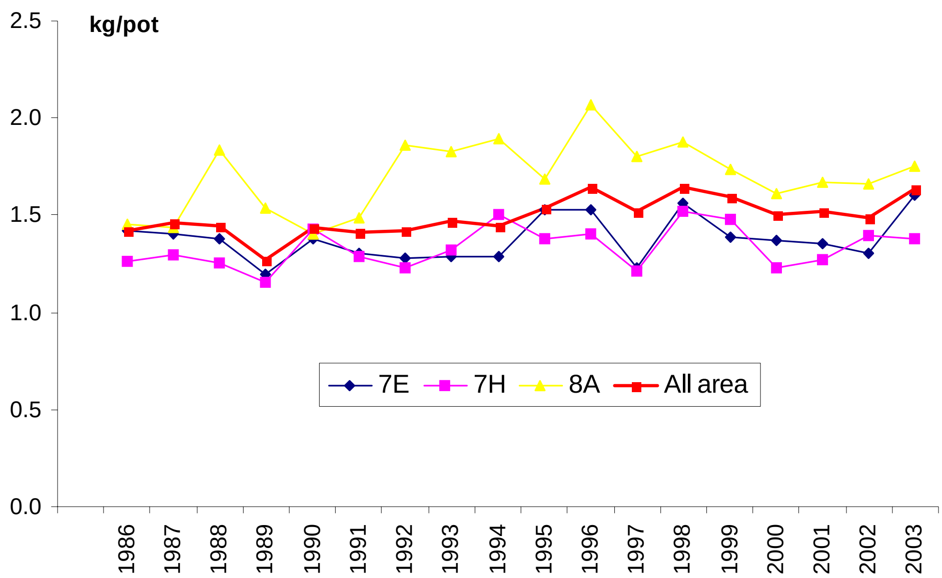


Figure 9: Catch rates of French offshore crabbers in 3 ICES sub-divisions from 1986-2003.

2.1.4 *Cancer pagurus* Ireland, ICES Area VI (Oliver Tully and Martin Robinson)

2.1.4.1 Landings

Landings of crab from Area VI into ports on the northwest coast of Ireland are collated annually by the Department of Communications and Natural Resources in Dublin, Ireland (DCMNR).

The crab fishery in Area VI is one of the largest and commercially important crab fisheries in Europe. Crab was one of the top 5 most valuable species landed into Ireland in 2001-2003. The stock is fished mainly by the Irish, Northern Irish and Scottish fleets.

Annual landings into Ireland, from the Area VI stock, increased annually from 1990 by an average of over 300 tonnes per annum. Landings from Area VI stabilised between 3-4000 tonnes between 1994 and 2000 but rose significantly to 6-7500 tonnes from 2001-2003 (Figure 10). The stock supports an Irish offshore fleet of 5 vessels fishing mainly outside of the national 12 nm limit. Two vivier vessels fish from northern Ireland and an unknown number fish from Scotland. Inshore over 300 Irish vessels off the north west coast currently access crab to some degree although approximately 50 inshore vessels and the 5 offshore vivier vessels account for perhaps 95% of Irish landings from this stock. The inshore fleet in some ports rely almost completely on crab. For instance the relatively small fleet of 17 inshore vessels at Malin Head land over 1000 tonnes of crab per annum.

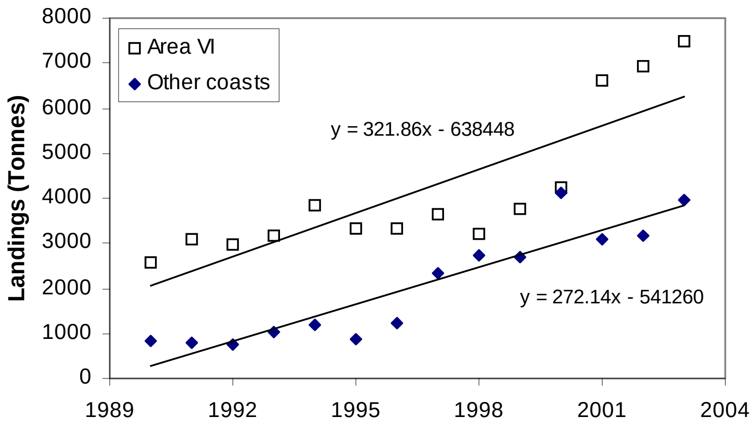


Figure 10: Annual landings (tonnes) of crab from Area VI and other areas into Irish ports

2.1.4.2 Monitoring of the fishery

Since 1990 The Irish Sea Fisheries Board (BIM) in collaboration with the Marine Institute (1990-1997) and Trinity College Dublin (TCD, 1990-2003) and the fleet has monitored the distribution of fishing and catch rates in the offshore fishery. The geographic position of the fishing gear, amount of gear at each position, the frequency of hauling the gear and the landings deriving from each unit of gear is recorded by the skippers and compiled annually to provide a catch index (Table 1). The quality of this catch and effort data is known to be very high. The data are recorded in private diaries by the skippers and are voluntarily given to BIM. The geographic position and catch data in fact need to be accurate as the diary record is the only hard copy of the actual position of the gear when fishing and is needed as a back up to the vessel's electronic plotter data. Similarly the accumulation of catch during the 5-7 day fishing trips has to be monitoring accurately and recorded in real time by the skipper as the capacity of the live holding tanks of the vessels is limited. Observer data in 1996-1997 and

2001 also verified that the data recorded by the skippers were accurate. 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 catch rates to be mapped and the behaviour of the fleet to be monitored. Changes in catch rate can therefore be associated with shifts in the geographic location of fishing. Efforts to maintain catch rate due to depletion of regularly fished grounds by expanding the area fished or shifting to previously unfished areas can be monitored. The fine spatial scale data also allows the impact of short but quite intensive periods of fishing in a given location to be approximately assessed using depletion methods.

Fishing activity and catch rate data, as described above, has been obtained from 3 of the 5 vessels over 15m (called index vessels below) fishing in Area VI annually between 1992-2003. In 1990 and 1991 only 1 and 2 vessels respectively over 15m fished the stock (Table 2). In 2003 an additional fourth vessel supplied data. This has just recently been compiled and is not included in Table 2. The data represents an average of 1225 fishing activity records per annum and in 2003 included almost 1 million trap hauls.

Table4: Annual fishery monitoring data for the Irish offshore fleet in Area VI. Index vessels are those who supply fishery data. The same 3 vessels have been used since 1992. In 1996 the position of each 'string' of traps was recorded rather than the average daily position hence the higher number of database records in that year.

YEAR	N (FISHING RECORDS)	NUMBER INDEX VESSELS	VESSELS FISHING	INDEX VESSELS	NUMBER OF INDEX POTS HAULED
1990	54	1	2	1	27000
1991	348	2	2	1,2	155,700
1992	637	3	3	1,2,3	214,700
1993	1181	3	4	1,2,3	471,614
1994	1338	3	4	1,2,3	664,520
1995	1432	3	4	1,2,3	666,288
1996	5013	3	4	1,2,3	586,668
1997	1215	3	4	1,2,3	665,740
1998	1416	3	4	1,2,3	840,025
1999	1121	3	4	1,2,3	629,175
2000	1275	3	4	1,2,3	703,470
2001	1213	3	5	1,2,3	928,375
2002	1155	3	5	1,2,3	951,750
2003	1183	3	5	1,2,3	984,200

Although the index is an accurate record of the quantify of crab landed per unit of effort a number of factors could introduce bias that would affect its relationship to the actual abundance of the stock. This could include

1) Vessel performance: Varying performance of a vessel over time due to crew or skipper effects. However, the same 3 vessel owners submitted catch rate data throughout the period although 2 of the 3 vessels were changed in 2001.
2) Returning of crabs live to sea: Generally a high percentage (10-50%) of legal sized crab are returned live to the sea and are not landed. This is largely due to subjective grading for quality or internal meat content. As grading is subjective the ability of the crew to grade successfully will affect rates of live return and therefore the amount of crab landed for each trap hauled. There is no evidence that there has been any trend in grading practices during recent years.

3) Hauling frequency: Changes in the frequency of hauling traps will affect the index as catch rate is related to the frequency at which gear is hauled at least for frequencies between 2 and 4 days.

The annual average landing per unit of effort (LPUE; kgs of crab landed for each trap hauled) declined between 1990-1994 as the offshore fishery developed (Table 5, Figure 11). This decline was an initial fishing down of the stock and the older age groups of crabs that had accumulated in the population. Crabs with old shells, as evidenced by the high prevalence of necrotic shell disease, were common in the stock at this time. From 1994-2000 LPUE was quite stable varying between a high of 1.93 in 1995 and a low of 1.64 in 1998. In the period 2001-2003 LPUE varied between 1.40 (2003) and 1.59 (2002). LPUE deviated negatively from the 1994-2003 average in 2001-2003 by between 7-18%.

Table 5: Annual catch index (LPUE), effort and landings by 3 index offshore vessels. Deviations indicate changes in catch (kgs and %) annually from the 1994-2003 average.

				Deviation 94-03				
Year	N	LPUE (mean)	LPUE (s.d.)	Kgs	%	Pots fished	Tonnes landed (Index vessels)	Area VI landings * Irish and NI into Irish ports
1990	54	2.82	1.43			27,000	76.2	2558
1991	348	2.82	1.26			155,700	417.3	3075
1992	637	2.66	1.38			214,700	567.8	2961
1993	1181	2.29	1.06			471,614	1066.6	3175
1994	1338	1.81	0.92	0.08	4.92	664,520	1161.7	3823
1995	1432	1.93	0.94	0.21	12.16	666,288	1267.8	3321
1996	5013	1.83	0.98	0.11	6.28	586,668	1061.6	3319
1997	1215	1.85	0.75	0.13	7.44	665,740	1179.0	3635
1998	1416	1.64	0.79	-0.08	-4.82	840,025	1358.0	3195
1999	1121	1.84	0.84	0.12	6.70	629,175	1163.8	3754
2000	1275	1.88	0.84	0.16	9.34	703,470	1306.5	4226
2001	1213	1.45	0.57	-0.27	-15.62	928,375	1315.3	6632
2002	1118	1.59	0.54	-0.13	-7.69	951,750	1515.0	6924
2003	1186	1.40	0.48	-0.32	-18.73	984,200	1399.0	7491

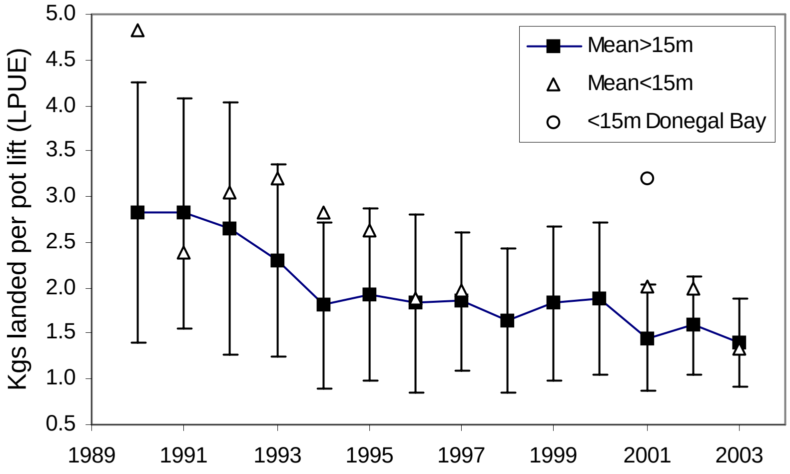


Figure 11: The annual index of abundance of crab in Area VI from 1990-2003. The index is in kgs of crab landed for each trap hauled for 3 index vessels and representing between 27000 (1990) and 984200 (2003) trap hauls. Catch rates from logbook and survey data for the Irish inshore fleet are also shown.

The relationships between annual effort and annual landings and annual catch rate are highly correlated (Figure 12). Production modelling is not possible at this time because the annual total effort (pot hauls) on the stock is not available and the trend in fishing effort has been in one direction only. It is difficult to estimate the parameters of the model therefore and any estimates derived from these data would probably be unreliable. There is a direct negative relationship between annual effort and annual LPUE. It seems possible therefore to forecast the implications of any changes in effort on catch rate.

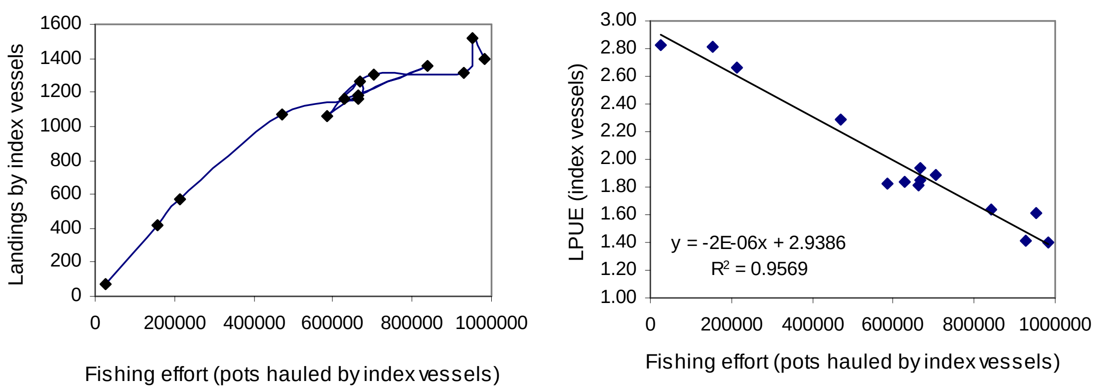


Figure 12: The relationship between catch, effort and catch rate by index vessels 1990-2003.

2.1.5 *Cancer pagurus* Scotland (Jim Kinnear)

The official landings of Brown crab into Scotland totalled just under 7,000 tonnes in 2004, down from a peak of 10,000 tonnes in 2000 (Figures 13 and 14, Table 6). Value in 2004 was £7 million. The decrease in landings is primarily due to decrease in effort. The inshore fleet often have problems in marketing their catch, resulting in changes of effort towards other target species and grounds (many inshore potters have switched to *Nephrops* fishing). Approximately 50% of the landings originate from "super crabbers" operating well offshore. These vessels are migratory in habit and shifts in ground and target species occur on a regular basis resulting in fluctuations in effort and landings.

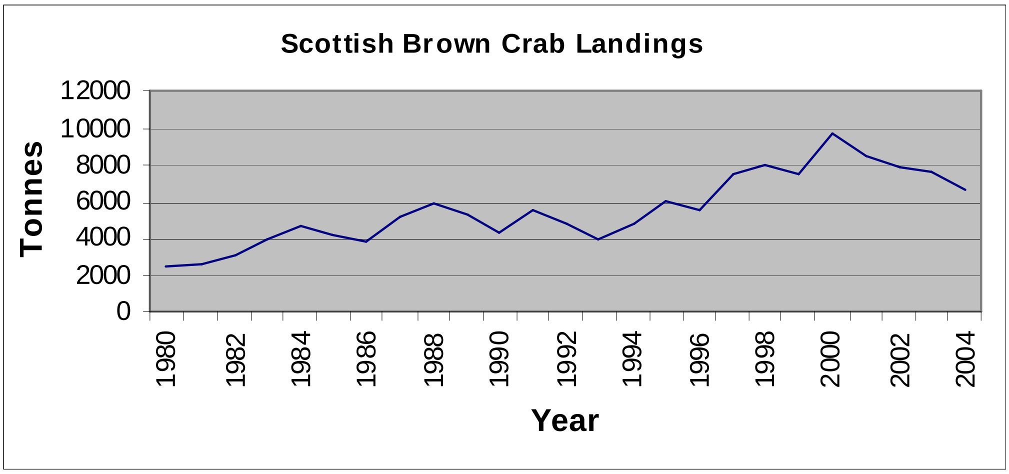


Figure 13: Landings of brown crab into Scotland.

Table 6: Landings by area and year of brown crab into Scotland.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Area	Weights in Tonnes														
South east	281	216	130	97	109	74	234	293	355	348	481	148	97	23	129
East	409	227	224	194	148	230	74	233	361	589	1098	855	475	427	369
North	142	199	25	16	0	48	291	189	136	136	713	615	494	793	318
Orkney	528	712	107	117	655	1279	1336	1667	2131	1766	1510	1539	1309	1362	1309
Shetland	392	348	214	221	311	481	538	588	396	470	583	416	317	217	33
Hebrides	1119	1539	1770	1543	1200	2263	731	2056	2322	2013	1841	1828	1538	1453	1312
Ullapool	302	284	92	116	166	135	235	70	98	268	134	146	176	233	194
South Minch	915	1452	1822	945	1410	1127	1471	1355	1120	566	978	1113	1093	1116	961
Mallaig	0	97	112	23	1	9	7	0	0	8	11	18	2	2	7
Clyde	7	18	23	33	102	23	4	44	84	28	155	87	10	57	21
SWsq							5	38	8	6	0	0	0	0	0
Papa Bank						6	42	25	39	241	511	215	99	445	289
Sule	87	372	171	311	303	273	418	731	805	736	1239	787	952	845	1170
Other	100	21	65	322	354	143	139	174	158	256	396	691	1312	552	525
All landings	**4282**	**5485**	**4755**	**3938**	**4759**	**6091**	**5525**	**7463**	**8013**	**7431**	**9650**	**8458**	**7874**	**7525**	**6637**

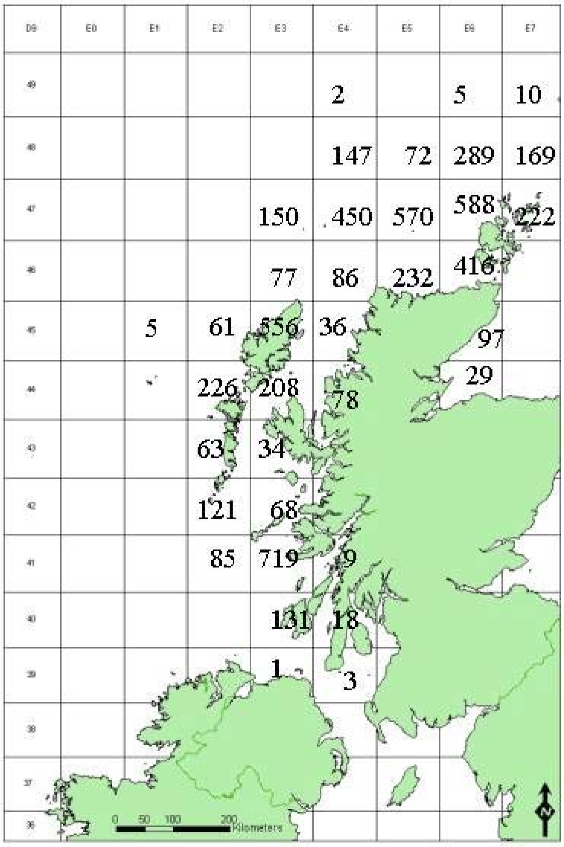


Figure 14: Landings of brown crab by statistical rectangle into Scotland in 2004.

2.1.6 *Cancer pagurus*, Shetland (Suzanne Henderson)

The Shetland Islands Regulated Fishery (Scotland) Order has been in operation since January 2000, and is managed by the Shetland Shellfish Management Organisation (SSMO). All fishermen fishing commercially for shellfish inside 6 miles around Shetland are required to hold a SSMO licence.

It is a prerequisite of the SSMO license that fishermen return their weekly log sheets to the SSMO every month. Logbook data provides information on catches and fishing effort by SSMO statistical squares (5 mile squares). Whilst the majority of licensed boats are handing in log sheets there are still a good number that are not (Figure 15). It is thought that most of those vessels not handing in log sheets are not actually fishing, although there are definitely some exceptions to this.

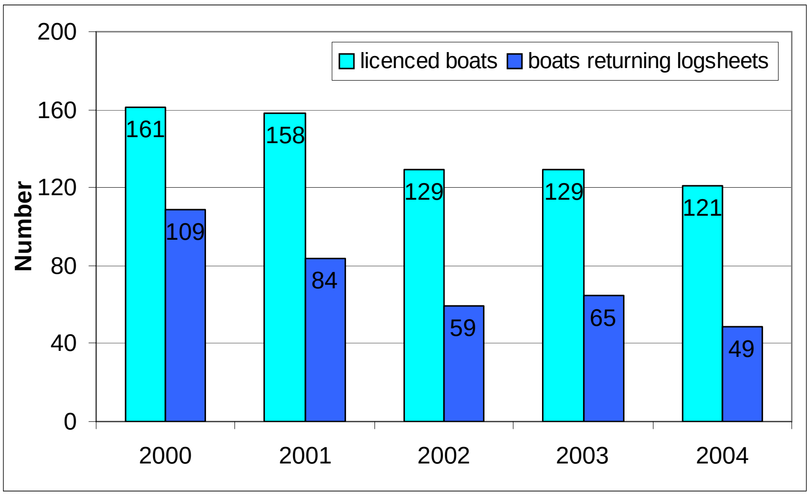


Figure 15: Vessels returning SSMO log sheets over past 5 years.

SSMO membership is made up of predominantly creel or pot licensed vessels, of which a maximum of 125 were licensed in 2001, but this number has reduced in recent years to 90 vessels (Figure 16).

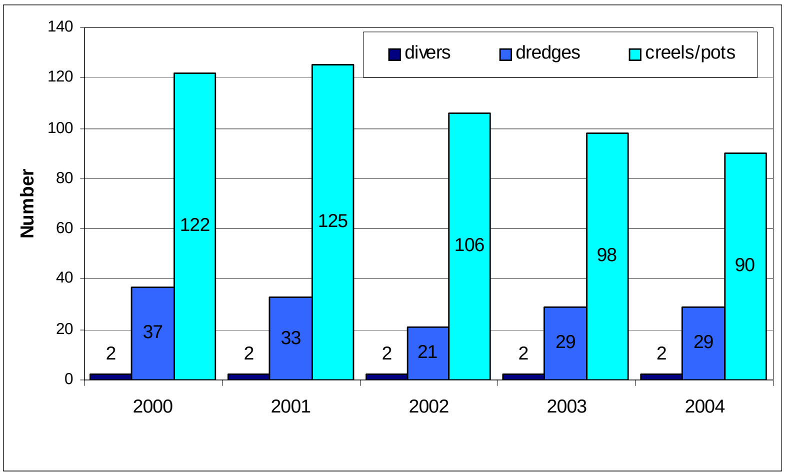


Figure 16: Total numbers of SSMO licensed vessels shown by their main gear used.

Landings of brown crabs in Shetland have decreased by over 100 tonnes in the last 5 years (Figure 17 - SSMO data). Prior to this landings steadily decreased from 1997 when nearly 600 tonnes were landed (Scottish statistics). All Shetland brown crabs are processed locally at one factory and the factory sells the processed crabs as cooked fresh and frozen whole or processed, or are canned for John West. It is possible that fishing effort is partially controlled by the amount of crabs that can be processed by the factory.

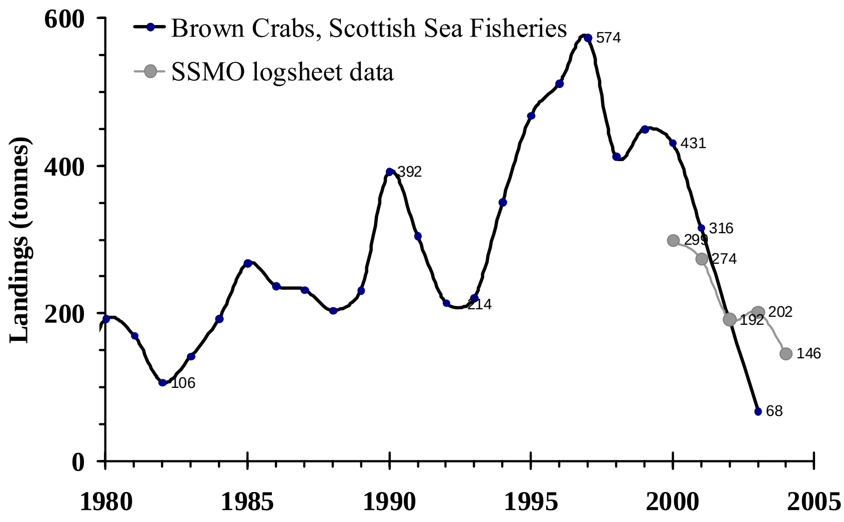


Figure 17: Annual landings of brown crab into Scotland between 1980 and 2004.

The landings and total numbers of creels catching brown crabs in Shetland have reduced by half since 2000 (Figure 18), although the average LPUE has not followed a similar trend - showing a relatively unchanged pattern over the last few years (around 0.7 to 0.8 kg of brown crabs per creel fished). This decline in effort and in landings may be linked to the market and processor's demands and tied in with the profitability of fishing.

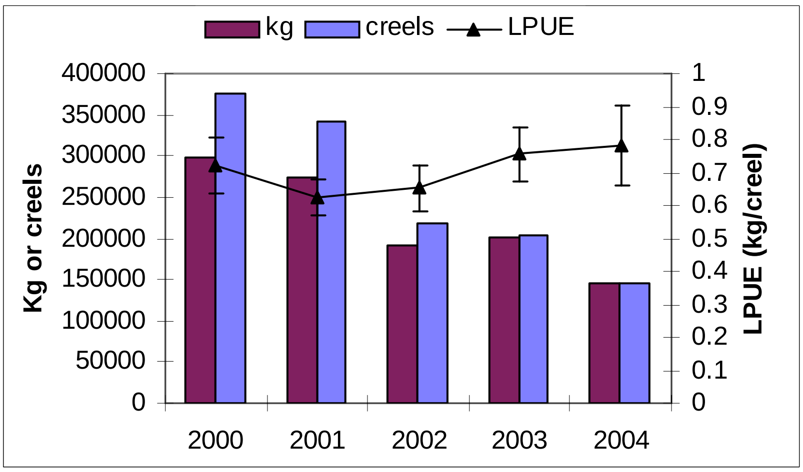


Figure 18: Total landings of brown crab, total creels catching brown crabs and the average LPUE from SSMO logbook data with the 95% confidence intervals shown.

2.1.7 Velvet crab (*Necora puber*) in Shetland (Suzanne Henderson)

The velvet crab fishery is a relatively recent fishery to Shetland and is becoming increasingly important to many inshore fishermen. In July 2001 the SSMO introduced a new 70mm carapace width minimum landing size (originally 65mm) and implemented a summer closed season (July and August) to protect crabs during their vulnerable moulting period. On the whole these changes have been welcomed by fishermen.

In recent years the landings of velvet crabs have fluctuated considerably; from 99 tonnes (the highest landings recorded) to half that value last year (Figure 19- SSMO data). The fluctuations in landings from the Scottish Sea Fisheries statistics and the SSMO logbook data show similar trends (except in 2003), although different absolute amounts.

The fishery in Shetland is very much dependant on the markets in Spain and at present relies on one local and one Spanish vivier operator who transport all Shetland velvet crabs live to Spain. Problems sometimes arise with landings outweighing the market demand (or vivier operators capacity), particularly in September, just after the seasonal reopening of the Shetland fishery.

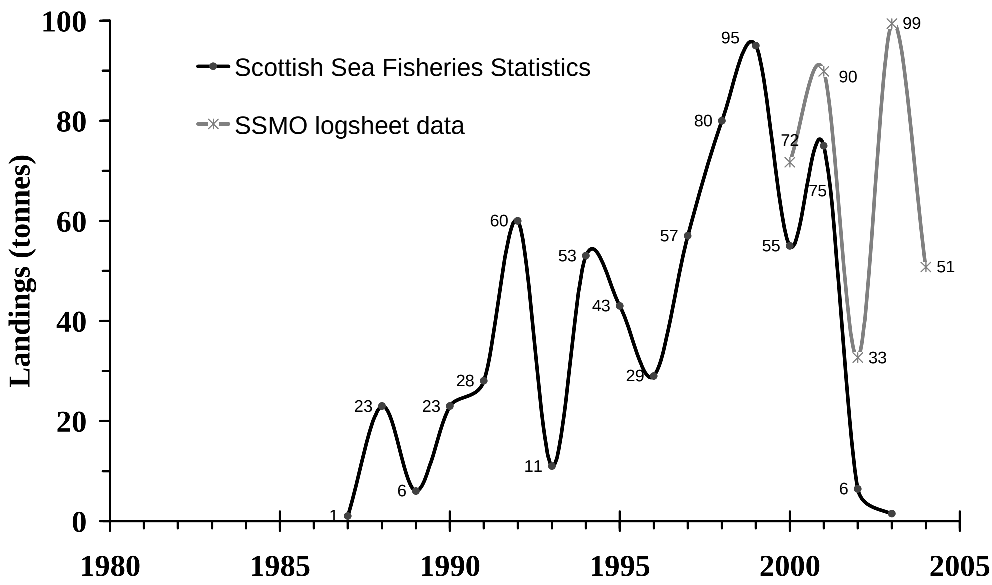


Figure 19: Landings of velvet crabs in Shetland from two different sources.

The landings of velvets and the total numbers of creels catching velvets have fluctuated over the last 5 years (Figure 20) with values halving between 2003 and 2004. The average LPUE has remained between 0.3 and 0.5 kg per creel, with evidence of a small peak in 2003.

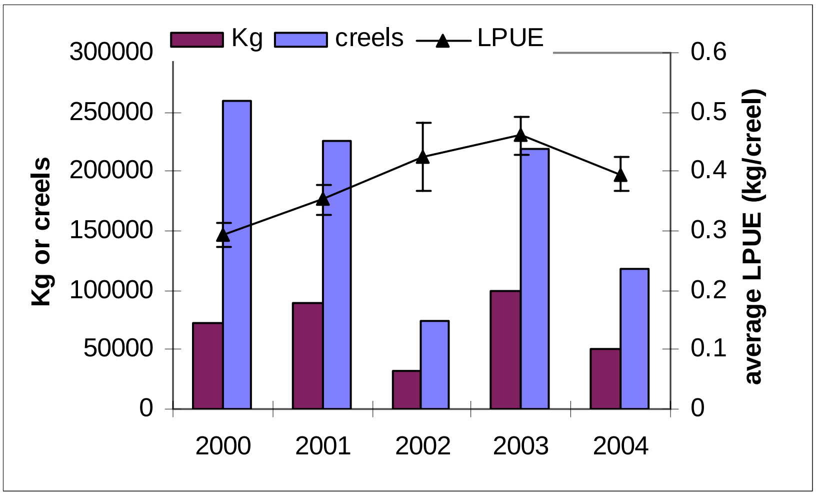


Figure 20: Total velvet crab landings, total creels catching velvet crabs and the average LPUE obtained from SSMO logbook data with 95% confidence intervals shown.

2.1.8 *Cancer pagurus*, Sweden (Annette Ungfors)

No dramatic change in landing, effort or market strategy has occurred in the Swedish Brown crab fishery in recent years but the positive spirit among crab fishermen still exists. In 2004 crab fishermen in Kattegat fishing area began to organise the delivering of crabs into a factory. This action may be an important push for the undeveloped fishery, increasing the possibilities for fishermen to deliver in prolonged periods and guarantee products to the contracted fishmongers.

Compared to the leading crab fishing nations in Europe Sweden is a developing country regarding this resource, which still is used by innovative, young or old fishermen. The official data of landing based on reports from first-hand dealers for the last 10 years, in 1994-2004, are given in Table 1. These original monthly reports are founded on 160 fishmonger's trade with Brown crab. Landings based on fishermen log-books and gears targeting for Brown crab or lobster are about thirty tonnes more than reported by fishmongers. Additionally around 40 tonnes are reported if all fisheries are included. In total Brown crab is captured in 19 different gears types (codes).

Table 7: Reported landings (tonnes) of Brown crab in 1994-2004 in Sweden by fishmongers and from log-book data. *All fishery, by-catches included. #Landings from crab and lobster pots, crab gillnets and crab fyke-nets (gear code 823, 821, 713 and 826 respectively).

(TONNES)	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Reports by Fishmongers	111	64	40	39	55	59	65	60	68	85	**98**
Log-book*all gear	161	105	71	76	94	89	127	133	147	160	**170**
Log-book #targeting	130	90	70	64	79	89	104	108	104	131	**134**

2.1.9 Collection and analysis of LPUE data in England and Wales (Julian Addison)

In England and Wales the fishery for edible crab (*Cancer pagurus*) is one of the most valuable. The largest fishery is in the English Channel with recorded landings of over 11 000 tonnes per annum, and there is also an important and expanding fishery in the North Sea. In all areas the fishery is targeted primarily at females in the autumn.

Data collected on landings and fishing effort for the whole crab fishery contains numerous uncertainties, primarily because much of the fishery is artesanal in nature with landings being made at very large numbers of ports or other landing areas such as beaches and may therefore go unreported, and because the collection of fisheries statistics in the past has rightly concentrated its effort on quota managed species. Landings by weight of the various species of crabs at all ports in England and Wales have been collected for many years, and although these officially recorded landings may not include all landings of crabs, the annual trends in reported landings are considered to provide an accurate reflection of the true trend in landings over time. However accurate data on the fishing effort that was expended to achieve these landings is not available, and thus it is not possible to provide an accurate index of landings per unit effort (LPUE) for the crab fisheries as a whole, or indeed for specific regions. This is frustrating for fisheries biologists and managers alike because trends in LPUE from commercial fisheries sources provide an important index of the status of crab fisheries and can be used in a range of stock assessment models. CEFAS has recently evaluated the LPUE data currently available primarily for the edible crab fishery in England and Wales, attaching particular emphasis on the accuracy of the recording of such data and on the spatial scale at which the data has been collected. Both these attributes of the data are critical to the utility of the data in stock assessment models.

Since January 2000, all vessels over 10 m in length have been obliged to complete EU log book returns on landings and effort for all species including *Cancer pagurus* and other crab species. Most of the fishing effort expended in the English Channel crab fishery is accounted for by over 10m vessels, so trends in this data set should mirror what is happening in the whole fishery. There is little trend in the levels of landings and effort for *Cancer pagurus* in the English Channel fishery over the period 2001-2004, but there appears to be a slight downward trend in both landings and effort targeted at spider crab in the English Channel fishery over the same period. CEFAS has also evaluated the data that has been collected through EU log books since 2000, and found that through comparisons with other sources of the same landings and effort data that the EU log book returns had significant inconsistencies particularly due to poor recording of data by fishers in terms of effort information and area fished and poor processing of data in the local port offices. The EU log book data were generally inaccurate for trips of more than one day for the larger Channel vessels because only one record per trip is required and recording of total effort for the multi-day trip was often highly inaccurate. For crab fisheries one record per day would be more appropriate to ensure that landings from very different grounds are not aggregated. Most importantly, however, recording fishing effort for crab vessels is not compulsory, which is a major flaw in the system. In conclusion, the EU log book scheme has the potential to provide accurate LPUE information for the largest vessels in all EU crab fisheries, but there are a number of issues which need to be resolved before the data can be considered to be accurate and reliable. CEFAS and the data collectors are currently working together to resolve these inaccuracies.

A more reliable source of accurate LPUE data is from fishers' personal log books. Since 1987 CEFAS has been running a scheme whereby selected individual fishers around the coast of England and Wales have made daily returns of landings, number of pot hauls and associated information. Approximately 40 individuals have returned log books and therefore trends in LPUE are available from this source for each important crab fishing region in England and Wales. Whilst these log books provide detailed information on LPUE for an individual vessel, further investigation suggests that care must be taken in extrapolating trends in LPUE from only a few log books because different vessels may target different crustacean species, and catch rates from a single day's fishing may aggregate catch rate data from a number of areas with differing population densities. Many of the Sea Fisheries Committees in England and Wales have had licensing schemes in place for potting vessels for many years with a condition being the return of daily catch and effort data. When combining data for all vessels in the fleet, it is possible to gain a broad brush understanding of the trends in LPUE for fisheries. Even then however, these aggregated trends in LPUE of the various crab species need to be interpreted with some care.

In the UK a shellfish licensing scheme was introduced for all vessels (including under 10 m vessels) in 2004 and as from 1st January 2006 all potting vessels will have to make returns of landings and effort, including fishing grounds. The over 10 m component of the fleet will simply have to complete their EU log books for crustacean species, and the less than 10 m component will have to complete paper log sheet returns of their daily landings and effort. This will provide a census of total effort, which is essential if there is a requirement within a management regime to control or reduce fishing effort. Undoubtedly from 2006 onwards, the collection of LPUE data from EU log books and paper records for the less than 10m component of the fleet should provide accurate data on LPUE for all the crab fleet. However the problem of how to aggregate this data remains. For example in the English Channel fishery, we are beginning to understand more fully the relationship between the inshore and offshore fishing grounds and between fishing grounds in the eastern and western English Channel, but we still need to consider various scenarios in crab stock structure before we can confidently aggregate LPUE data from all the individual vessels to obtain a robust index of the status of the whole Channel fishery.

2.1.10 *Cancer pagurus* landings in England and Wales (Julian Addison)

Landings of *Cancer pagurus* into England and Wales have increased by an average of approximately 400 tonnes per annum since the early 1980s. This trend, ignoring the provisional figures for 2004, is continuing (Table. 8). The majority of the landings originate from ICES sub-areas IVB and IVC (North Sea) and VIID and VIIE (English Channel).

Landings of *Necora puber* increased to over 300 tonnes in 2003.

Landings of *Maja* have declined from a peak of over 2100 tonnes in 1995 to just over 1000 tonnes in 2003. The majority of these landings are from the English Channel.

Table 8: Landings of *Cancer pagurus* into England and Wales between 1980 and 2004. Data for 2004 are provisional.

Year	104A	104B	104C	105B	106A	106B	107A	107B	107C	107D	107E	107F	107G	107H	107J	107K	108A	108B	Total
1980		106	65				0.9			24	419	14	2.7	0.0					631
1981		78	41				1.1			31	417	52	3.8	0.0	0.1		0.0	0.0	624
1982		889	585				31.4			335	3074	206	42.0	0.9	0.5				5163
1983		842	966				17.5			854	3714	493	0.1	0.2					6886
1984		469	553				1.8			963	4621	190	0.1	0.2	0.1				6798
1985		304	54				10.9			786	4557	353	104.5		0.2				6170
1986		1032	507				0.2			747	4194	359	186.6	0.2					7027
1987		923	1332				1.8			597	3514	924	0.9	0.8					7294
1988		644	873				0.7			433	3793	1062	9.2	0.7	0.1				6816
1989		627	567				199.8			338	3427	818	185.8	0.1					6163
1990		1953	1152		0.0		219.4			926	4047	806	178.3	0.1					9282
1991		1839	1325				209.6			751	4084	400	183.6	0.2					8793
1992		2208	617		4.3		146.5			1392	3562	295	318.4	2.7					8546
1993	0.0	978	747		1.0		0.4	3.9		1220	3032	644	0.1	2.4	0.8			9.7	6640
1994	0.2	872	1397				0.1			1797	4024	484	0.0	0.4					8576
1995	0.1	918	1495				66.7			1948	4941	397	70.6	0.5					9837
1996	0.4	1234	1440		0.7		5.9			1283	4761	326	1.3	1.8					9055
1997	1.2	1448	1263		0.9		100.0	0.6		1457	5868	367	322.0	1.4	0.1				10830
1998		1754	1295		223.1		82.2	3.6	0.4	1324	9778	557	367.2	4.7	2.0				15391
1999	16.2	1994	1292		0.3	3.3	76.8		0.2	1121	6485	700	159.4	1.9					11850
2000	12.7	3317	1406		3.4	47.1	106.6	0.4		793	4957	680	111.7	7.3	2.9	0.0		0.0	11444
2001	7.4	3428	1676		188.1	21.2	118.7	1.3	0.1	749	4859	881	143.5	30.9	11.0				12115
2002		2983	1804		4.0	116.8	214.2	0.5	0.1	876	4784	502	244.3	59.3	3.4	0.0			11592
2003	0.2	3805	1523	3.0	3.5	23.8	132.8	0.3		822	5568	543	127.4	13.7	2.2				12568
2004	1.5	3392	1180		1.5	8.7	152.8	1.1	0.1	693	4040	670	100.8	12.6	3.0		21.4		10278
Total	40	38037	25157	3	431	221	1899	12	1	22261	106519	12725	2864	143	26	0	21	10	

Table 9: Landings of *Necora puber* into England and Wales from 1980 and 2004. Data for 2004 are provisional

Year	104B	104C	107A	107D	107E	107F	107G	Total
1980					0.32			0.3
1981					0.83			0.8
1982				0.01	3.49			3.5
1983				0.53	6.83			7.4
1984				1.07	5.91			7.0
1985				0.64	2.25			2.9
1986					4.37			4.4
1987					0.89	0.41		1.3
1988			0.55		9.29	1.04		10.9
1989		0.14		0.02	13.90	0.58		14.6
1990		0.13		0.73	17.77			18.6
1991				3.98	15.03	3.44	2.73	25.2
1992	0.97	0.06	0.19	21.30	45.39	1.26		69.2
1993	1.67	0.06	0.76	31.20	26.21	2.54	21.49	83.9
1994	39.81		11.93	24.73	43.18	2.14	2.51	124.3
1995	4.55	0.89	5.24	19.94	50.96	1.29	1.95	84.8
1996	8.45	0.08	3.44	1.37	42.97	2.24	0.03	58.6
1997	8.38		5.97	0.42	23.19	5.35	13.03	56.3
1998	2.09		1.61	0.43	16.51	1.08	12.44	34.2
1999	12.86		5.45	5.44	1.74	2.82	6.19	34.5
2000	48.72	0.95	15.75	11.96	2.44	2.46	5.54	87.8
2001	93.43	0.06	4.70	12.23	6.59	2.00	5.43	124.4
2002	146.06	0.12	2.78	14.86	1.62	1.08	3.67	170.2
2003	303.74	0.43	3.00	3.25	1.56	0.88	4.01	316.9
2004	348.64	33.20	0.37	3.30	0.28	0.11	0.50	386.4
	1019	36	62	157	343	31	80	

Table 10: Landings of *Maja brachydactyla* into England and Wales between 1980 and 2004. Data for 2004 are provisional.

Year	104A	104B	104C	107A	107D	107E	107F	107G	107H	Grand Total
1980					4.9	72.1	4.1	0.2		81
1981					6.9	49.5	28.6	0.2		85
1982		0.1	0.040	0.13	6.3	93.2	168.2	1.9		270
1983					183.4	198.5	171.7	1.2		555
1984		1.3		0.13	428.8	404.4	345.0	2.5		1182
1985		1.7	0.318	0.05	349.3	364.0	521.0	4.3		1241
1986		4.2			109.4	213.5	579.2	7.3		914
1987		7.8			32.7	196.1	568.4			805
1988		17.0		0.01	6.1	151.3	277.5			452
1989	0.007	34.8			3.2	97.2	208.4			344
1990		35.0		0.55	33.9	184.9	53.6	14.3		322
1991		26.4		1.03	52.3	388.2	141.5	67.1		677
1992		11.6		6.46	189.1	403.2	266.4	117.4	0.41	995
1993		35.6			166.2	247.8	309.1	50.7		809
1994		30.0	0.016	1.12	589.5	520.6	205.8	6.7	0.04	1354
1995	0.043	24.2	0.003	0.44	1237.1	741.5	186.7	7.5		2197
1996		12.2	0.103	13.34	575.5	625.6	240.4	3.1	0.04	1470
1997		0.3	0.004	28.37	645.2	765.8	253.7	124.5		1818
1998		2.0		28.69	536.3	912.6	292.3	218.0	0.02	1990
1999		0.9		34.83	184.1	621.8	372.9	134.7	0.01	1349
2000		0.6	0.002	94.30	144.0	327.6	308.9	129.9	0.01	1005
2001		2.8	0.246	101.42	137.6	345.5	436.9	161.3	0.36	1186
2002		1.2	0.109	142.02	131.8	418.1	239.9	233.8	3.08	1170
2003		26.1	0.026	119.63	181.4	318.3	229.2	144.5	4.02	1023
2004		9.9		10.05	103.6	257.8	182.0	53.3	0.04	617
Total	0.05	285.67	0.87	582.55	6038.64	8919.44	6591.21	1484.46	8.02	

2.2 ToR B): Review methods for the acquisition, standardisation, analysis and interpretation of CPUE, size frequency and research survey data in order to assess the suitability of such data for monitoring and assessment of crab stocks

2.2.1 *Cancer pagurus* Norway (Astrid Woll)

Large spatial variations in catch rates and catch composition were documented for the reference fleet described in ToR (A). From 2000 throughout 2003 each fisher collected samples from 10 weeks of the season, 4 daily reports each week. Relatively large quantities of data were collected in order to allow for detailed description and possible simplification of sampling strategy later on. To determine a suitable sampling strategy for biological parameters size distribution was used as an indicator. A three-stage variance analysis following Helle and Pennington (2004) was used. In the analysis different variance components were included to describe the precision in the estimate of mean length. These were number of fishermen, number of sampling weeks and number of crabs measured per week. The largest source of variability was, by far, the boat component (Table 1).

Table 1: Contribution of each variance component to the total variance for the data sampled during 10 weeks in 2003 in Midt-Norge, Helgeland, Vesterålen and Rogaland. In brackets: the numbers of crab fishing boats and weeks in the season for the particular region.

	Sampling scheme				Sources of variance			Grand mean	
	Boats	Weeks	Crabs measured week^{-1}	No.of crabs measured	Boat comp.	Day comp.	Within comp.	Variance	S.E.
Midt-Norge	13 (201)	10 (18)	123	15976	63.520	0.101	0.0003	63.621	7.976
Helgeland	5 (50)	10 (15)	109	5426	81.507	0.066	0.0004	81.573	9.032
Vesterålen	3 (6)	10 (12)	34	1030	3.271	0.017	0.0018	3.290	1.814
Rogaland	4 (50)	10 (30)	115	4595	118.015	0.464	0.0008	118.479	10.885

To identify the preferred sampling scheme, different number of crabs measured, weeks reported and boats selected were selected as shown for Midt-Norge (Figure 1). The effects of reducing the number of sampling weeks or the number of crabs measured was small compared to changes in the number of boats. A logbook system used for about 5 weeks during the high season of September and October, by a reference fleet in “target areas” representative for that region, was found to be sufficient to give a reliable size distribution as shown in Figure 1. However, the large between boat variance means that if changes are needed, as adding or removing a boat in the reference fleet, a detailed knowledge of the fishing strategy and fishing ground of the particular boat is needed.

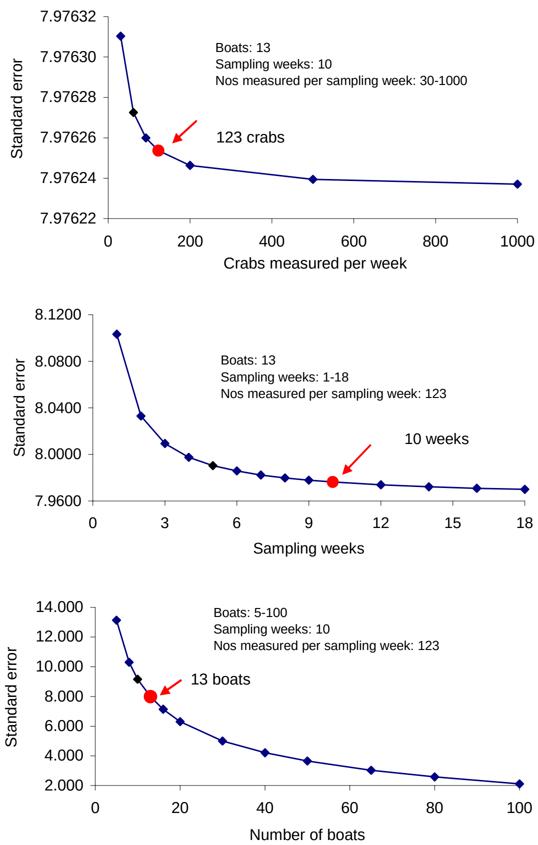


Figure 1: Precision of the estimate of mean carapace width of *Cancer pagurus* as a function of the number of crabs measured per week (a), the number of reporting weeks per boat (b), and the number of boats in the reference fleet (c). The arrows denote the precision of the 2003 data from Midt-Norge.

Due to the marked within region variation in catch composition it is important that the selected reference fleet is representative for the fishery in the region. In Rogaland most of the data was collected from exposed or medium exposed grounds around Kvitsøy. Observations from the 1920's showed that crabs from Kvitsøy were smaller and more dominated by male than the crab population in the fjords near by. This indicates that the data sampled from Rogaland might not reflect the whole crab population in the Rogaland region.

For Midt-Norge and for Helgeland the reference fleet was more spread in different exposure grounds. In 2004 it was possible to compare the portion of female of the total landings of crabs as Norges Råfisklag, the Fish sale organization from 63°N and northwards, for the first time started to report the landings separated in male and females. The portion of females for Helgeland was 72.1% which was in good correspondence to the portion of landable females in the logbook program (72.6%). Midt-Norge is divided in several zones. For Nord-Trøndelag the portion of females was 74.1% and 82.2% for Råfisklaget and the logbook program respectively, and for Sør-Trøndelag 53.2% and 59.8%.

The logbook program does not work very well in order to calculate the effort in the fishery and the overall catch rates. About 400 vessels participate in the professional Norwegian crab fishery and ideally all of them should have participated in order to get accurate data. Catch rates (LPUE) estimated from each landing is less labour-demanding than using the method with trial traps and a reference fleet. The landings are already been recorded by the fish sales organisations and the only extra information will be to add the record of the numbers of trap hauls. By relating such data more fishers could participate and provide data on a finer scale, as the extra work for each fisher would becomes much less than a detailed logbook. A logbook system based on a reference fleet and a collection of LPUE and effort data from all or as many as possible of the fishers is a good place to start to monitor the fishery. This is also indicated by several authors to be better than traditional resource surveys that reflect only limited areas and time periods.

Reference

Helle, K. and Pennington, M., 2004. Survey design considerations for estimating the length composition of the commercial catch of some deep-water species in the northeast Atlantic. Fisheries Research, 70: 55-60.

2.2.2 *Cancer pagurus* Shetland (Suzanne Henderson)

Logbook data was used to investigate the trends in landings, fishing effort, and LPUE. The total number of creels that caught crabs represents the total number of creels that logbook data recorded catches of crabs, regardless of whether they were targeting the species or if recordings were by-catch. An average LPUE was calculated for each fishing vessel for each month, from which an annual average was calculated to give an indication of the trends in LPUE.

The monthly LPUE from each SSMO statistical square were calculated for each vessel and examined statistically in relation to long term trends, seasonality, area fished and the fishing vessel. Data were examined with a generalised additive model (GAM); a flexible non-parametric approach to exploratory data analysis used to investigate non-linear relationships between data. Model selection was undertaken by stepwise removal of terms that did not significantly improve the fit of the model following a likelihood ratio test within an ANOVA; an approach appropriate to a nested analytical design. Data were weighted with √fishing effort to limit the effect of catch rates associated with small amounts of effort on the final model. To remove the influence of large standard errors on the residual plots, vessels and areas that had three or less data entries over the five year period were omitted from the analysis.

All the explanatory variables tested within the GAM framework added significantly to the model (overall $p < 0.0005$). Variation in LPUE from the logbook data during the period 2000-2004 could be explained by the following minimal model:

$$\text{LPUE} \sim \text{lo(YearNo)} + \text{(MonthNo)} + \text{(AreaFished)} + \text{(VesselCode)}$$

where (YearNo) = monthly time series from January 2000 to December 2004; (MonthNo) = the month of the year that fishing took place; (AreaFished) = the statistical rectangle fished; and (VesselCode) = the fishing vessel. lo before the term (YearNo) indicates that a LO(W)ESS[1] smoother was applied and retained in the final model.

Statistical analysis of long term trends show that LPUE has been fairly steady from 2000 to 2004, with a gentle but steady increase throughout this time, suggesting there is no cause for concern for the fishery at present. A point to note however is that length cohort stock assessments indicate that brown crab stocks in Shetland are close to their maximum sustainable yield. Seasonal effects indicate that LPUE is fairly constant throughout the year,

1 LO(W)ESS - locally weighted running line smoother; a form of non-linear regression.

with the lowest values in December and January, perhaps indicating less fishing due to bad weather or crab behaviour at this time. There are quite marked spatial differences in brown crab LPUE around Shetland with higher LPUE in the south west mainland and in the waters around Foula - this may indicate different stocks or a reflection of individual vessel variations. There were large between vessel variations which add to the model, but which have not been explored further.

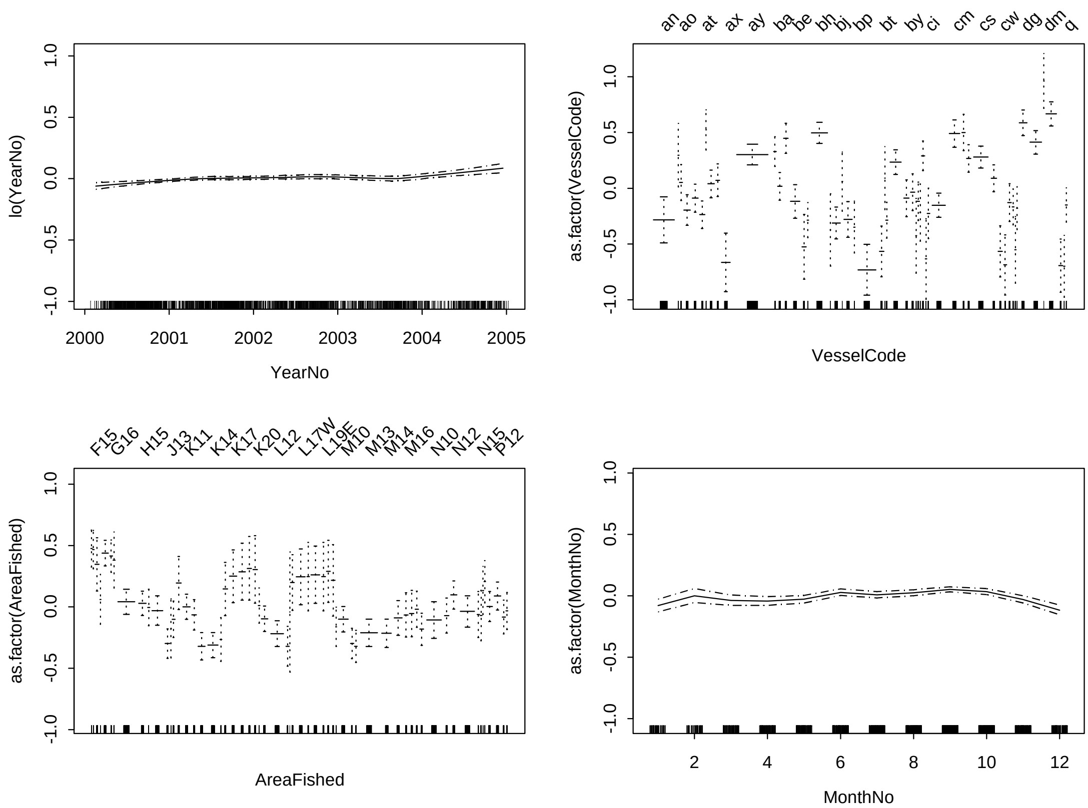


Figure 2: Brown crab diagnostic GAM plots of the fitted curve (continuous line) and factors included in the minimal model. Data are: YearNo - monthly time series from Jan 2000-Dec 2004; MonthNo - month of fishing regardless of year, months are represented by numbers commencing with 1 ~ January; AreaFished - SSMO statistical rectangle; VesselCode - fishing vessel. The rug plot at the base of each figure indicates the location of each of the data points fitted for the variable, and the broken lines indicate standard errors.

2.2.3 Velvet crab (*Necora puber*) Shetland (Suzanne Henderson)

Statistical analysis shows that LPUE has been fairly steady over the five year period, with a slight rise in 2002 to 2003 and an indication of a decline in late 2004, however these patterns are not marked and do not give rise for concern (Figure). However again, length cohort stock assessments indicate stocks are operating very close to their maximum yield. Seasonal effects indicate that LPUE tends to be lower during February - July (note that the data include landings in 2000 and 2001, before the closed period during the summer months was implemented in this fishery). Area effects, as designated by SSMO statistical squares, indicate that LPUE is higher in the coastal waters around the south west mainland and lower in the waters in the northern isles. Vessel effects are marked with large between vessel differences - however details of these differences have not been examined further.

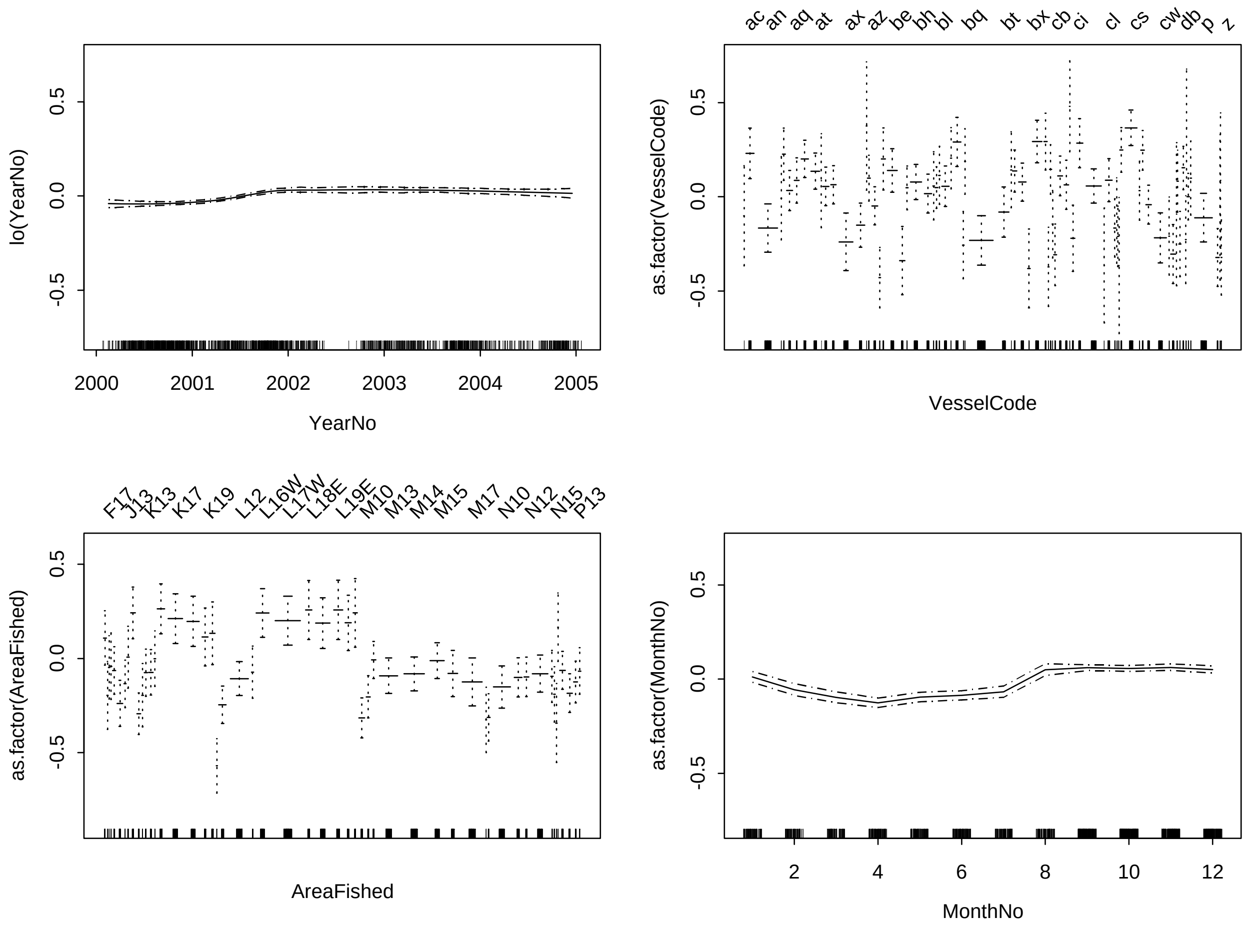
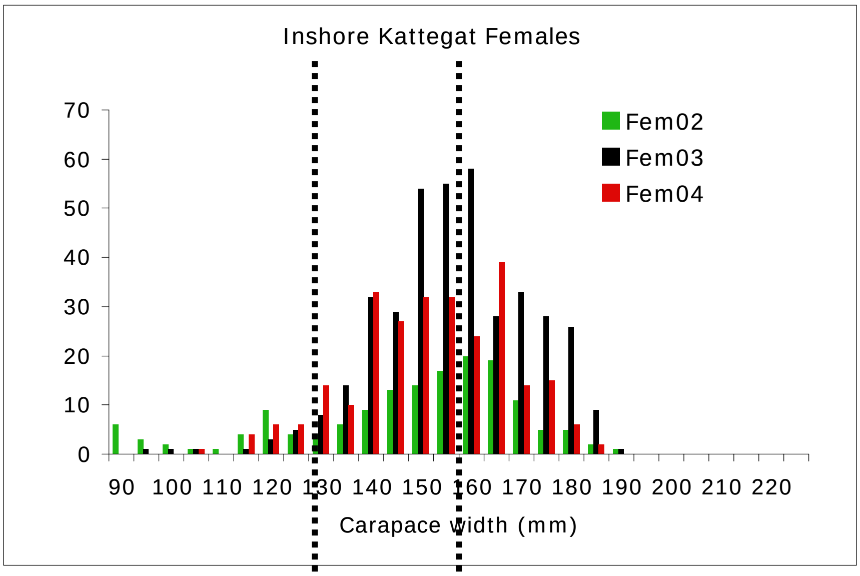


Figure 3: Velvet crab diagnostic GAM plots of the fitted curve (continuous line) and factors included in the minimal model. Data are: YearNo. - monthly time series from Jan 2000-Dec 2004; monthNo - month of fishing regardless of year, months are represented by numbers commencing with 1 ~ January; AreaFished - SSMO statistical rectangle; VesselCode - fishing vessel. The rug plot at the base of each figure indicates the location of each of the data points fitted for the variable, and the broken lines indicate standard errors.

2.2.4 Effect of pot type on catch rates *Cancer pagurus*, Sweden (Annette Ungfors)

Three standard pots, or research pots, are used by a couple of Swedish fishermen in addition to their commercial pots of own design. The main difference between the two kinds of pots is the lack of escapement gaps in the research pots. A circular escapement gap of 75 mm diameter is obligatory in pots and fyke-nets in the Swedish crab fishery. Comparative capture data from Kattegat exists for the years 2002-2004. The impact of escapement gaps on the capture is larger inshore than offshore Kattegat (fishing bank Groves flak). Almost no female crabs less than 130 mm are captured in commercial pots with escapement gaps inshore compared to a higher proportion in standard pots without gaps (Figure 4). On the other hand, size frequency offshore does not differ between the two pot types (Figure 5). The same capture pattern holds true for males. The difference in size frequency between the pot types is statistically analysed with $\chi 2$-test comparing proportion of the capture divided into three size classes: <130 mm, 130-160 mm and > 160 mm. The $\chi 2$-test show significant differences inshore between size classes for both females and males. However, offshore $\chi 2$-tests for both sexes show insignificant differences in size classes between the pot types.

a)



b)

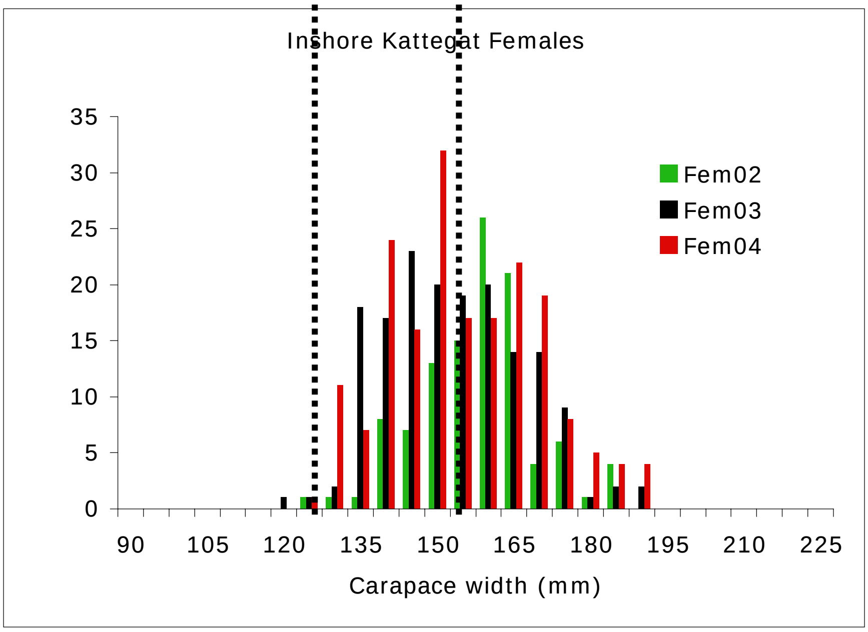


Figure 4: Size frequency of female Brown crab captures Inshore Kattegat. a) Standard/Research pots without escapement gaps of 75 mm Ø, b) Commercial pots with escapement gaps. The dotted lines divide the size frequency into three groups: <130 mm CW, 130-160 mm CW and >160 mm.

a)

b)

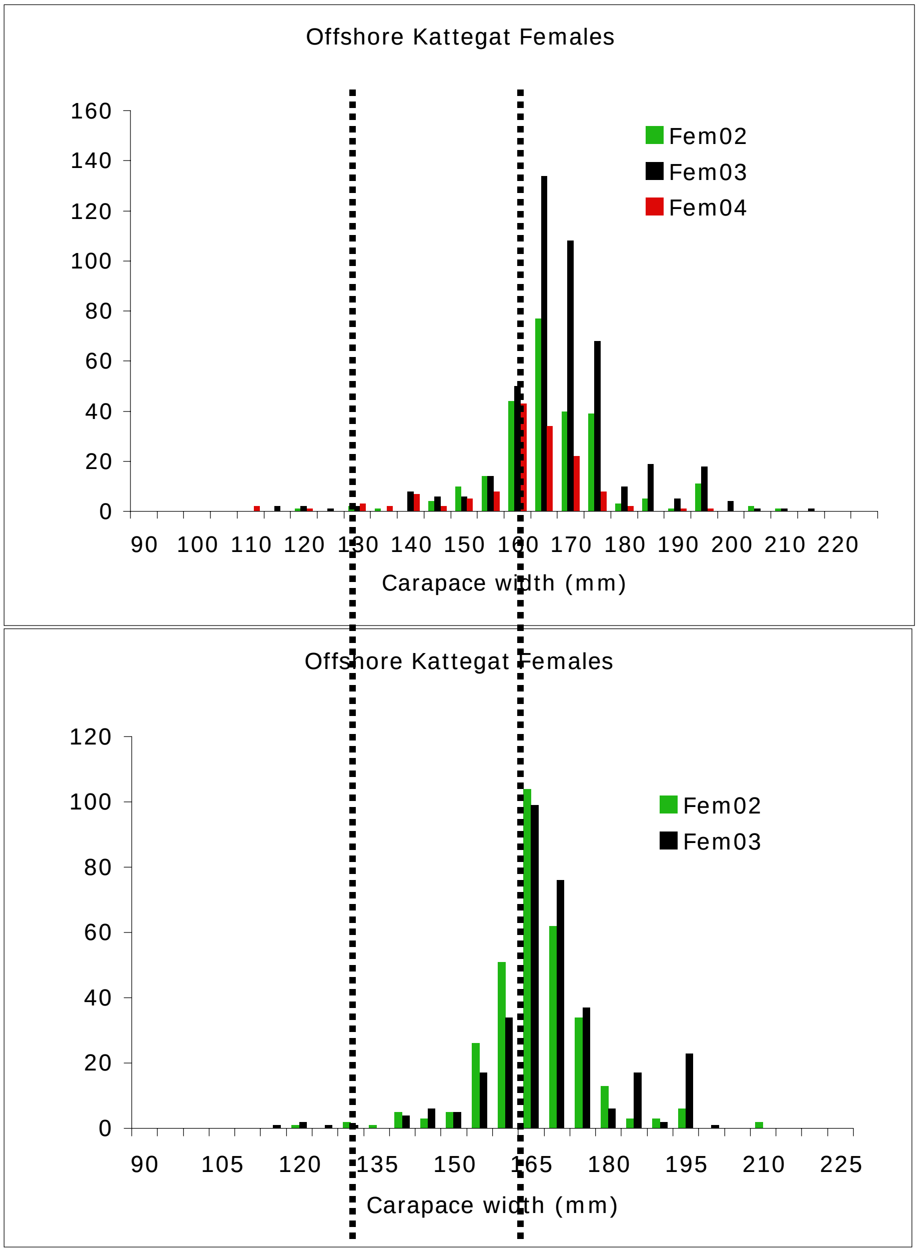


Figure 5: Size frequency of female Brown crab captures Offshore Kattegat. a) Standard/Research pots without escapement gaps of 75 mm Ø, b) Commercial pots with escapement gaps. The dotted lines divide the size frequency into three groups: <130 mm CW, 130-160 mm CW and >160 mm.

The fact that small-sized crabs are captured in lower numbers offshore in pots without escape gaps probably indicates larger average size of crabs in deeper water. Offshore fishing grounds seem to be inhabited by adults whereas pubescent or crabs which have recently matured are present on a higher degree in inshore areas. Females dominate the captures (not shown in figures), even more offshore and during late autumn which indicate that offshore areas may be important as spawning areas. In conclusion, these data show the advantage of escape gaps in areas where small crabs are present. The fishermen do not need to handle small-sized crabs and the stress to and any mortality associated with capture is minimised.

2.2.5 *Cancer pagurus*, northwest Ireland: General Linear Modelling of catch rate data from the offshore fleet (Mike Bell, Oliver Tully, Martin Robinson)

2.2.5.1 Data specification

The data is specified above under ToR A) of this report.

The data consist of 18,652 records, covering the period July 1990 to December 2003 for three vessels. Data are not available for all months in all years for all three vessels. Records are given for 28 ICES statistical rectangles (Figure 6). The most northerly records are close to the Outer Hebrides (North Uist), but the greatest concentration is close to the north-west coast of Ireland.

2.2.5.2 Analysis

Differences between years and vessels in the spatial and temporal coverage of log-book records, and the likely effects of soak time on CPUE, mean that it would be hazardous to interpret the data in terms of stock trends without first accounting for known sources of variation. Generalized linear modelling (GLM) was used for the dual purposes of: (i) describing patterns of variation in CPUE in relation to time-of-year, location, vessel, soak time, etc.; and (ii) deriving standardized CPUE indices which isolate the components of variation due to long-term, seasonal or spatial trends.

Trap soak times are likely to be very important in determining realised CPUE, but there is unlikely to be a linear relationship between CPUE and soak time at the scale of days, i.e. trap-days is probably not a good measure of fishing effort. Recorded soak times 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 (Figure 7). Average soak times varied two-fold between years (Figure 8). 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 CPUE has an asymptotic relationship with soak time, whereas CPUE potentially could decline over longer soak times owing to escapement and cannibalism. The relationship was modelled as:

$$\ln(\text{CPUE}) = \alpha - \beta \frac{1}{\text{soak time}} , \qquad \text{(Equation. 1)}$$

where α is the value of ln(CPUE) after infinite soak time (effectively an asymptote) and β 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.

After removing records for soak times >10 days and records with missing or unfeasible fields (>10 crabs per pot, out of range locations, etc.), a total of 18,130 observations was available for analysis. Catch locations were simplified to ICES statistical rectangles; dates were simplified to months, after adjustment to the mid-points of the soak times. CPUE 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, rectangle and vessel were included as factors (categorical effects) in the models, and 1/soak time was included as a continuous variable.

Initial analyses considered each month separately, with additive effects of year, vessel, rectangle and soak time. Comparison of annual trends (year factor effects) between months was used to explore whether calendar year or some other 12 month period (e.g. July-June) was the best definition of the annual time step in the long-term variation in CPUE. No clear distinction was observed between different groupings of months, but calendar year appeared to give marginally the most consistent definition of annual variation and so this was retained as the basis for further analysis. The final analysis 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.

2.2.5.3 Results of analysis

The GLM model accounted for 66.8% of the variation in the full data set. All model effects were statistically significant (P<0.001). This result may give a slightly misleading impression of the amount of 'pattern' in the data set, since the very large number of observations allowed statistically significant distinction of relatively minor features. This is demonstrated by the fact that even if seasonal changes in distribution and rate of trap entry were ignored (i.e. interaction effects were removed from the model), 64.6% of the variation was still explained.

The spatial distribution of CPUE does not suggest any clear seasonal patterns of crab population movement across the fishing grounds.

The GLM estimates show CPUE to have fallen by half over 1990-2003, with most of the decline occurring over the first five years of this period (Figure 9). Average CPUE values calculated from the unadjusted data (all vessels, soak times, months and rectangles), show a virtually identical pattern (Figure 9), demonstrating that at the spatial scale of the fishery differences in the spatial and seasonal coverage of records have not introduced a significant bias in the estimated trend over years. There appear to be no strong seasonal patterns of CPUE, although there is a slight tendency for higher values in late summer to early winter in the more easterly rectangles (40-41E2) compared with higher values earlier in the year in the westerly rectangles (39-40E0). Again, trends in the unadjusted data averages compare well with the GLM estimates although the match is not as strong as for the annual indices.

Despite the statistical significance of vessel effects in the GLM model, estimated CPUE index values were very similar between the three vessels providing records. This indicates that measured trends at the largest spatial and temporal scales are unlikely to be biased by selection of vessels, but this would not necessarily apply to any new vessel (or skipper) adding records to the data set.

The GLM results demonstrate the clearly non-linear relationship of CPUE with soak time (Figure 10). For the example given, CPUE after 2 days is only 44% higher than that after 1 day, and after 10 days is still only 92% higher. Clearly, it is vital to account for soak time in any comparison between individual catch rates, although the match between GLM estimates and unadjusted data demonstrates that this effect may be averaged out in larger data aggregations. The slope of the soak time effect (β in Eqation 1) varied almost three-fold between months (Figure 11), as would be expected if the rate of trap entry was 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 β is potentially useful as an index of stock abundance. Addition of a year × soak time term to the GLM is statistically significant (P<0.001), but only improves the amount of variation to 66.9% (compared with 66.8% for the original model). The trend of β over years (Figure 12) does not resemble that of CPUE although if 1990 and 1992 are excluded there is the same suggestion of overall decline. Trap saturation effects may have been more important in the period 1990-1994 as the fishery developed.

2.2.5.4 Conclusions

A strong pattern of decline in CPUE is evident in the crab fishery to the north-west of Ireland over the years 1990-2003, with most of the decline occurring before the mid-1990s. Analysis by GLM shows that this pattern is robust to changes between years in the seasonal and spatial coverage of records. Strong seasonal and spatial patterns in CPUE were not apparent, either because the fishery was not affected by spatio-temporal patterns of crab availability, or because the distribution of fishing effort responded very effectively to these patterns. Even if the latter was true, GLM analysis should, to a certain extent, have been able to reveal the underlying patterns. However, if fishing occurred only at times and locations when catch rates were above a given minimum value, then even the most rigorous statistical methods would fail to detect the true abundance signal.

The responsiveness of fishing activity to the availability of crabs is a particular concern if commercial CPUE data are to be used for stock monitoring. If fishing effort only occurs at times and locations of relatively high crab availability, then CPUE may be only weakly sensitive to trends in stock abundance. The relationship between CPUE and abundance is in any case likely to be non-linear for a trap fishery, particularly because of trap saturation effects. Market factors are another possible source of variation to bear in mind when interpreting commercial CPUE trends.

Despite the apparent robustness of the data averages to variations in vessels, soak times and the spatial and temporal coverage of the fishery, it is recommended that GLM or similar approaches be used to describe trends in CPUE. This is because it cannot be guaranteed that important sources of variation, such as soak time, will always be averaged out. This is particularly the case for smaller scale comparisons. Gradual ‘creep’ in fishery practices could potentially cause serious biases in estimated trends if the underlying sources of variation are not accounted for. The use of statistical approaches is also advocated because it allows rigorous consideration of statistical uncertainty, which may be important for the purposes of stock assessment.

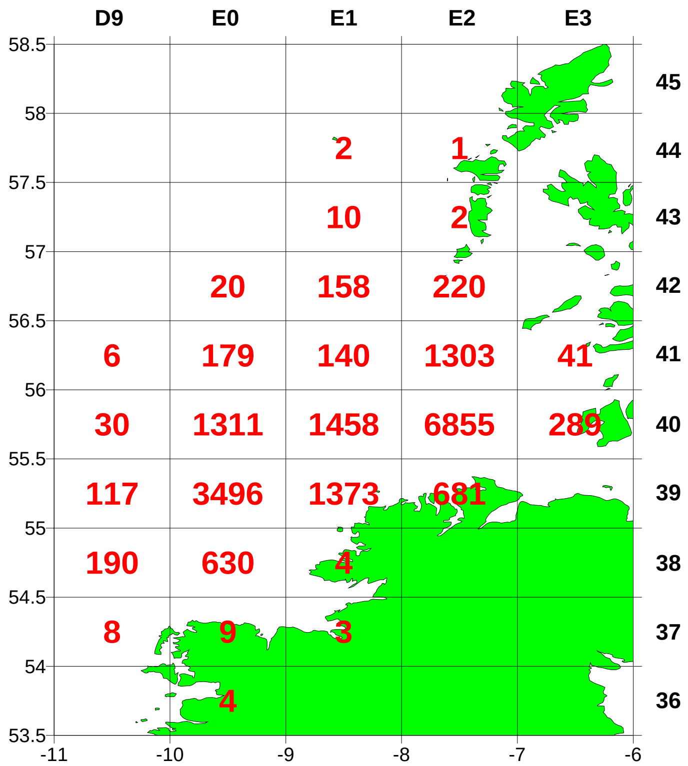


Figure 6: Numbers of crab log-book records, 1990-2003, by ICES statistical rectangles.

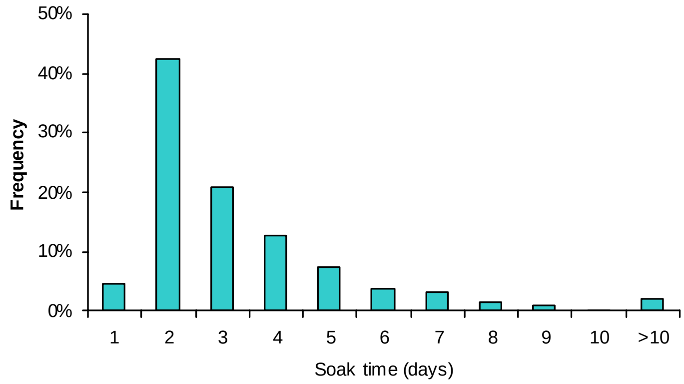


Figure 7: Distribution of recorded soak times.

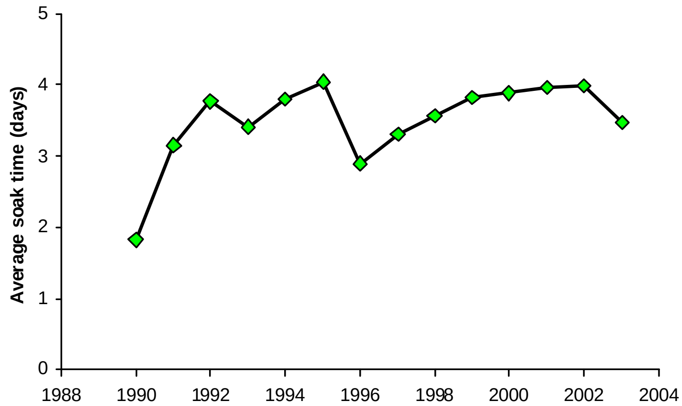


Figure 8: Average soak time in each year.

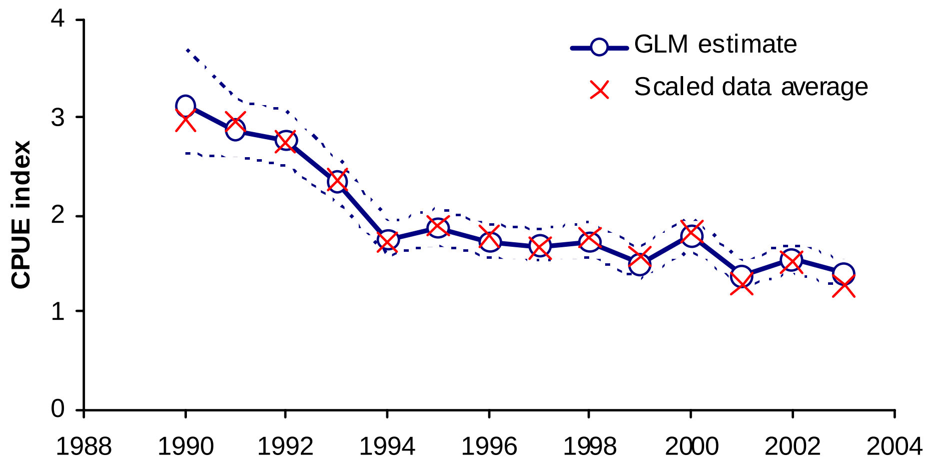


Figure 9: Monthly CPUE patterns, scaled to 2-day soak time, Vessel X, 2003 for selected ICES rectangles. GLM estimates (± 95% C.I.) are shown together with unadjusted data averages, scaled to the same mean and standard deviation.

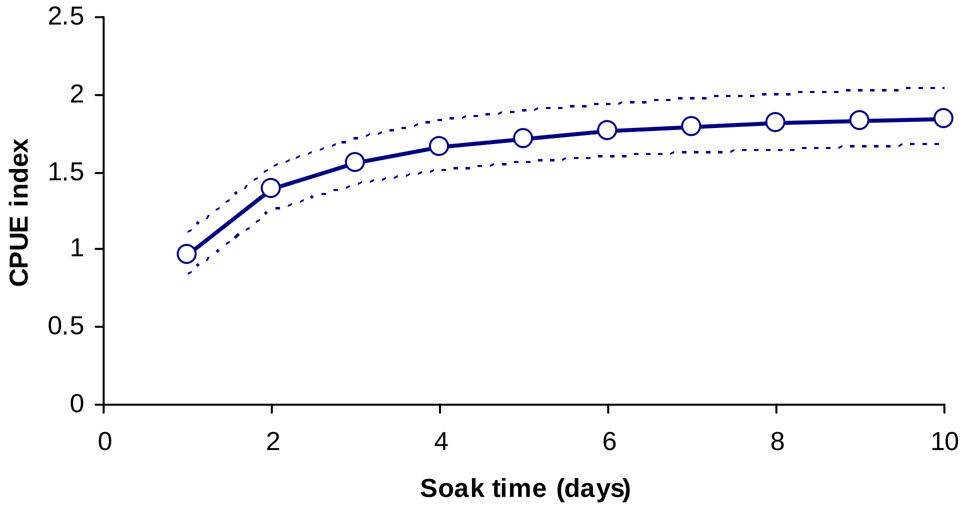


Figure 10: Effects of soak time on CPUE, scaled to Vessel X, January, 2003 in ICES rectangle 39E0, estimated by GLM (± 95% C.I.).

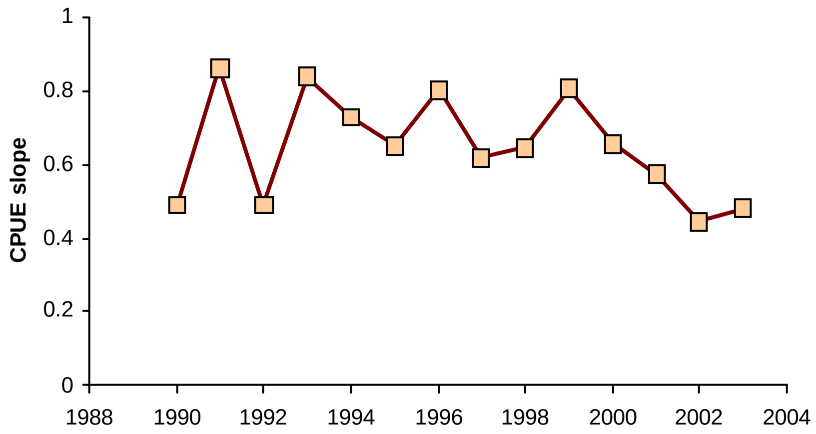


Figure 11: Slope of soak time effect (β in Eqation 1) in each month estimated by GLM (± 95% C.I.).

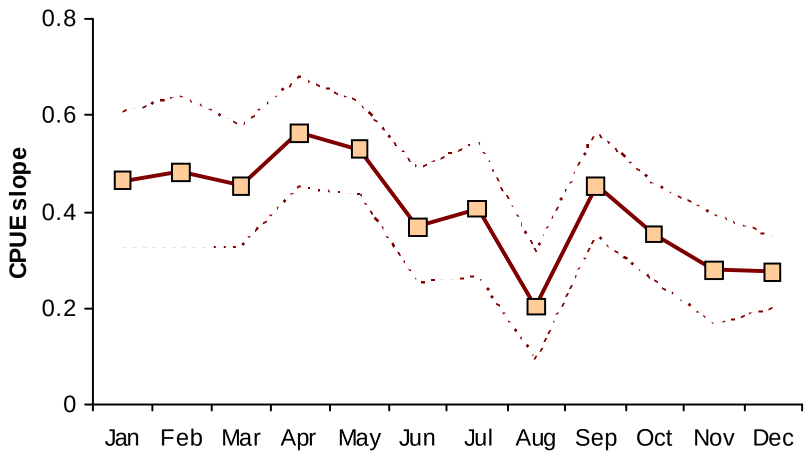


Figure 12: Slope of soak time effect (β in Eqation 1) in each year estimated by GLM.

2.2.6 Assessment and modelling of *Cancer pagurus* in the English Channel (Mike Smith, CEFAS Lowestoft)

A complex model is being developed to try and take account of seasonal aspects of the biology and fishery of edible crabs in the English Channel. Ovigerous females are rarely caught in the pot fishery and there is also some evidence that moulting female crabs may also become less available to the fishery. Since males may often guard a succession of soft females during the moulting and mating processes, it seems likely that they also may be less catchable at this time. Three seasons were therefore defined to account for these variations in catchability; late summer - autumn, winter - early spring and late spring - early summer.

The model is length structured with growth occurring instantaneously between the early and late summer seasons and modelled probabilistically by moult frequency and moult increment. Moult frequency is modelled on the log scale as a linear function of weight, which was found to fit better than carapace width (Bennettt, 1974) and has some biological basis for males, which greatly increase their relative claw size after maturity. Logistic curves have been used (Zheng *et al*., 1995; 1998), but they have the disadvantage that they do not accommodate more than one moult per year. Moult increment was modelled either as proportion of premoult width with normally distributed errors (Bennett, 1974) or as absolute increments with gamma distributed errors (Zheng *et al*., 1995; 1998). Within the range of the data, both moult increment models fit very well, but their behaviour differs at extreme large and small sizes. The growth parameters are externally estimated and supplied to the model.

Recruitment is modelled using a Beverton & Holt (1957) stock recruitment relationship, with a 4 year lag and recruits are distributed across a range of size classes according to a gamma distribution. These parameters are fitted as part of the model minimisation.

Fishing mortality is separable with a constant selection pattern modelled using two logistic curves (Sparre *et al*., 1989) and close to unity for most of the exploited size range, but declining at the minimum landing size and extreme large sizes. Parameters for this were set arbitrarily and supplied to the model. F multipliers are applied by season and are fitted during minimisation. Natural mortality was constant by length but different by sex. It was set externally to the model and considered to act as two components, one occurring instantaneously during moulting, and the other applying continuously and equally distributed between seasons.

A time series of observed catch at length data was aggregated on a seasonal basis and the model fitted to this assuming using least squares minimisation of log residuals. Currently convergence is poor and there appears to be parameter confounding, resulting in different solutions with similar convergence criteria. However the results from the model highlighted an interesting change in the seasonal pattern of landings during the 1990s, a period of high landings. At the moment it is not clear if this is genuine or an artefact caused by the reporting system.

The model appears to provide a useful tool for investigating the dynamics of crab stocks and the potential effects of management measures on crab stocks, and may also in time become a valuable assessment tool if improvements to the fitting can be made.

Further work is required to investigate whether extra data (e.g. on fishing effort) can be included to improve model fitting. Consideration needs to be given to ways of reducing the number of parameters to be fitted and also whether others can also be included in the model minimisation. Initially however it will be important to investigate the catch data thoroughly to ensure that the best possible seasonal length distributions are utilised.

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Zheng, J., Kruse, G.H., Murphy, M.C., 1998. A length based approach to estimate population abundance of Tanner crab, *Chionocetes bairdi*, in Bristol Bay, Alaska. In: Jamieson, G.S., Campbell, A. (Eds.), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Can. Spec. Publ. Fish. Aquat. Sci. 125, 97-105.

2.3 ToR C): define stock structure / management units for crab stocks

2.3.1 Stock structure of Brown crab according to the genetic tool AFLP

The genetic stock structure of brown crab along the Swedish west coast (Kattegat and Skagerrak) was investigated by the Amplified Fragment Length Polymorphs (AFLP) (Vos *et al*., 1995). Genetic variation among three locations Strömstad, Lysekil, Groves flak was investigated. In addition, AFLP was performed on individuals from a location on the West coast of Norway (N 62°40 E06°39) and from the English Channel W France (N 48°45 W 04°30) for stock structure analysis of a wider geographic area 64 individuals per location were used for analysis. The geographic distance between the samples from Norway and France is 1600 km, between the Norwegian sample and the middle sample in Sweden is 550 km, the largest distance among the Swedish samples is 200 km with only 75 km between Strömstad and Lysekil.

About 80 alleles were found for the two used primer pairs (three combinations). Preliminary results show statistical difference (AMOVA in GenA1Ex) between the French, Norwegian and Swedish samples. The population along the Swedish coast seem to be structured. The middle sample from Sweden (Lysekil) is statistical different from the northern Swedish sample. The genetic variation between samples within Sweden is not as large as between countries but still significant. Further genetic analyses are necessary for a reliable conclusion to be drawn.

2.3.2 *C. pagurus* larvae in the English Channel and eastern Celtic Sea; distributions, timing and possible implications for stock structure (Derek Eaton)

A series of crab larvae surveys undertaken by CEFAS in the English Channel and eastern Celtic Sea area since 1981 (Table 1) have been re-examined to produce a coherent summary of the spawning distribution of *C. pagurus* in the area, the hatching dynamics and subsequent distribution of the larvae. These are then considered in the light of the hydrography of the area and hypotheses offered concerning the stock structure of *C. pagurus*.

2.3.2.1 Timing of hatching and distribution of larvae

The incidence of different zoeae stages in the samples shows that hatching starts in the extreme southwest, in North Biscay and around the western Brittany peninsula, as early as March. But the main hatch in the Western Approaches occurs in late April or May and moves progressively north and east throughout the western Channel and Celtic Sea. By June the total numbers of all larvae have fallen in the western areas and late stage larvae outnumber the earlier stages. At this time however the main hatch occurs in the eastern Channel. The development of *C. pagurus* eggs and larvae is temperature-dependent, with a minimum critical level around 8-9°C. The progress of hatching closely follows the pattern of seabed warming above this critical level.

Table 1: CEFAS *C. pagurus* larvae surveys in the English Channel and Eastern Celtic Sea area.

YEAR	SAMPLING DATES	SURVEY AREA	STNS
1981	31 Mar - 14 Apr	English Channel to 4°W	99
	29 Apr - 12 May	English Channel to 4°W	98
	9 - 26 June	English Channel to 4°W	39
1989	19 - 25 May	Bristol Channel, 50°-51°45′N	88
	21 May - 10 June	Bristol Channel, 50°-51°45′N	65
	8 June - 3 July	English Channel and N Biscay	319
	4 July	E. Channel & Hastings Shingle Bank	17
1990	15 - 22 Feb	Bristol Channel & NW English Channel	67
	9 - 13 Mar	Bristol Channel & NW English Channel	81
	1 -6 Apr	Bristol Channel & NW English Channel	84
	17 - 23 Apr	Bristol Channel & NW English Channel	84
	23 - 24 Apr	W. English Channel	24
	25 - 26 Apr	NE. English Channel	33
	18 - 23 May	Bristol Channel & NW English Channel	84
	24 - 25 May	Western English Channel	22
	23 - 29 June	Bristol Channel & NW English Channel	84
	29 Jun - 2 Jul	Western English Channel	21
	20 - 22 July	Western English Channel	32
1991	20 - 27 Mar	Eastern Channel + Thames	68
	12 - 19 Apr	Eastern Channel + Thames	69
	16 - 25 May	Eastern Channel + Thames	84
	31 May - 7 June	English Channel + Thames	88
1992	27-Jun	Eastern Channel	20
	14 - 15 July	Western Channel	28
2002	1 - 12 May	NE Celtic Sea and W English Channel	111
2003	5 - 18 May	English Channel	163

The surveys have consistently identified two main spawning areas, as indicated by the main concentrations of the newly hatched zoeae I. These are the mid-western Channel centred around 49°30′N, 4°W and extending towards the south Devon coast, and off the north Cornwall coast between the Isles of Scilly and Lundy Island (approximately between 50° and 51°N and 5° and 7°W). Limited coverage in other areas indicates the presence of significant spawning in the Western Brittany/North Biscay area and zoeae I aggregations was also noted on the Nymphe Bank in the north-east Celtic Sea. In the eastern Channel dense aggregations of early stage zoeae have only been observed on one occasion, in the Dover Straits. Other surveys in the area at the same time of year have only found moderate levels of zoeae, mainly east of the Greenwich meridian. The central Channel area north of the Cotentin peninsula appears to be an area of relatively low production compared with the rest of the Channel, a feature also noted for other species with planktonic eggs or larvae; (e.g. *Pecten maximus*, *Sprattus sprattus* and *Sardina pilchardus*).

Comparisons of the distributions of zoeae I and later stage zoeae during the course of surveys show very little dispersal of the later stage larvae away from the main spawning grounds in the western Channel. There are indications that there is some northward drift of larvae from the western Brittany peninsula and north Cornwall coasts, with later stages being seen in the Western Approaches around 49°N and in the Bristol Channel, north of 51°N towards the Welsh coast.

The situation in the eastern Channel remains unclear. The only survey to find *C. pagurus* larvae in any numbers was in June 1989 when the larvae had an easterly distribution, mainly in the Dover Straits. Whether the much localised, dense aggregations of early stage zoeae (I – III) were the result of localised production or aggregation through physical means is not known. In 2003 a small patch of zoeae I was also found in this area but at much lower densities, extending in a narrow ribbon through the Straits into the Southern Bight of the North Sea with the highest density at the north-eastern end. This survey was in mid-May however and was probably too early to sample the main hatching period.

2.3.2.2 Hydrography of the area

The long-term residual transport patterns in the Channel have been modelled by Salomon et al (1993) and in the north-east Celtic Sea by Young et al (2004). These show a flow (the Ushant Front) emanating from north Biscay that divides into two arms in the Western Approaches. One arm passes north around the Cornish peninsula and circulates in a cyclonic manner across the entrance to the Irish Sea and then southwest along the Irish coast. A weak gyre is seen in the area of the Nymphe Bank and off the north Cornwall coast. The other arm of the Ushant Front passes up the English Channel and into the southern North Sea. Under average annual conditions the velocity of the residual tidal transport is very low in the western Channel (<1cm sec^{-1}). Stronger flows are seen around headlands and peninsulas and along the north Brittany coast. In the eastern Channel the flows are also stronger and are at their maximum in the Dover Straits. There are permanent gyres around the Channel Isles and the Isles of Scilly.

The water column is generally well-mixed in the eastern Channel but a thermocline does become established in western areas which lead to the formation of cyclonic, baroclinic flows in both the western Channel and northeast Celtic Sea during the summer months.

2.3.2.3 Implications of the hydrography for larvae distributions

The weak residual transport in the western Channel equates to a movement of approx. 1km/day. With a planktonic phase of approx. 40 days, larvae from the western Channel spawning grounds would not be transported far enough to provide significant recruitment to the eastern Channel. In the eastern Channel larvae are transported more rapidly eastwards & potentially lost through the Dover Straits, but limited survey coverage in the Southern Bight of the North Sea has not found *C. pagurus* larvae other than as isolated occurrences. The very small *C. pagurus* fishery in the area suggests that there is not a large population present and the strong tides and mobile bottom sediments in the area would make it an unsuitable habitat for *C. pagurus*. Few larvae are found in the central Channel which can be interpreted either as a lack of production or the result of stronger tidal regimes in this area transporting larvae rapidly to the east. However, if this were so then higher concentrations of larvae than are seen would be expected further to the east. The stronger residual flows emanating from Biscay and moving north could transport larvae from Brittany towards the main mid-western Channel spawning areas. Survey results have shown patches of late stage larvae in this area whilst earlier stages have a more easterly distribution.

Larvae would tend to be retained within strong gyres systems such as around the Channel Isles and the Isles of Scilly. Depending upon the time of formation, the baroclinic frontal features could significantly affect the retention and distribution of any larvae in the area, having strong flows along the fronts whilst effectively acting as barriers to the transport of planktonic material across them.**Discussion**

French and English tagging studies in the Channel area have shown that mature females tend to move against the direction of the prevailing long term, tidal residuals. These movements have been interpreted as an ontogenetic adaptation to maximise the chances of the larvae being returned to the areas of maternal origin and as such forwarded as evidence for a single stock throughout the area. However, the distribution of the main spawning grounds, the differences in the timing of hatching and the impact of the local hydrography on larval distributions suggest that there are two spawning populations in the west and east Channel, with a possible third in the northeast Celtic Sea. Ongoing genetic studies may provide more information.

2.4 ToR D): Assess the effects of environment including the impacts of diseases on crab stocks

No report.

2.5 ToR E): Assess the interaction between net/dredge fisheries other anthropogenic activities and crab stocks

2.5.1 Monitoring catch rates of edible crab (*Cancer pagurus*) in relation to gravel dredging on Hastings Shingle Bank in the eastern English Channel (Julian Addison and Colin Bannister)

Fisheries biologists are increasingly involved with evaluating the impact of other seabed uses, such as gravel dredging and the construction of wind farms, on the fishery resources in the locality of the dredging or construction works. In many cases these dredging or construction works are permitted on the condition that fisheries monitoring programmes are undertaken which may be used subsequently in evaluating the potential impact of the works on the local fisheries. This note summarises recent monitoring programmes for the edible crab (*Cancer pagurus*) fishery close to Hastings Shingle Bank in the eastern English Channel. The study provides a case study of such fishery monitoring programmes and highlights some of the problems inherent in evaluating impact of dredging activities on local fisheries.

2.5.1.1 Background

The fishery for the edible crab (*Cancer pagurus*) around Shingle Bank off Hastings in the eastern English Channel was pioneered in the 1980s, and produces 50-100 tonnes of crabs per annum. Following a positive Government View, gravel dredging began in a licensed extraction area on Shingle Bank in 1989, and has continued to the present day through subsequent licence renewals in 1996 and 2001. The main fisher in the area contends that dredging on Shingle Bank threatens his livelihood from the crab fishery. He argues that sediment plumes emanating from the dredging or the dredger spillways are transported by the local tidal ellipse towards his crab pots set south and east of Shingle Bank. His contention is that these sediment plumes smother his pots and adversely affect his catch rates. In view of these concerns, the dredging licence was issued on condition that a monitoring programme was carried out by the licence holder to identify any changes in the catch rate of crabs following the onset of dredging and evaluate whether those changes could be linked to dredging activity. We summarise the data on crab catch rates collected and analysed as part of the monitoring programme, and discuss what further data are required before we can evaluate fully whether gravel dredging has had any impact on local crab stocks.

2.5.1.2 Data on catch rates of crabs

The fisher's contentions about the impact of dredging on crab catches were investigated through analysis of two data sources. Firstly the fisher's personal log books which contain daily records of crab catches with detailed positional information were analysed to identify any changes in catch rates covering the pre- and post-dredging periods. Secondly, as a condition of the renewal of the dredging licence in 1996, the dredging companies were required to finance the independent monitoring of crab catches in the Shingle Bank area using 'sentinel' strings of crab pots set and hauled during the main autumn season. The sentinel strings were fished by the local fisher, but catch data were recorded by environmental consultants on board the vessel on a pot-by-pot basis.

The two sets of data were analysed at varying spatial scales to test the general hypothesis that if the fisher's contentions were correct, then we would expect to find lower catch rates of crabs in pots fished in areas likely to be influenced by settlement of sediment plumes than in areas well away from the dredging operation.

2.5.1.3 Results of data analysis

Prior to analysis, the catch rate data from the fisher's commercial strings of pots were grouped into areas determined by the approximate north-east / south-west movement of the sediment plume on the prevailing tide and the seasonal westwards movement of the crabs along the southern slope of Shingle Bank. In particular catch rates of crabs from strings fished in downstream 'treatment' areas potentially at risk from transported sediment to the south and south-east of the dredging area (Areas A&B) were compared with catch rates from an upstream 'control' area (C) to the north-west of Shingle Bank which is unlikely to be affected by sediment from dredging. Good quality data from these commercial strings of pots were available from 1985 to 2003. Analysis showed that following the onset of dredging in 1989, there had been a sudden drop in catch rates in all three areas in 1991, but the decline in catch rate was greater in treatment areas A&B than in control area C. There was no overall downward trend in catch rates of crabs either before or after this "step change" observed in 1991. More detailed comparison of the catch rates from strings of pots closer to (inner strings) and further out from (outer strings) the southern slope of Shingle Bank in areas A&B showed that catch rates from the inner strings had declined in comparison with catch rates from the outer strings (Figure 1). This change in relative catch rates was generated by a stable catch rate in the outer strings, but a gradual and progressive decline in catch rate in the inner strings. Analysis of the catch data from the fisher's commercial pots provides some support therefore for the hypothesis that catch rates of crabs had declined close to the dredging area on Shingle Bank. However, the observation that catches rates also declined in the control area, albeit to a lesser extent, provides warning that other factors in addition to dredging may be driving the observed change in crab catch rates.

Three strings of sentinel pots had been fished: two across the crab migration path to the south east and east of Shingle Bank, and a 'control' string further south. Whilst catch rates averaged at the string level were generally higher in the southern area furthest away from the dredging site, analysis of the catches on a pot-by-pot basis showed no clear evidence of lower catch rates in pots closest to Shingle Bank at the northern end of the strings. There was therefore no measurable effect that might be attributable to the settlement of the sediment plume from the dredging operation.

2.5.1.4 Discussion

Whilst the data analysis showed a clear stepwise decline in catch rates of crabs following the onset of dredging, the results were somewhat equivocal. Analysis of the fisher's commercial catches showed clearly that catch rates in strings of pots close to the dredging site were lower than catch rates in strings further away from the dredging site supporting the hypothesis that settlement on the fishing grounds of the sediment plume from dredging had caused a reduction in catch rates of crabs. In contrast there was no clear evidence from the analysis of the catch rates from the sentinel strings that catch rates were lower closer to the dredging site.

The analysis was complicated by the fact that fishing effort had increased significantly from 1991/92 onwards (i.e. two/three years after the onset of dredging) particularly Area E to the east of Shingle Bank, which is thought to be the source of the crabs which exhibit seasonal migrations westwards across the main fishing grounds. Taken at face value, the commercial catch rate data show that catch rates of crabs were lower following this increase in fishing effort in 1991/92 than in the period prior to the onset of dredging from 1985-1989 (Figure 2). This raises the possibility that the observed decline in catch rates of crabs may be caused by increased fishing effort either in addition to, or in place of, the potential effect of dredging.

Interpretation of the observed step change in catch rates of crabs in relation to the two potential causes, onset of dredging and increased fishing effort, is complicated. There was no doubt that there had been an abrupt drop in catches but the timing of this did not fit well with either the onset of dredging or the increase in fishing effort. There is a significant time lag between the onset of dredging and the observed decline in catch rates, whereas the increase in fishing effort appears to occur after the step change in catch rates (Figure 2). This lack of synchronisation of observed effect with potential causes suggests that there may be other factors driving the observed changes in catch rates of crabs, a hypothesis supported by the observation that the step change in catch rates in 1991 was observed in both treatment and control areas.

2.5.1.5 Conclusions and implications for monitoring programmes

Some general conclusions can be drawn from this case study which has implications for other monitoring programmes in relation to the potential impact of dredging on commercial fisheries.

Firstly, the Shingle Bank crab monitoring programme shows that unequivocal results will not necessarily be obtained even with long time series of good quality fisheries data. Secondly, the analysis of crab catch rate data on its own cannot provide a definitive statement or proof about cause, because the data do not inherently contain causal information. Conclusions about cause and effect therefore rest on interpretations about whether the crab fishery changes are what we would expect to see if the cause was either sediment transport, or some other hypothesis such as fishing effort. This report highlights how difficult it is to make scientifically firm conclusions in this context. What is required is either more scientific data from the field about sediment transport, or more information about alternative biological or mechanical hypotheses including, for example, the possibility of some cause further east at whatever location is the actual source of the crab migration that feeds Shingle Bank each autumn. Attempts have been made to use logger pots to link the occurrence of pulses of sediment in the vicinity of crab pots to the local pattern of dredging activity at Shingle Bank, but a convincing answer was not obtained. Further physical monitoring is planned for autumn 2005 which should help to clarify whether material from the dredger does indeed settle out over the commercial potting grounds. In addition, historical data are being evaluated to determine whether other physical interpretations such as bathymetric change, seabed disturbance by trawlers and changes in long term temperature or salinity regimes can explain the observed declines in crab catch rates. Similarly, historical data relating to crab biology and fisheries in the region are being examined to determine whether the observed changes in crab catch rates are caused by natural fluctuations in crab abundance or fishery- induced changes.

This study highlights the need to ensure that monitoring studies on catch rates in fisheries are carried out in conjunction with physical, benthic and other monitoring programmes which can identify the likely mechanisms through which dredging operations can potentially impact catch rates in commercial fisheries.

It is essential that the purpose of any fisheries monitoring programme is made clear before it is implemented. Without concurrent physical and benthic monitoring, the monitoring of catch rates in commercial fisheries will not provide answers to questions about potential impact of dredging operations. In these circumstances, the monitoring programme becomes a surveillance exercise which simply identifies changes in commercial catch rates without evaluating the causes of those changes. It is important therefore to differentiate between the differing capabilities of the various forms of monitoring programmes at their outset.

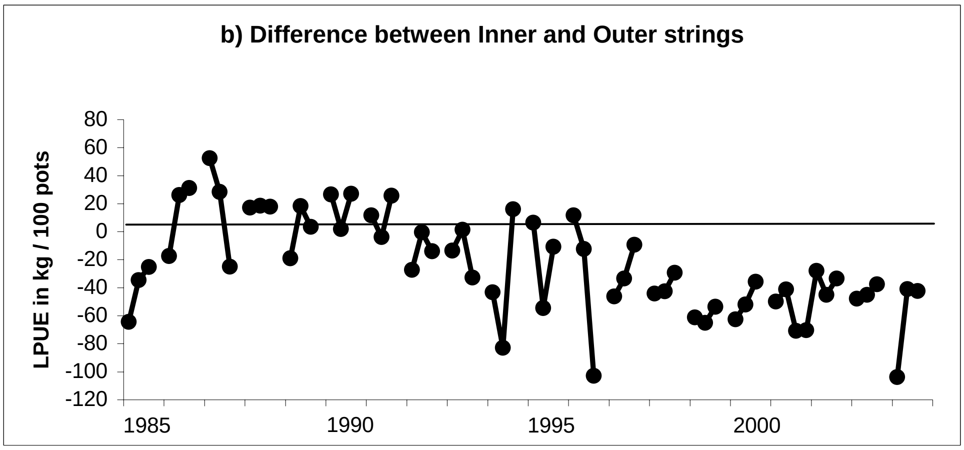

Figure 1: Difference in catch rates of crabs (landings per unit effort, LPUE) between strings of pots fished close to Shingle Bank (Inner strings) and further away from the Bank (Outer strings). A positive value represents higher LPUE in the Inner strings, and a negative value represents higher LPUE in the Outer strings.

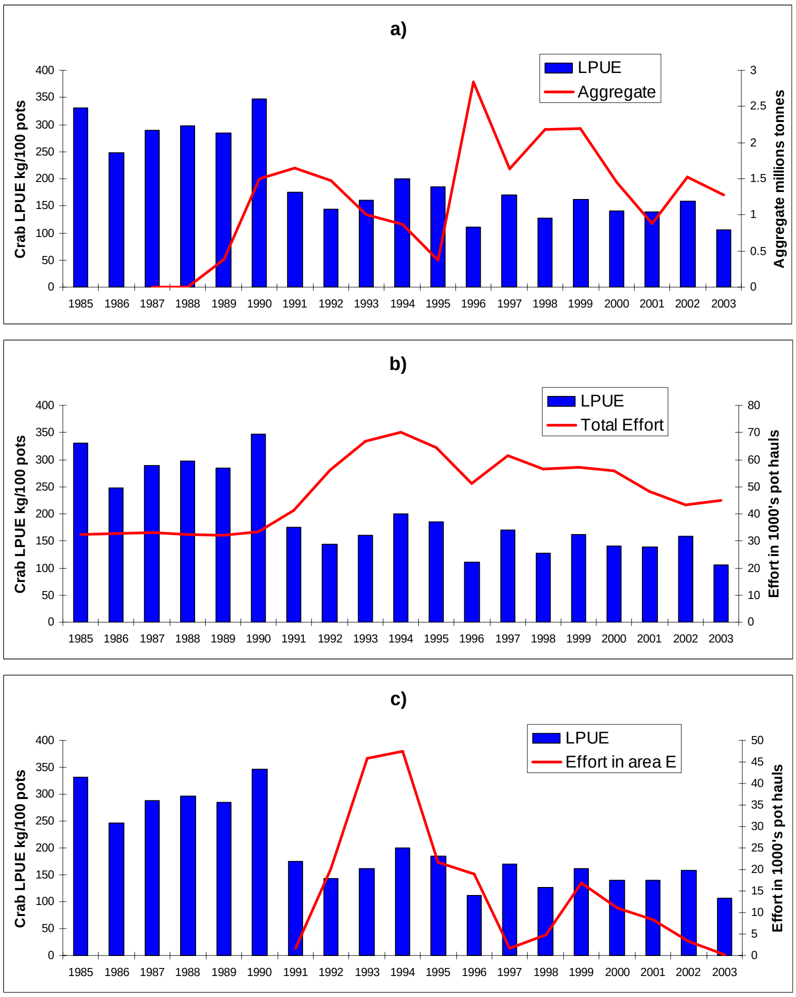

Figure 2: Trends in landings per unit effort (LPUE) of crabs in area AB close to Shingle Bank with (a) quantity of aggregate dredged, (b) total fishing effort and (c) fishing effort for Area E to the east of Shingle Bank.

2.6 ToR F): Assess fishery and non-fisheries effects on populations and abundance of crab

2.6.1 Size at sexual maturity of female Brown crab (*Cancer pagurus*) in three regions in coastal Norway (Astrid Woll and Wenche Emblem)

2.6.1.1 Introduction

Size distribution varies for female Brown crab along the Norwegian coast (Woll *et al*, submitted.) Exploitation rate, bottom substrate and size at maturity are believed to be steering parameters. Maturity is usually determined by visual observation of the ovaries. Classification is based on subjective evaluation and is therefore likely to depend on the person who is conducting it. It is therefore important that visual criteria are clear and based on objective criteria determined through microscopic analyses. A 4-stage macroscopic scale is previous described by Williamson (1904) and Edwards (1979).

A study carried out in autumn 2003 aimed to establish a microscopic maturity scale and by use of this, modifying the previous described macroscopic maturity scale. By use of the “new” macroscsopic scale, size at maturity should be determined in three regions along the Norwegian coast. Size at mating should at the same time be determined by the presence of sperm in spermateca.

Females were collected in September 2003 in three areas: Kvitsøy (N 60°, n=178), Trøndelag (N 64°, n=181) and Vesterålen (N 69°, n=166), all together 524 crabs. The crabs were captured in traps from randomly selected locations in the study area at depths of 20-40 m. Carapace width was measured and shell condition determined to soft, pale or hard. In each of the 3 areas, 20 crabs were sampled in each 5 mm size class interval from 100 mm to 150 mm carapace width. In each size interval 10 soft, i.e. crabs which had moulted this season, and 10 hard shelled crabs, i.e. moulted the previous year, was sampled. The crabs were killed and fixed in 4% seawater-diluted formaldehyde for further analyses in the laboratory. In the laboratory the crabs were dissected and the ovaries weighed and classified. Gonadosomatic index (GSI) was calculated as 100*(weight of ovary)/ (total live weigh). Total live weigh was estimated by using a CW-W relation (Woll, in prep).

All the 524 crabs were used for macroscopic analyses and 101 of them for microscopic. Macroscopic evaluation was based on weight, volume, extension and colour of ovary. For the microscopic preparation the ovarian tissue was embedded in Technovit® as described by Kjesbu. The blocks were sectioned to 3µm and stained in Tolouidine blue. Microscopic analyses were based on development of primary and secondary oocyttes and follicle cells as describes by Charniaux-Cotton (1985).

2.6.1.2 Results and discussion

A microscopic scale was established with two stages as immature and 4 stages as mature (Table 1). A six-stage macroscopic maturity scale was established based on the microscopic scale and the external appearance of the ovaries. This scale had only one stage as immature: stage 1 = immature, stage 2 to 4 = successively maturity stages, stage 5 = spawning, stage 6 = spent or resting. (Table 1).

The difference in weight of the ovaries or mean size (diameter) of the secondary oocytes in stage 1.5, 2 and 6 were not significant (Table 2).

When evaluating the ovaries macroscopic, stage 1.5, 2 and 6 were difficult to distinguish and all together 10% of the 101 ovaries macroscopically determined as immature showed up to be mature stage 2 or 6 when examined microscopically. This resulted in a smaller size at 50%

mature for microscopic evaluation (CW = 111.8 mm) compared to macroscopic (CW = 116.0 mm) (Figure 1).

Table 1: Macro- and microscopic scale for maturation of female *Cancer pagurus*. PO=primary oocyttes, SO=secondary oocyttes, PFC=primary follicle cells, SFC=secondary follicle cells.

	Microscopic description		Macroscopic description
	IMMATURE		
1. Previtellogenesis.	Oogonium covers lobes. PO occasionally observed. PFC.	1.	Gonad small threadlike string. Colour: Whitish, transparency, pale.
1.5 Primary vitello-genesis	Less oogonium. PO cover 10-50% of lobes. SO occasionally observed, vesicles in cytoplasma. PFC surrounds most PO.		Gonad small threadlike string, lobe formation may have started. Colour: Whitish, transparency, pale.
	MATURE		
2. Early secondary vitellogenesis.	PO covers 50-80% of lobe. SO more yolk than vesicles in cytoplasma. PFC and SFC surround oocytes.	2.	Gonad extended in carapace. Lobes distinct some increase in volume. Colour: Greypinkish/pink.
3. Secondary vitellogenesis.	SO covers 50-80% of lobe, more yolk than vesicles in cytoplasma. SFC surround oocytes.	3.	Orange to red. Lobes increased both in extension and volume.
4. Late secondary vitellogenesis.	SO cover 90-100% of lobe SFC in a one cell layer around the oocyttes. Yolk melting together, nucleus colour changed.	4.	Gonad filling most of carapace. Connection between the lobes swollen. Colour: Bright red.
5. Spawning		5.	Bright red and running
6. Spent /resting	Several oogonium and PO. Some SO. Net of secondary SFC, space in lobe. Atrofi.	6.	Gonad extended in carapace. Lobes slender (loose, puffy). Remnants of eggs may be present. Colour: White/yellow/beige.

Table 2: Weight of ovaries (mean±S.D.) and diameter of primary (P) and secondary (S) oocyttes (mean±S.D) at different maturity stages. N = 101 ovaries examined.

	Maturity stage					
	1	1.5	2	3	4	6
N (ovaries)	4	18	34	18	12	15
Weight ovaries	0.52±0.3	1.0 ± 0.6	3.7 ± 2.0	11.6 ± 7.4	32.7 ± 14.4	3.2 ± 1.6
Diameter S.oocyttes (µm	-	84 ± 31	118 ± 32	210 ± 55	337 ± 36	125 ± 69
Diameter P.oocyttes (µm)		33 ± 11	42 ± 12	38 ± 10	39 ± 9	40 ± 10

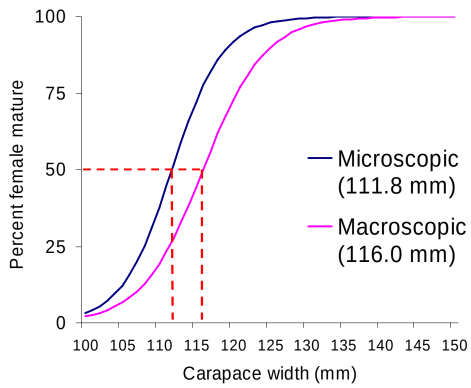

Figure 1: Size at 50% maturation for the 101 ovaries evaluated macro- and microscopically.

The 524 ovaries determined macroscopically were used to estimate the size at 50% maturity in the three regions. The differences were negligible ranging from 113.9 mm in Trøndelag to 117.8 mm in Rogland. The size at first maturity differed from 104 mm in Rogaland to 110 mm in Vesterålen. These sizes are close to the smallest sampling size (100 mm), and to do a correct evaluation smaller crabs should probably be sampled (Table 2).

The size where 50% of the females had mated varied from 109.8 mm to 112.3 mm (Table 3). This is very close to the size at 50% mature determined microscopic (111.8 mm).

Table 3: Size at 50% maturation of ovaries and mating in three regions in coastal Norway. Macroscopic determined.

Region	Examination	Female	Ovary mature		Sperm present	
		(n)	50 %	1st	50 %	1st
Rogaland	Macroscopic	166	117.8	104	110.1	103
Trøndelag	Macroscopic	180	113.9	108	112.3	103
Vesterålen	Macroscopic	178	116.4	110	109.8	109

2.6.1.3 Conclusions

1) The macroscopic stages 1, 2 and 6 might be difficult to distinguish.

2) Macroscopic examination gave 10% more immature ovaries compared to microscopic evaluation. This resulted in a size at 50% mature which was 4.2 mm larger for macroscopic evaluation.

3) The differences in size at 50% maturity were negligable in the three regions ranging from 113.9 to 117.8 mm carapace width macroscopic determined.

4) The size where 50% of the females had mated was smaller than the macroscopic evaluation of 50% mature, but approximately the same as for microscopic evaluation of the ovaries.

5) The size of ovigerous females in the commercial catches seemed to be larger indicating that some of the females needed another moult before spawning.

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Charniaux-Cotton, H. 1985. Vitellogenesis and its control in Malacostracan Crustacea. American Zoology, 25: 197-206

Woll, A., Meeren, G.I., Fossen, I., Tveite, S. Subm. Spatial variation in abundance and catch composition of *Cancer pagurus* in Norwegian waters.

2.6.2 *Cancer pagurus* size at maturity in Swedish waters (Anette Ungfors)

Sampling of females and males for maturity analyses occurred in July-December 2001-2002 on commercial fishing boats at six locations. Both physiological and morphometric characters were used to determine CW_{50} (carapace width were 50% of the population is mature). The results show that females mature morphometrically (wider abdomen) and behaviourally (copulation indicated and confirmed) at smaller carapace sizes than physiological maturity (Table 4). Male sperm development stage was visually classified as immature (transparent or non-visual vas deferens), pubescent (vas deferens whitish and coiled) or mature (vas deferens thick, white and heavily coiled). Considering the pubescent stage as being mature indicates physiological sperm development before morphological changes occur in the chela (Table 4). However, if pubescent development is considered immature then there is a snychrony in the size at which physiological and morphometric maturity in males occurs.

Table 4: Size at maturity of female and male Brown crab in Sweden based on biometric characters. The carapace width were 50% of the population is mature is given.

Character	CW_{50} (mm)
Females	
Gonad development	132
Sperm in spermatheca	107
Sperm plug	118
Abdomen width	104
Males	
Gonad 1; scenario pubescent immature	117
Gonad 2; scenario pubescent mature	101
RPL (right propodus length)	122
RPH (right propodus height)	122
RPW (right propodus width)	120

References

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2.6.3 Preliminary re-analysis of size at sexual maturity data for the brown crab (*Cancer pagurus*) in the England and Wales fishery (Andy Lawler and Julian Addison, CEFAS Lowestoft)

Historical data from an experiment designed to investigate the reproductive cycle in brown crabs (*Cancer pagurus*) were re-evaluated to help determine size at sexual maturity in three regions around England and Wales. Size stratified samples of crabs were obtained from fishermen operating baited commercial pots from two areas of the English Channel and from sites off North Norfolk. Five crabs per 5mm carapace width size class by sex were collected from the size ranges available from the catch. Eight samples were analysed from the Western Channel, 9 samples from the Eastern Channel and 20 samples were obtained from off North Norfolk. Over 6000 crabs were examined over a period of about six years.

At the laboratory biometric data were obtained and internal examination of the gonads made possible by dissection. Only two individuals working together carried out all dissections to maintain a degree of consistency in determining the condition of the gonads. Three characteristics of the gonads were categorised for each crab following the keys in Tables 5 and 6. Crabs were nominally classified as sexually mature or immature based on two methods, either on a combination of the factors describing gonad extent, colour and ripeness or the extent of the gonad alone.

A “mature” male crab is defined as having a gonad extent that is not invisible or restricted to the anterior margins of the carapace (not A in key above). To reduce misclassification an alternative criterion used the feature above and in addition the colour of the testes and the appearance of the vas deferens to assign maturity (gonad colour 3, 4, 5 or 6 or gonad ripeness b, c or d).

As the gonad in females crabs is proportionally more extensive than that for a similar sized male, a “mature” female crab is defined as having a gonad which extends beyond half way round the interior of the carapace (not A and B in key). The alternative criterion also used the colour of the ovary and the presence of eggs to determine “mature” animals. If the gonad was pale orange or darker or eggs were present either in the ovary or externally this was taken as confirmation of sexual maturity (gonad colour 3, 4 or 5 or gonad ripeness c, d or e).

Logistic regression analysis was carried out using the GENMOD procedure in SAS by specifying a logit link function. The probability of a crab being “mature” was modelled with carapace width as an explanatory variable. Analyses were carried out by sex for each of the three geographic regions and for each of the months that were sampled.

There was considerable seasonal variation in the predicted size at maturity. In general crabs from samples taken during the winter appear to mature at a larger size than from other times of the year. This is considered to be sampling bias and is expected for the females given berried females in the winter do not enter baited traps. This does not explain the same phenomena in male crabs. It is recommended therefore that samples obtained using baited traps in the winter be excluded for determination of size at maturity because of the unavailability of mature crabs at this time of the year.

Using factors that describe the ripeness of the gonads to improve determination of sexually mature crabs does little to improve accuracy over using the gonad extent alone, even when targeting months when the gonads are expected to be most obviously ripe. Analysis of variance showed there was no difference between the maturity ogives produced by assigning crabs as mature based on the two methods of classifying mature crabs regardless of the time of year.

Preliminary analysis suggests that males appear to mature at a smaller size in the North Sea with the size at 50% maturity being only 88.9 mm carapace width (CW). In the Western

Channel and the Eastern Channel the estimated values were 94.9 mm and 104.9 mm CW respectively. The same pattern is evident for the females with the size at 50% maturity for the North Sea, Western Channel and Eastern Channel being 108.5, 113.7 and 125.9 mm CW respectively. It is not known whether this is due to genetic differences between the populations or an artefact of sampling bias. Problems associated with gear selection and spatial and seasonal distributions of crabs potentially all play a role in reducing the accuracy of estimates, and these processes need investigating more fully before any conclusions can be drawn about factors determining the observed variation between fisheries in size at 50% maturity.

Table 5: Male maturity stages.

Gonad extent:

A. Invisible or not extending beyond the anterior margin of the shell.
B. Extending from the anterior margin up to half way down.
C. Extending beyond half round the carapace and may reach the branchial cavity.
D. Thin and narrow in appearance. Spent.

Gonad colour:

1. Transparent.
2. Up to one half of the testes white in colour.
3. More than one half of the testes white.
4. Up to one half of the testes milky white.
5. More than one half of the testes milky white, easily ruptured, releasing sperm.
6. Flaccid and creamy in appearance. Spent.

Gonad ripeness (condition of vas deferens):

a. Narrow and almost colourless.
b. Beginning to swell.
c. Milky white and swollen, easily ruptured, releasing sperm.
d. Swollen but partially or wholly transparent. Spent.

Table 6: Female maturity stages.

Gonad extent:

A. Invisible or not extending beyond the anterior margin of the shell.
B. Extending from the anterior margin up to half way round the shell.
C. Extending beyond half round the carapace and may reach the branchial cavity.
D. Extends over all or part of the branchial cavity.

Gonad colour:

1. Transparent.
2. Whitish cream.
3. Pale orange.
4. Orange.
5. Deep orange to red.

Gonad ripeness:

a. No sign of eggs in ovary.
b. Grainy appearance to ovary.
c. Eggs clearly visible in part of the ovary and maybe visible in the oviduct.
d. Eggs clearly visible in the whole of the ovary and the oviducts.
e. Eggs attached to abdomen, ovary containing few or no eggs.

2.6.4 Update on neurolipofuscin demographic analysis of *Cancer pagurus* in the main English regional fisheries (Julian Addison)

The following is an extract from DEFRA Marine Fisheries R & D Final Report MF0225 (Sheehy and Prior 2005).

2.6.4.1 Objectives

The purpose of the project was to evaluate and develop the lipofuscin ageing method for *C. pagurus* and to use it to obtain demographic information for stocks in the three main English regional crab fisheries, E. coast (Yorkshire district), E. Channel and W. Channel, for use in new stock assessments.

2.6.4.2 Calibration and thermal correction of age estimates

Calibration of eyestalk neurolipofuscin concentration to chronological age and correction of age estimates for sea temperature variation was achieved, for the first time, solely on the basis of intrinsic time reference points (cohort modes) in regional neurolipofuscin concentration frequency distributions (NCFDs) (see Figure 5.6 in ICES 2003), without known-age captivity reared or microtag-recaptured reference material. Variation in modal separation of the most prominent cohorts in regional NCFDs indicated a significant linear relationship ($r^2 = 0.78$, $p < 0.001$) between annual average sea temperatures and neurolipofuscin accumulation rates (Figure 2). The coefficients of this relationship do not differ significantly from those obtained previously for microtagged *Homarus gammarus* (Sheehy and Bannister 2002).

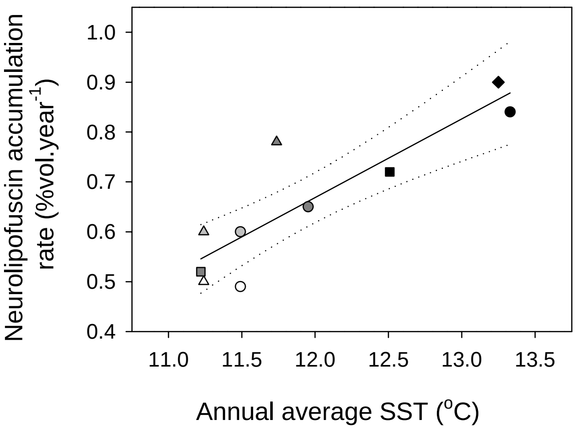

Figure 2: Relationship between annual average sea temperature and neurolipofuscin accumulation rate in *C. pagurus*, as estimated from modal separations in regional NCFDs.

Based on this relationship, average neurolipofuscin accumulation rates over the last 20 years for E. coast, E. Channel and W. Channel crabs were estimated to be 0.51, 0.58 and 0.72% vol·year^{-1}, respectively. The implications of directional migration through varying thermal regimes for age determinations and parameter estimates were assessed for adult W. Channel female crabs by simulation and found likely to be negligible.

2.6.4.3 Recruitment

Neurolipofuscin age estimates indicate that juvenile *C. pagurus* remain in intertidal nursery areas for up to 5 years. Recent fishery landings (2001-2003) in all regions are almost exclusively derived from settlement during the 1990s and particularly from the mid to late 1990s. Adult age distributions show prominent cohort structure, the 1995 year-class being the strongest component in 4 out of 5 age distributions. Independent confirmation of this finding comes from the International Beam Trawl Survey dataset for the southern North Sea. The differential relative strength of the 1995 year-class between the IBTS abundances of very small crabs and neurolipofuscin age distributions for samples of landings appear to suggest some form of post-settlement damping of year-class strength fluctuation. Year-class strength variability in the age distributions may reflect an environment-recruitment relationship. However, before definitive conclusions can be drawn, the patterns must be confirmed through specifically tailored, geographically and seasonally standardized, time series of neurolipofuscin sampling. The limited available successive samples from both E. coast and Channel suggest that year-classes can be tracked through time.

2.6.4.4 Lifespan

The average maximum lifespan of *C. pagurus* is around 10 years with the greatest individual age estimate being 15 years for an E. Channel female of 202 mm carapace width. The characteristically large size of some W. Channel males reflects the upper extremity of individual growth variability rather than great age. Small but statistically significant sex and regional lifespan differences were found for the first time. Female and E. coast crabs live longer than male and W. Channel crabs. Comparative analyses suggest that some crabs in each fishery approach their maximum physiological lifespan and, therefore, that the ages of the oldest surviving crabs are determined by senescence rather than fishing. This may, in turn, suggest the existence of important mechanisms of resilience to exploitation, such as offshore refugia or limited catchability, which remain incompletely understood.

2.6.4.5 Growth

Generalized growth in *C. pagurus* is spatially complex and does not appear to conform to latitudinal trends. Of particular interest is the finding that W. Channel male crabs grow slightly faster than W. Channel females, while on the E. coast, female growth is significantly faster than that for males. New data for the E. Channel shows a greater similarity with the E. coast than the W. Channel in that female growth is faster than that for males. The present curves fall within the range of most previous stock assessment options but are, nonetheless, not identical to any single previous growth curve. The age-length relationship for individual crabs of legal size is extremely poor in all sites and both sexes. This explains how major changes in exploitation patterns and stock status can occur without being reflected in landings size compositions. Growth variability means that between 4 and 7 year-classes recruit to legal size each year, increasing the probability of selective fishing impact on fast-growers and tending to obscure recruitment relationships in annual landings and size compositions.

2.6.4.6 Mortality

Neurolipofuscin longevity-based estimates of M are somewhat higher (0.39-0.52) than most previous speculation. M varies regionally and between the sexes. It is highest in the W. Channel and in males. Our age-based linearized catch curve estimates of Z for *C. pagurus* are a methodological improvement over purely size-based approaches but in future, further refinements are possible by tracing the fate of individual cohorts through time in sequential age distributions. The present F estimates for the E. coast (av. 0.45) are lower than previously published estimates (av. 0.80), largely due to assumptions of lower M in previous assessments. Male F was found to be lower than that for females, contrary to previous expectation. For the E. Channel the present male and female F estimates are similar and not markedly different from the E. coast average. On the W. Coast, male F is markedly higher (1.02) than previous assessments (0.46). Present and past estimates for females are closer (0.21 and 0.45, respectively) and lower than those for males. Male and female Fs on the W. coast are the highest and lowest estimates, respectively, for any of the regions. The relatively low female F is surprising given that the W. coast fishery is principally based on female landings in autumn. It may well be that the mortality estimates here are biased downward by immigration of mature females into the western mid-

Channel grounds. Alternatively, it may be that the offshore migration of mature females and very low catchability of berried females affords protection from harvesting that males do not have the benefit of.

2.6.4.7 Conclusion

The project outcome strengthens the basis for *C. pagurus* assessment. Improved spatial resolution of demographic data for target species is a requirement for ecosystem management. This is the first study to show how neurolipofuscin-based ageing can be extended to the provision of knowledge about regional differences in population parameters and recruitment, particularly in circumstances where tag-recapture reference material is lacking.

Reference

ICES. 2003. Report of the Study Group on the Biology and Life History of Crabs. ICES CM 2003/G:11 Ref. D.

Sheehy, M.R.J. and Bannister, R.C.A 2002. Year-class detection reveals climatic modulation of settlement strength in the European lobster, *Homarus gammarus*. Can. J. Fish. Aquat. Sci. 59: 1132-1143.

Sheehy, M.R.J. and Prior, A.E. 2005. Analysis of stock age structure and population parameters in edible crab, *Cancer pagurus*, using lipofuscin age pigments: data for resource management. DEFRA Marine Fisheries R & D Final Report MF0225, 48 pp.

2.7 ToR G): Review the methods for estimating recruitment in crab stocks

No report.

3 Recommendations

The SGCRAB unanimously recommends that Julian Addison, UK should be invited to Chair SGCRAB from 1 January 2006.

The **Study Group on the Biology and Life History of Crabs** [SGCRAB] (Chair: Julian Addison UK) will work by correspondence in 2006 and will meet in Lowestoft, UK in May 2007 to:

- a) compile data on landings, discards, effort and catch rates (CPUE) for the important crab fisheries in the ICES area;
- b) standardise methods for the acquisition, analysis and interpretation of CPUE, size frequency and research survey data;
- c) define stock structure / management units for crab stocks;
- d) assess environmental effects including diseases on crab fisheries;
- e) assess the interaction between net/dredge fisheries other anthropogenic activities and crab stocks;
- f) assess the effects of fishing on the biological characteristics of crab stocks;
- g) review the methods for estimating recruitment in crab stock.

SGCRAB will report by 30 August 2006 for the attention of the Living Resources and Resource Management Committees

Annex 1: Action Plan Audit

Year	Committee Acronym	Committee name	Expert Group	Reference to other committees	Expert Group report (ICES Code)	Resolution No.		
2004/2005	**LRC**	**Living Resources Committee**	**SGCRAB**	**RMC**	2005/G:10	2G08		
Action Plan	**Action Required**	**ToR's**	**ToR**	**Satisfactory Progress**	**No Progress**	**Unsatisfactory Progress**	**Output (link to relevant report)**	**Comments (e.g., delays, problems, other types of progress, needs, etc.**
No.	**Text**	**Text**	**Ref. (a, b, c)**	**S**	**0**	**U**	**Report code and section**	**Text**
1.2.2	Quantify the changes in spatio-temporal distribution of the stocks of important species in relation to environmental change, using survey and commercial data.	compile existing data on landings, discards, effort and catch rates (CPUE) for the important crab fisheries in the ICES area;	1	s			TOR 1 SG Crab report 2005	
1.2.2	Quantify the changes in spatio-temporal distribution of the stocks of important species in relation to environmental change, using survey and commercial data.	standardise methods for the acquisition, analysis and interpretation of CPUE, size frequency and research survey data;	2	s			TOR 2 SG Crab report	
1.2.1	Understand and quantify the biology and life history, stock structure, dynamics, and trophic relationships of commercially and ecologically important species.	definition of stock structure/management units for crab stocks;	3	s			TOR 3 SG crab report	more work needed in the areas of tagging, genetics, bio-physical modelling
1.6	Assess and predict impacts of climate variability and climate change, on scales from populations to marine ecosystems, including impacts on commercially important fish stocks. [	assess environmental effects including diseases on crab fisheries;	4		0		TOR 4 SG Crab report	No data reported but work is in progress in Ireland, Canada and UK on disease monitoring
2.13	Evaluate and increase knowledge of the effects of activities that alter physical habitat structure, such as dredging and extractions, on marine ecosystem structure and functions	assess the interaction between net/dredge fisheries, other anthropogenic activities, and crab stocks;	5			u		no data reported on interactions between mobile and fixed gears on crab stocks
3.16	Expand investigations on different ways (including species and size selectivity of fishing gears, closed areas etc.) to reduce by-catch, seek ways to increase the utilisation of unavoidable by-catch, minimise discards and improve their survival, as well as that of fish escaping from fishing gears.	assess the interaction between net/dredge fisheries, other anthropogenic activities, and crab stocks;	5					no data reported on interactions between mobile and fixed gears on crab stocks
1.2.1	Understand and quantify the biology and life history, stock structure, dynamics, and trophic relationships of commercially and ecologically important species.	assess the effects of fishing on the biological characteristics of crab stocks;	6	S				no estimates of fishing mortality produced, information on maturity is improved
		g) review the methods for estimating recruitment in crab stock.	7			u		no report. Some work is ongoing in Ireland on Cancer pagurus