Bord Iascaigh Mhara
Irish Sea Fisheries Board

Assessment, Monitoring and Management of the Dundalk Bay and Waterford Estuary Cockle (*Cerastoderma edule*) Fisheries in 2007

Antonio Hervas, Oliver Tully, John Hickey, Eimear O'Keeffe, Eoghan Kelly

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Fisheries Resource Series

Foreword

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Michael Keatinge
Fisheries Development Manager,
Bord Iascaigh Mhara,
P.O. Box, 12,
Crofton Road,
Dun Laoghaire,
Co. Dublin,
Ireland

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Antonio Hervas[1], Oliver Tully[2], John Hickey[2], Eimear O'Keeffe[1], Eoghan Kelly[1]

1. Martin Ryan Institute, National University of Ireland, Galway, Tel 091 750386, e-mail hervas@bim.ie
2. Inshore Fisheries Section, BIM, New Docks Road, Galway, Tel 091 539362, e-mail tully@bim.ie, hickey@bim.ie

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The Fisheries Development Manager,
Fisheries Development Division,
Bord Iascaigh Mhara,
P.O. Box 12,
Crofton Road,
Dun Laoghaire,
Co. Dublin,
Ireland.
Tel: +353 1 2144 100
Fax: +353 1 2300 564

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This document was reviewed and approved by the committee listed below.

Review Committee: Michael Keatinge (BIM), Ian Lawler (BIM), Oliver Tully (BIM), John Hickey (BIM)

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External Reviewer: Dr. Mike Bell, Millhouse, Stenness, Stromness, Orkney KW16 3LB, UK, Tel +44 (0)1856 850513 E-mail bandm.bell@virgin.net

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Preface

The Management framework for shellfisheries was established in 2005 to oversee the sustainable development and management of the shellfisheries sector in Ireland. The Framework is a co-operative management model between state and industry centred around four Species Advisory Groups (SAGs). Cockle Advisory Committees in Dundalk and Waterford co-operate in the development of management plans for these fisheries based on best available scientific advice. This report presents the advice, outlines the co-operative management plan and describes how the fisheries were monitored in 2007.

National Development Plan 2007 - 2013

Bord Iascaigh Mhara
Irish Sea Fisheries Board

Martin Ryan Institute
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Summary

Dundalk Bay and Waterford Estuary in Ireland support commercial populations of cockle (*Cerastoderma edule*). Both areas are environmentally designated under the EU Habitats and Birds Directives.

Pre-fishery surveys for cockles were undertaken in Dundalk Bay and Waterford Estuary in 2007 to estimate the distribution and biomass of cockles. Limited surveys were also completed in 2006. In 2007 total biomass of cockles in Dundalk Bay was 2,277±172 tonnes. In Waterford total biomass was estimated to be 284±22 tonnes and 267±26 tonnes in the Woodstown and Passage East areas respectively. In the Tramore area of Waterford there was an estimated 2,303±403 tonnes.

Differences in the size distribution of cockles in 2006 and 2007 in Dundalk and Waterford were related to the time of year in which the surveys were completed. In Dundalk the 0+ and 1+ age classes accounted for over 80% of the population. Shell height was 12, 22 and 28mm for age classes 0+, 1+ and 2+ respectively. In Waterford in 2007 age classes 3+ and 4+ accounted for over 70% of the population. Shell height was 11, 16 and 20mm for age classes 0+, 1+ and 2+ respectively.

Crude estimates of overwintering mortality were estimated by comparing densities of each year class from the 2006 and 2007 surveys. In Dundalk overwintering mortality was 29±27% or, expressed as the instantaneous rate (M), 0.33±0.31. In Waterford mortality was 82±11% or 1.69±0.11 (M). Overwinter mortality was highest in the 0+ age class. Yield per recruit at recruit sizes between 17-22mm depended on assumed rates of natural mortality. As M increased the optimum recruitment size that maximised YPR decreased.

Cockle fishery management plans were agreed, in Dundalk and Waterford, prior to opening the fisheries in 2007. The Tramore area of Waterford, however, remained closed as no management plan was agreed. Cockles were fished with suction and non-suction hydraulic dredges and by handraking. Entry to the fishery was effectively unrestricted and was open to all vessels registered in the polyvalent or bivalve segments of the Irish fleet. A number of vessels registered in Northern Ireland also participated. Twenty eight and 15 vessels participated in the Dundalk and Waterford fisheries respectively. An estimated 100 handrakers were involved. Total allowable catch (TAC) was limited to 41% and 33% of the survey biomass estimates in Dundalk and Waterford respectively. Spatial restriction limited the fishery to areas where cockle density was higher than $4m^{-2}$. Daily fishing hours and total daily catch were limited to between 07:00-19:00 hrs and 1 tonne respectively. It was compulsory to use graders on board the fishing vessels. These graders were set, by choice, at 22-24mm although the minimum legal size was 17mm. Conditions for closing the fishery in Dundalk were when the TAC was taken, when daily catch, averaged over 1 week for all vessels declined to 250kg or on February 28th 2008, whichever was reached first. In Waterford the fishery was to close when the TAC was taken or on January 15th 2008.

The fishery was monitored using custom designed logbooks. Daily catch, effort and location were reported and compiled at the end of every week. The decline in catch rate in relation to the cumulative catch was used to calculate the pre-fishery biomass and exploitation rate. These were compared to estimates obtained from the catch and pre-fishery biomass data. In Dundalk exploitation rates estimated from the total catch, as a proportion of the survey biomass estimates, for cockles over 22mm, were higher (57-68% depending on area) than those estimated from the depletion in catch rate (50-53% depending on area). In Waterford the exploitation rate estimated from the catch, as a proportion of the survey biomass, was 27% compared to 46% estimated from decline in catch rate. Differences were due to uncertainty in both methods of estimating biomass and violation of model assumptions in the case of catch rate depletion.

Ways in which the management plans for cockle fisheries in Dundalk and Waterford could be improved are identified. Management plans for cockle fisheries should incorporate environmental impact monitoring for habitat and non-target species especially if these fisheries are in areas designated by the Habitats and Birds Directives so that the long term conservation status of the sites is not compromised. Managing access to the dredge and handrake fishery would help secure earnings for participating vessels and better enable co-operative management.

Introduction

Dundalk Bay and Waterford Estuary on the east and southeast coasts of Ireland, respectively, support commercial populations of cockles (*Cerastoderma edule*). The Dundalk Bay fishery was closed to fishing for cockles by agreement in 2006 and by legislation in early 2007 (SI 02/2007, 269/2007) following discussions between Dundalk Bay Cockle Local Advisory Committee (LAC) and Bord Iascaigh Mhara (BIM). The LAC is facilitated by BIM and is comprised of a number of fishermen who represent the local fleets. The legislation provided for a closure up to July 15th 2007. No fishing took place in Waterford in 2006. The main purpose of the closures was to allow time for completion of a stock assessment so that the fishery could be re-opened under a rational management regime to ensure that adequate measures were taken to protect the recruitment potential of the cockle population and that the conservation requirements of the sites, which are classified under both the EU Habitats and the Birds Directives as Special Areas of Conservation (SAC) and Special Protection Areas (SPA) respectively, were considered. This precautionary and planned approach to potential exploitation of the fishery represented a fundamental change in management, which heretofore had allowed the fishery to take place without necessarily considering the status of the cockle stock in the area and with no particular controls on catch or effort.

Although the areas are environmentally designated, an appropriate environmental assessment (*sensu* Article 6 of the EU Habitats Directive) of the possible effects of the fishery on the conservation status of each site was not completed. Specific conservation objectives for the sites had not been established by 2007 when the current assessments took place. Nevertheless the management plans for the cockle fishery and the new management approach led to the introduction of a significant raft of agreed regulations that limited the potential impact of the fishery on both the environment and the cockle populations. A survey of regulations used in other cockle fisheries in the UK, operating in environmentally designated areas, was also completed. The conditions described in the management plans were consistent with, or were in fact over and above, the regulations used in many of these cockle fisheries. Although the intention is to complete appropriate environmental assessments for these fisheries, if this is deemed necessary following the screening process specified in the EU Commissions Guidance notes on Article 6 of the Habitats Directive (Anon 2001), the 2007 management plan for the fishery included a significant number of precautionary and limiting conditions.

The assessment, management plans and monitoring of cockle fisheries in Waterford and Dundalk Bay are described in this report. Pre-fishery surveys were completed to obtain an estimate of cockle biomass, density and distribution. This information was used in pre-fishery discussions by the LACs which eventually formulated the management plans outlined here. Scientific data on the stock, the environmental conservation requirements of the site, the economic issues facing the fishermen and the logistics of operating a cockle dredge fishery in an intertidal area were the main issues dealt with by the LAC in formulating the management plan. The operation of the fishery was monitored by logbook reporting of daily catch, landings and location. These data, received from the fleet, were also used to provide a post-fishery estimate of what the pre-fishery abundance of cockles was and to estimate the final exploitation rate. This was compared with the estimates from the pre-fishery scientific survey.

Fisheries for cockles in Ireland

The main fisheries for cockles in Ireland are in Dundalk Bay and Waterford estuary. Other smaller cockle beds exist around the coast but these are not regularly exploited. Previous cockle surveys in Dundalk Bay indicate that density is generally low typically ranging from 0-20m^{-2} (Fahy *et al*. 2005). Biomass in the spring of 2004 was estimated to be 1654 tonnes (Fahy *et al*. 2005). The development of the commercial dredge fishery in Dundalk, starting in 2001, was documented by Fahy *et al*. (2005). In 2001, 3 vessels fished from August to December landing 9 tonnes. Vessel numbers and landings increased until 2004 when over 20 vessels landed 201 tonnes. In 2007 approximately 28 commercial dredgers (Table 1) landed 652 tonnes as part of an agreed management plan based on pre-fishery survey biomass estimates reported below. In addition, an unknown quantity of cockles, possibly amounting to 200 tonnes, was landed by handrakers in 2007.

The fishing gear consists of hydraulic suction and hydraulic non-suction dredges. The hydraulic suction dredge (Fig. 1) operates by fluidizing the sand using water jets and then lifting cockles from the beach onto the vessel. The dredge has a cutting blade at the front of a grid. Jets of water positioned in front of the blade fluidize the sediment. This sediment is then sieved through the grid and the cockles are drawn through a suction pipe to the deck of the vessel. The hydraulic non-suction dredge also operates by fluidizing the sand using a water jet that lifts the sediment and cockles. It differs from the suction dredge in that cockles are not drawn to the deck of the vessel but remain in the dredge box.

Table 1. Profile of vessels operating in the Dundalk Bay and Waterford estuary fishery in 2007.

Dundalk				Waterford			
Vessel ID	Overall length (m)	Tonnage (GT)	Engine Power (kW)	Vessel ID	Overall length (m)	Tonnage (GT)	Engine Power (kW)
1	8.05	3.16	44.7	1	10.01	6.11	122
2	7.85	3.23	36	2	10.26	10.27	60
3	11.19	7.73	89.53	3	8.2	4.91	49
4	11.12	9.48	96	4	8.4	2.59	33.62
5	8.4	2.59	33.62	5	11.15	12.97	80
6	11.09	6.78	104.44	6	10.81	10.92	50
7	9.26	5.16	35	7	10.47	7.26	55
8	10.47	7.26	55	8	11.93	14.9	179
9	9.14	5.66	40	9	17	15	97
10	10.81	10.92	50	10	9.14	5.66	40
11	11.15	12.97	80	11	9.26	5.16	35
12	11.91	9.76	49.5	12	11.06	6.97	81
13	8.2	3.08	23	13	11.19	7.73	89.53
14	6.61	1.87	25	14	9.99	4.42	59.68
15	11.06	17.23	186	15	10.36	11.56	75
16	11.54	13.28	67				
17	10.26	10.27	60				
18	10.78	12.34	90				
19	10.01	6.11	122				
20	10.7	7.67	60				
21	9.57	7.64	130				
22	9.16	4.32	35				
23	8.7	5.1	89.53				
24	9.33	4.99	40				
25	11.43	7.52	60				
26	11.05	6.2	53.5				
27	10.36	11.56	75				
28	10.9	9.07	80.58				

Figure 1. Vessels and suction dredge in the Dundalk Bay cockle fleet.

Pre-fishery distribution and biomass of cockles in 2006-2007

Cockle biomass surveys were undertaken in Dundalk Bay and Waterford Estuary to provide information and advice on a prospective fishery for cockles in these areas in 2007. In addition, in 2006, small scale local surveys in the south of the Dundalk Bay area and in Waterford were completed. Approximate estimates of overwinter mortality were derived by comparison of cockle densities in areas covered in 2006 and 2007 surveys. As the extent of the cockle bed was unknown the surveys in 2007 covered the entire extent of the intertidal zone.

Survey methods

Dundalk October 2006

A small scale survey in the Annagassan section of Dundalk Bay was completed on 25-27th of October 2006. This was with a view to estimating pre-winter abundance of cockles. A total of 102 quadrat samples were taken in an area of approximately 1.5 x 0.75km (Fig. 2). Samples were taken at intervals of approximately 50m along transects. Each sample consisted of a $0.5m^2$ quadrat which was dug to a depth of 10cm. The sample was sorted using a 5mm sieve and all cockles were measured to the nearest mm. A sub-sample was retained for estimation of weight and age.

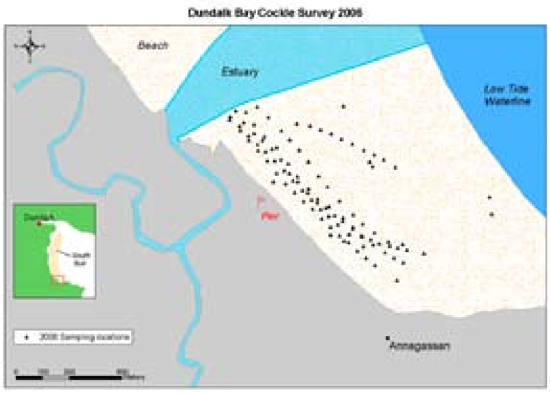


Figure 2. October 2006 cockle survey positions in the Annagassan section of Dundalk Bay.

Dundalk March 2007

A stratified random survey, based on a 500 x 500m grid, was undertaken during March 2007 (Fig. 3). Each 500 x 500m cell was divided into 400 sub-cells of 25 x 25m. Using random number tables, the 3 sub-cells from which the sample ($0.25m^{-2}$) was to be taken was identified. The GPS position at the centre of each sub-cell was sampled. A two phase adaptive procedure was planned whereby areas with the highest densities of cockles in a first pass over the area would be re-sampled in order to reduce the variance of the estimates in areas of high density. Logistical difficulties in accessing some of the area and tidal conditions restricted the second phase sampling. A total of 358 samples were eventually taken.

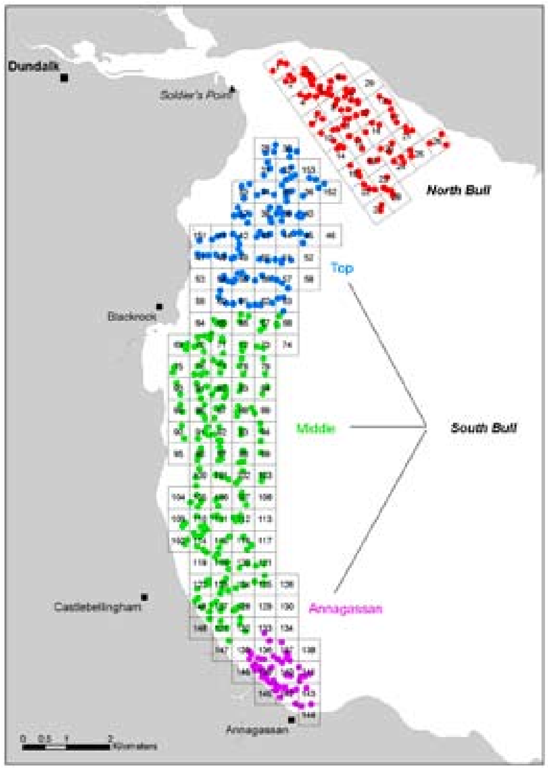


Figure 3. Quadrat survey area in Dundalk Bay, 2007.

Waterford 2006

A preliminary survey of the Woodstown area was completed on 10th and 11th of August 2006. A total number of 37 quadrat samples were taken in an area of approximately $800,000m^2$ (just under 50% of the area surveyed in 2007). Samples were taken at intervals of approximately 150m along 3 transects separated by 250m (Fig. 4). Each sample consisted of a $0.5m^2$ quadrat dug to a depth of 10cm.

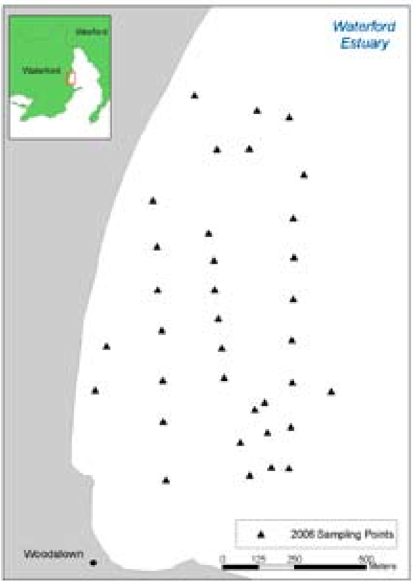


Figure 4. October 2006 cockle survey positions in the Waterford Estuary.

Waterford 2007

A stratified random survey, based on a 250 x 250m grid, was undertaken during March 2007 (Fig. 5). Each 250 x 250m cell was divided into 400 sub-cells of 25 x 25m. Using random number tables the 3 sub-cells from which the sample (0.25m^2) was to be taken was identified. The GPS position at the centre of each sub-cell was sampled. A total of 181 quadrats were sampled.

Figure 5. March 2007 cockle survey positions in the Waterford Estuary.

Estimation of biomass

All sand and cockles within the quadrats was riddled on a 5mm mesh using water. The shell height of all cockles collected was measured (±1mm). A sample of cockles were also weighed (± 0.1g) to allow conversion of numbers to weight.

The numbers of cockles per sample were re-expressed in numbers m^{-2}. An interpolated map of density (m^{-2}) was produced in ArcGIS using an Inverse Distance Weighting (IDW) algorithm, based on 3 nearest neighbouring data points, to produce an interpolated grid between sampling points throughout the survey domain. Within each IDW contour the mean number of cockles (m^{-2}) and the mean weight of cockles were used to calculate the mean biomass (m^{-2}). The biomass and its confidence interval, within the geographic area encompassed by the contour, was calculated by raising the mean biomass m^{-2} to the area enclosed by the contour. The total biomass and its confidence interval was obtained by summing the biomass estimates and confidence intervals of all IDW classes. An algebraic description of the procedure is given in Appendix 1.

Results

Dundalk Bay

October 2006

Average density of cockles was 35 cockles m^{-2} (± 31.76 S.D) in the 2006 survey (Fig. 6).

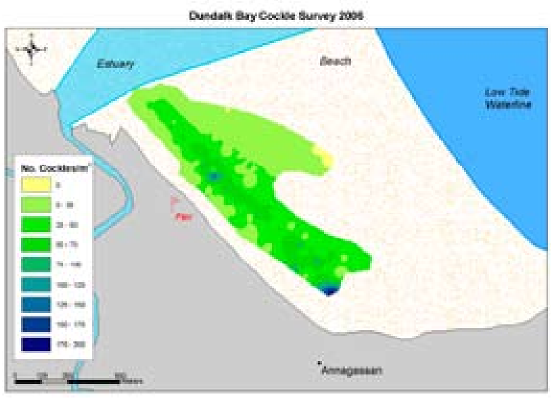


Figure 6. Number of cockles per sample (0.5m^2) in the Annagassan area of Dundalk Bay in October 2006.

March 2007

The interpolated estimates of cockle densities from the 2007 survey are shown in Fig 7. Highest densities occurred at mid-shore in an arc shaped distribution from Annagassan in the south to the north Bull. Locally dense patches were recorded close to shore at Annagassan and in the north west corner of the North Bull.

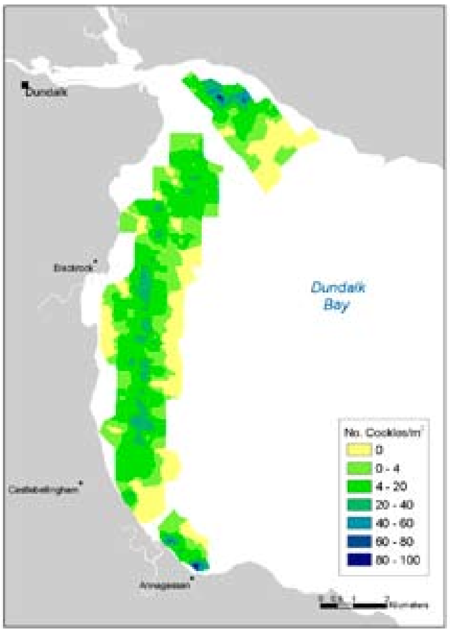


Figure 7. Distribution of cockles in Dundalk Bay in May 2007.

Biomass estimates, for cockles >5mm, are reported for 4 separate sub-areas of the Bay in Table 2-5 and Fig. 8. Commercial densities include areas within the 4m^{-2} contours.

Sub area Annagassan: Total biomass of cockles was 184±23 tonnes (Table 2, Fig. 8). Of this 167±21 tonnes or 91% of the biomass was of commercial density.

Sub area Middle Section South Bull: Total biomass of cockles was estimated to be 998±99 tonnes (Table 3, Fig. 8). Of this 956±96 or 96% of the biomass was of commercial density.

Sub area Top Section South Bull: Total biomass of cockles was estimated to be 696±103 tonnes (Table 4, Fig. 8). Of this 543±75 tonnes or 78% of the biomass was of commercial density.

Sub area North Bull: Total biomass of cockles was estimated to be 397±93 tonnes (Table 5, Fig. 8). Of this 383±91 tonnes or 96% of the biomass was of commercial density.

The overall biomass of cockles in Dundalk Bay was estimated to be 2,277±172 tonnes. Of this 2,049±153 tonnes or 90% of the biomass was of commercial density.

Table 2. Distribution and estimate of biomass of all cockles in the Lower section of the South Bull (Annagassan). CL= 95% confidence intervals.

Lower Section South Bull	Area (m^2)	Number (m^{-2})			Weight (g)			Biomass (gm^{-2})		Biomass (kg)	
Contour ID		Count	Mean	CL	Count	Mean	CL	Mean	CL	Mean	CL
0-4	569,868	19	1.68	0.91	8	17.86	4.32	30.00	17.84	17,099	10,164
20-40	422,979	9	10.22	2.95	21	9.37	2.26	95.76	36.07	40,505	15,255
20-40	168,122	8	24.00	2.57	52	11.42	1.82	274.08	52.57	46,079	8,838
40-60	96,463	5	51.20	5.76	62	10.23	1.28	523.78	88.31	50,525	8,518
60-80	41,983	3	68.00	8.68	17	9.09	2.16	618.12	166.91	25,951	7,008
80-100	5,387	3	88.00	10.40	22	8.66	2.63	762.08	248.55	4,105	1,339
									Total	184,264	23,186
									Commercial	167,165	20,840

Table 3. Distribution and estimate of biomass of all cockles in the Middle Section of the South Bull. CL= 95% confidence intervals.

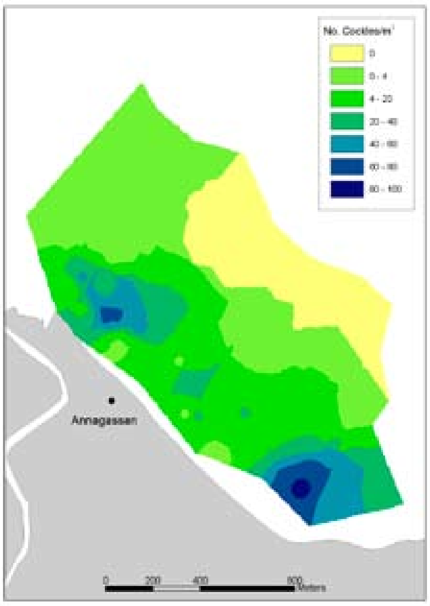
Middle Section South Bull	Area (m^2)	Number (m^{-2})			Weight (g)			Biomass (gm^{-2})		Biomass (kg)	
Contour ID		Count	Mean	CL	Count	Mean	CL	Mean	CL	Mean	CL
0-4	3,622,669	50	1.04	0.49	12	11.28	3.21	11.73	6.47	42,498	23,432
20-40	5,651,882	78	9.85	0.93	184	10.39	1.10	102.34	14.54	578,422	82,162
20-40	1,286,364	26	28.00	2.30	160	10.31	1.08	288.68	38.50	371,348	49,530
40-60	16,161	3	45.30	2.61	33	8.56	1.66	387.77	78.52	6,267	1,269
									Total	998,535	98,765
									Commercial	956,036	95,945

Table 4. Distribution and estimate of biomass of all cockles in the Top Section of the South Bull. CL= 95% confidence intervals.

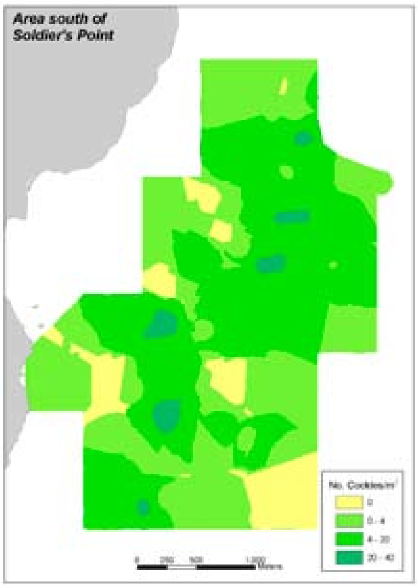
Top Section South Bull	Area (m^2)	Number (m^{-2})			Weight (g)			Biomass (gm^{-2})		Biomass (kg)	
Contoured densities		Count	Mean	CL	Count	Mean	CL	Mean	CL	Mean	CL
0-4	3,155,961	41	1.46	0.60	15	33.28	7.15	48.59	22.44	153,344	70,828
20-40	3,574,701	44	9.91	1.24	72	13.55	1.24	134.28	20.75	480,013	74,190
20-40	203,001	7	28.57	3.60	50	10.89	1.18	311.13	51.72	63,159	10,500
									Total	696,516	103,107
									Commercial	543,172	74,929

Table 5. Distribution and estimate of biomass of all cockles in the North Bull. CL= 95% confidence intervals.

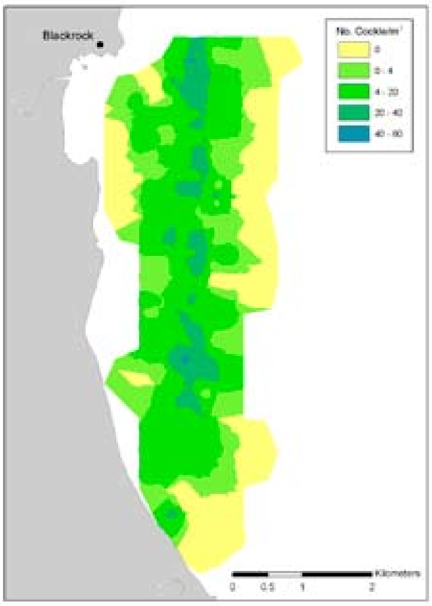
North Bull	Area (m^2)	Number (m^{-2})			Weight (g)			Biomass (gm^{-2})		Biomass (kg)	
Contour ID		Count	Mean	CL	Count	Mean	CL	Mean	CL	Mean	CL
0-4	1,533,347	25	0.80	0.64	7	12.24	13.19	9.79	13.14	15,015	20,149
20-40	1,483,097	27	12.74	4.83	68	10.53	2.46	134.15	59.68	198,961	88,509
20-40	509,976	13	30.77	3.37	117	6.56	0.92	201.85	35.96	102,939	18,339
40-60	176,243	6	48.00	5.73	72	6.85	0.89	328.80	57.89	57,949	10,202
60-80	30,319	4	76.00	13.20	57	8.13	1.16	617.88	139.01	18,734	4,215
80-100	5,961	3	104.00	16.86	26	7.01	1.10	729.04	164.43	4,346	980
									Total	397,943	93,268
									Commercial	382,928	91,065



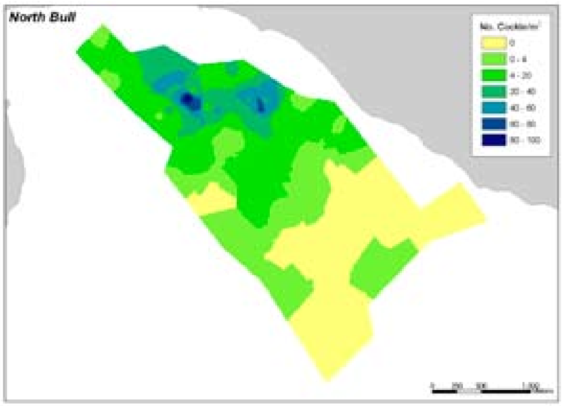
Lower Section South Bull



Top Section South Bull



Middle Section South Bull



North Bull

Figure 8. Distribution of cockles in 4 sections of Dundalk Bay in March 2007.

Waterford Estuary

August 2006

High densities of cockles occurred in the western part of the survey area reaching densities of over 900m^{-2} although this density occurred in only 1 sample (Fig. 9)

The total biomass of cockles in the section of Woodstown surveyed in August 2006 was estimated to be 476±70 tonnes (Table 6).

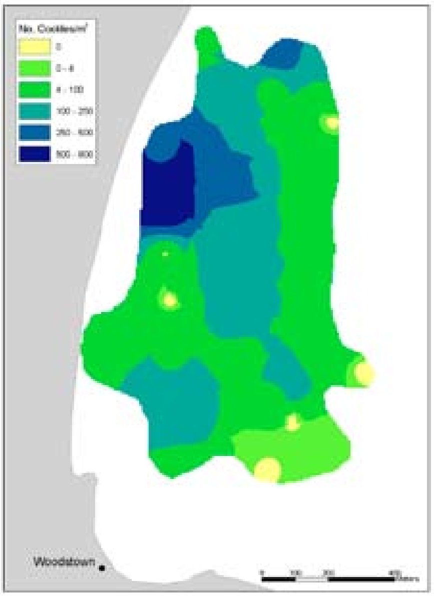


Figure 9. Distribution of cockles in the Woodstown area in August 2006.

March 2007

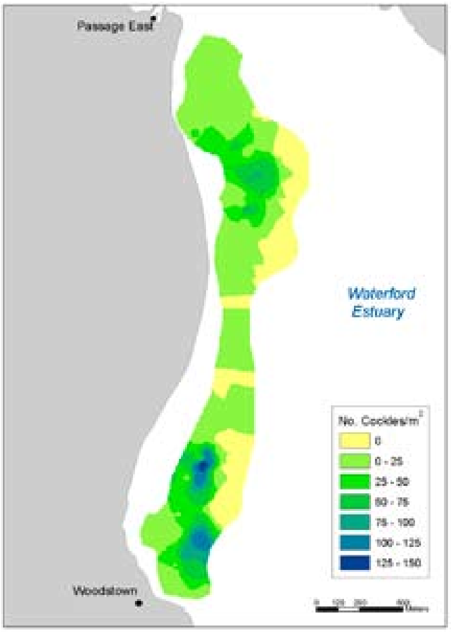
In Woodstown higher densities occurred in the centre and north east of the survey area. In Passage East highest densities occurred in the southern part of the survey area. Highest densities were 150m^{-2}. Cockles tended to be absent on the eastern borders of the survey areas in both Woodstown and Passage (Fig. 10).

Densities of cockles in the Back Strand of Tramore Bay were higher than in the Waterford Estuary reaching over 1300m^{-2} in the centre of the survey area. Cockles occurred throughout the survey area except at the extreme south east corner (Fig. 10).

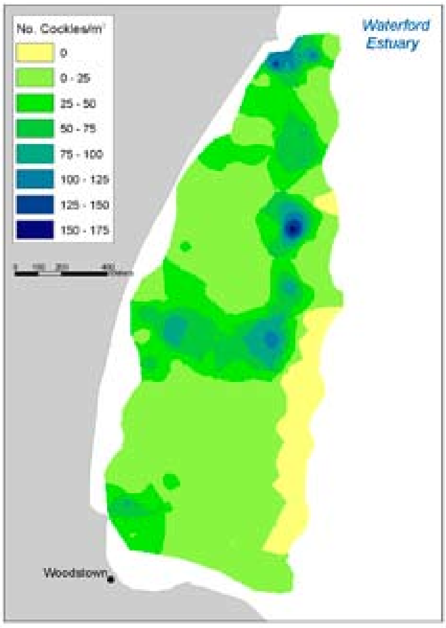
The total biomass of cockles in Woodstown and Passage East was estimated to be 284±22 tonnes and 267±26 tonnes respectively (Tables 7 and 8). In Tramore there was an estimated 2,303±403 tonnes (Table 9).

Table 6. Numbers of cockles within different density contours in Woodstown in August 2006.

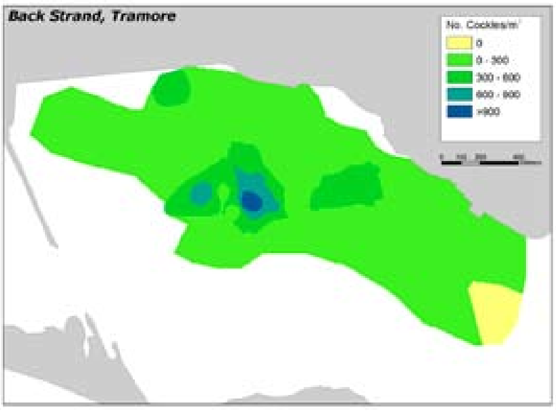
Contour	Area (m^2)	Number (m^{-2})			Weight (g)			Biomass (gm^{-2})		Biomass (kg)	
		Count	Mean	CL	Count	Mean	CL	Mean	CL	Mean	CL
0-4	60,159	4	4	0.00	10	3.90	0.12	15.6	0.5	938	27
4-100	354,230	17	37.43	26.33	20	4.24	0.08	158.7	111.8	56,217	39,561
100-250	249,839	4	191.5	15.78	30	4.22	0.07	808.1	68.2	201,902	16,938
250-500	69,999	5	316.8	124.12	20	4.10	0.08	1298.9	509.5	90,920	35,668
500-900	35,030	3	852	284.94	20	4.23	0.08	3604.0	1207.3	126,247	42,291
									Total	476,225	70,091



Passage East



Woodstown



Tramore

Figure 10. Distribution of cockles in Passage East, Woodstown and Tramore in March 2007.

Table 7. Distribution and estimate of biomass of all cockles in Woodstown in March 2007. CL=95% confidence intervals.

Contour	Area (m^2)	Number of cockles (m^{-2})			Weight (g)			Biomass (gm^{-2})		Biomass (kg)	
		Count	Mean	CL	Count	Mean	CL	Mean	CL	Mean	CL
0-25	907924	51	7.53	2.06	86	8.71	0.67	65.59	18.65	59,547	16,930
25-50	293372	12	38.33	4.07	109	7.46	0.50	285.94	35.97	83,887	10,552
50-75	166514	3	61.33	5.65	43	6.27	0.39	384.54	42.59	64,031	7,092
75-100	57931	6	82.67	7.07	116	10	0.68	826.70	90.26	47,892	5,229
100-125	16322	3	108	11.36	64	12.5	0.61	1350.00	156.43	22,035	2,553
125-150	4060	3	132	13.78	33	9.11	0.53	1202.52	143.86	4,882	584
150-175	684	3	156	16.2	37	12.07	0.79	1882.92	231.08	1,288	158
									Total	283,562	21,966

Table 8. Distribution and estimate of biomass of all cockles in Passage East in March 2007. CL=95% confidence intervals.

Contour	Area (m^2)	Number of cockles (m^{-2})			Weight (g)			Biomass (gm^{-2})		Biomass (kg)	
		Count	Mean	CL	Count	Mean	CL	Mean	CL	Mean	CL
0-25	617814	48	8	2.4	101	12.22	0.74	97.76	29.93	60,397	18,490
25-50	167181	4	38	8.08	38	10.63	1.48	403.94	102.57	67,531	17,147
50-75	94107	2	66	2.77	33	11.75	0.69	775.50	55.75	72,980	5,246
75-100	32666	4	82	5.88	82	12.53	0.51	1027.46	84.58	33,563	2,763
100-125	19420	3	116	3.7	87	13.02	0.54	1510.32	78.83	29,330	1,531
125-150	2393	3	148	18.67	37	13.62	0.73	2015.76	276.37	4,824	661
									Total	268,626	25,958

Table 9. Distribution and estimate of commercial biomass of cockles in Tramore Bay in March 2007. CL=95% confidence intervals.

Contour	Area (m^2)	Number of cockles (m^{-2})			Weight (g)			Biomass (gm^{-2})		Biomass (kg)	
		Count	Mean	CL	Count	Mean	CL	Mean	CL	Mean	CL
0-300	1517207	38	86.21	27.36	763	8.3	0.35	715.54	229.07	1,085,627	347,552
300-600	202437	3	438.67	116.66	229	8.13	0.62	3566.39	986.88	721,969	199,780
600-900	41439	2	754	69.3	199	11.55	0.43	8708.70	863.79	360,880	35,795
>900	8905	3	1216	197.06	100	12.44	0.46	15127.04	2513.54	134,706	22,383
									Total	2,303,182	403,097

Size, age and growth of cockles

Methods

Growth of cockles, like most bivalve species in temperate waters, is relatively easy to estimate because of the formation of annual rings or bands on the shell. Growth rings are formed after a winter stage of no growth, or very slow growth, that is associated with a decline in water temperature. Size at age data were obtained by measuring size and counting annual growth rings. The von Bertanlanffy function was used to model growth. This function is given by:

$$H_t \pm H_\infty \,[1\text{-exp}\,(-k(t\text{-}t_0))\,]+\varepsilon \qquad (1)$$

Where H_t is shell height at age t, H_∞ is the asymptotic height, k is the curvature parameter, t_0 is the estimated age at zero height and ε an error term that is assumed to be normally distributed and to have homogeneous variance. The growth model described in Equation (1) was fitted to mean size at age. Growth parameters were estimated separately for the Dundalk Bay and the Waterford Estuary. Growth estimates were used to calculate the yield per recruit (YPR) to investigate size at recruitment to the fishery that provides highest YPR.

Cockle sub-samples were selected for age determination ensuring that all size-classes in the age samples were represented. Size-frequency data was converted to age-frequency using an age length key (Appendix II).

Results

Dundalk Bay

The size distribution of cockles for 2006 and 2007 surveys showed different proportions of small cockles (Fig. 11 and 12). These differences are related to the time of year in which the surveys were completed. Cockles utilise the spring phytoplankton bloom to stimulate gametogenesis (Newell and Bayne, 1980) and spawning occurs mostly from May to July (Dare *et al*., 2004). The March survey was, therefore, too early to detect the 2007 settlement.

In Annagassan in 2006 four year classes were observed (Fig. 13). The 0+ age class accounted for 50% of the overall cockle population. Age classes 1+ and 2+ accounted for 30 and 15% respectively. In March 2007 five year classes were observed (Fig. 14). Between 57 and 70% of the population was age class 1+. Age class 0+ did not include 2007 settlement as the survey was carried out before the main spawning event occurred. Between 2-18 % of the cockle population was age class 0+ corresponding mostly to 2006 settlement. Age class 2+ accounted for 10-27%. Age classes 3+, 4+ and 5+ were less frequent accounting for 3-6%, 1-3% and 1-2%, respectively.

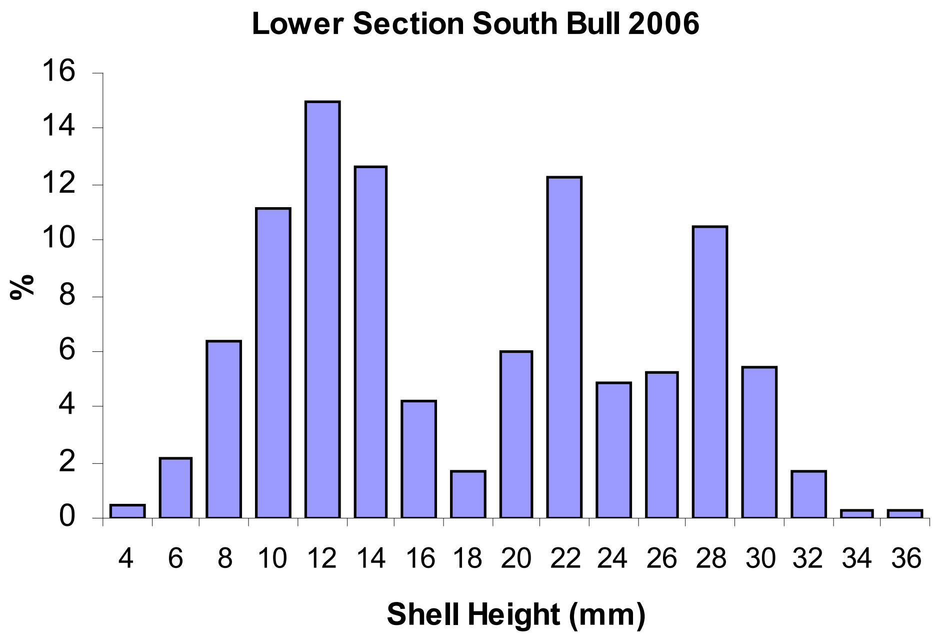


Figure 11. Size distribution of cockles in the Annagassan area in October 2006.

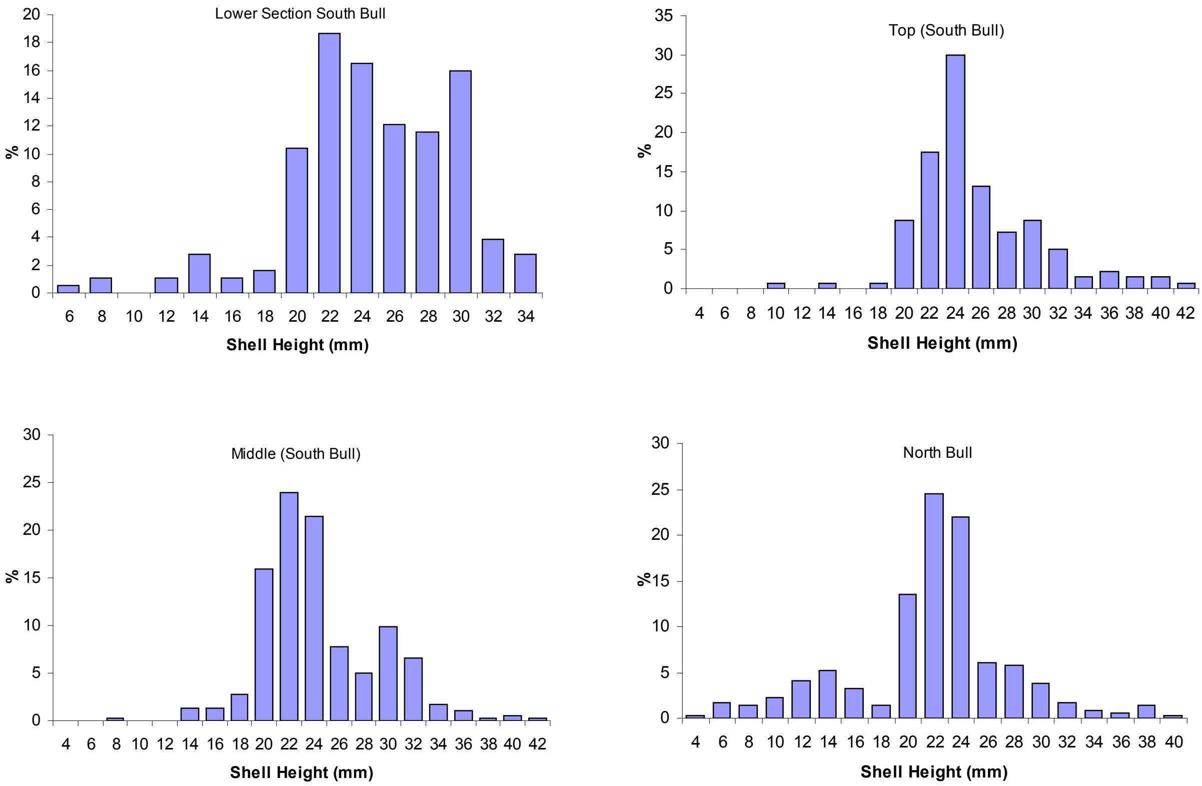


Figure 12. Size distribution of cockles for each sub-area of Dundalk Bay in March 2007.

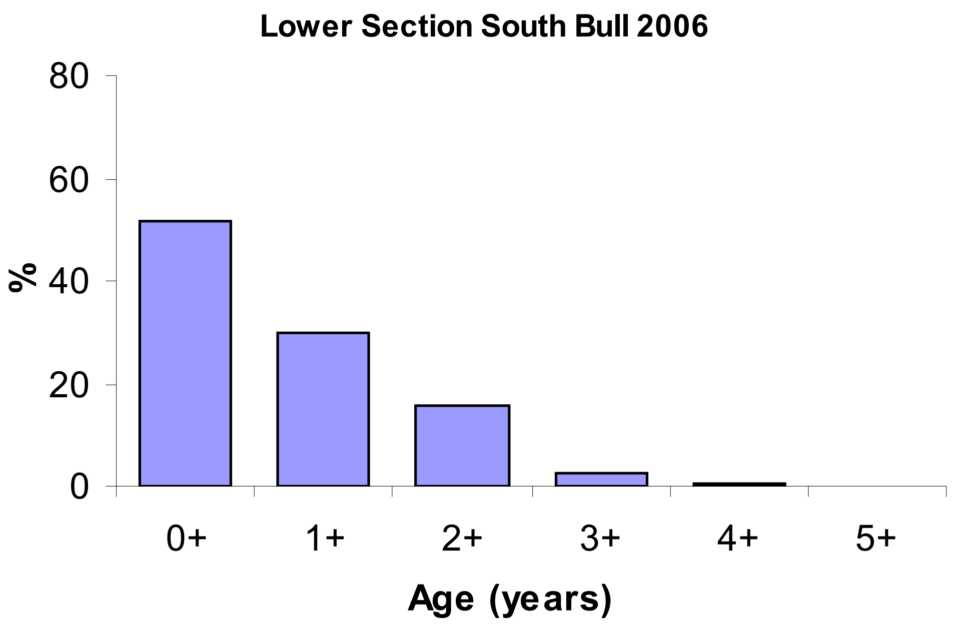


Figure 13. Age distribution of cockles in the Annagassan (Lower Section South Bull) area in October 2006.

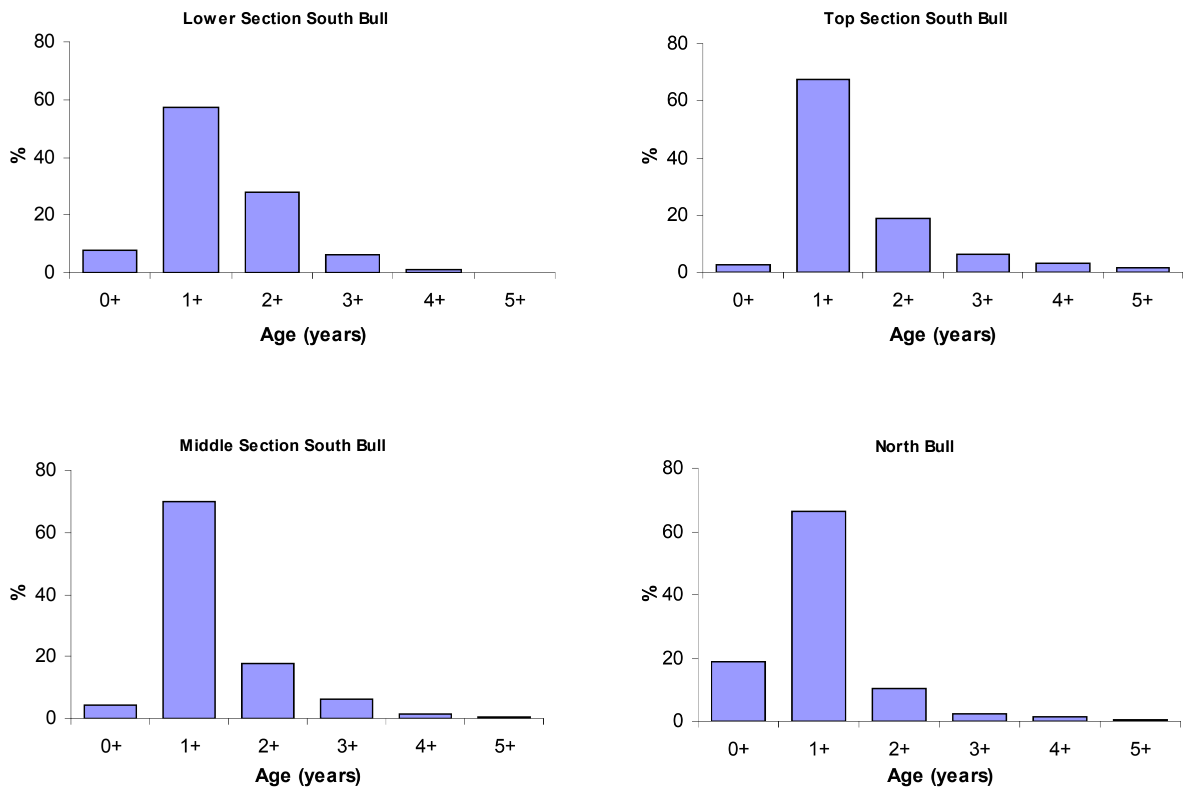


Figure 14. Age distribution of cockles for each sub-area of Dundalk Bay in March 2007.

Six age groups were used to fit the von Bertanlaffy growth curve. Growth parameters estimates were; H_{∞} = 44.39 mm, K = 0.34 and t_0 = -1.02 (Fig. 15 and Table 9).

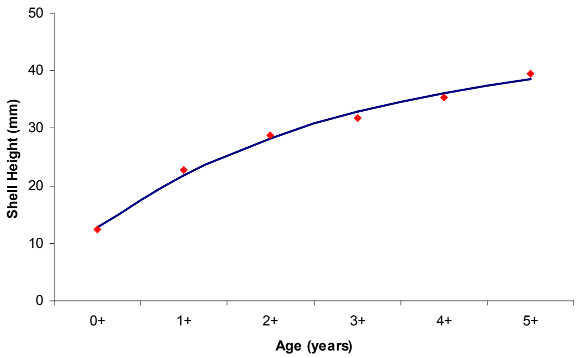


Figure 15. von Bertalanffy growth curve for cockles in Dundalk Bay.

Table 10. Size at age data used to fit the growth curve (Fig. 13) for cockles from Dundalk Bay. N = Number of measurements; O (H) = Observed mean shell height; E (H) = Expected shell height from model; CL = Confidence limit.

Age	0+	1+	2+	3+	4+	5+
N	42	235	85	36	11	7
O (H) (mm)	12.37	22.79	28.67	31.77	35.34	39.50
E (H) (mm)	12.84	21.83	28.26	32.86	36.15	38.49
CL (95%)	1.28	0.24	0.56	0.61	1.90	1.46

Waterford Estuary

As with Dundalk Bay, differences in the proportion of smaller cockles between 2006 and 2007 were due to the timing of the surveys. Twenty-five percent of the population was between 4-10mm in shell height in August (Fig. 16) indicating that settlement strength might be detected by carrying out the survey in August. Recent settlement was not detected in March 2007.

In Woodstown in 2006 5 age classes were observed in the samples (Fig. 17). However, age class 4+ only accounted for 4% of the overall population. In March 2007 6 age classes were observed and age classes 3+ and 4+ accounted for 51% and 35%, respectively. In Passage East age classes 3+ and 4+ accounted for 20% and 70% of the population respectively. In Tramore Bay 31% and 43% of the population were age classes 3+ and 4+ respectively.

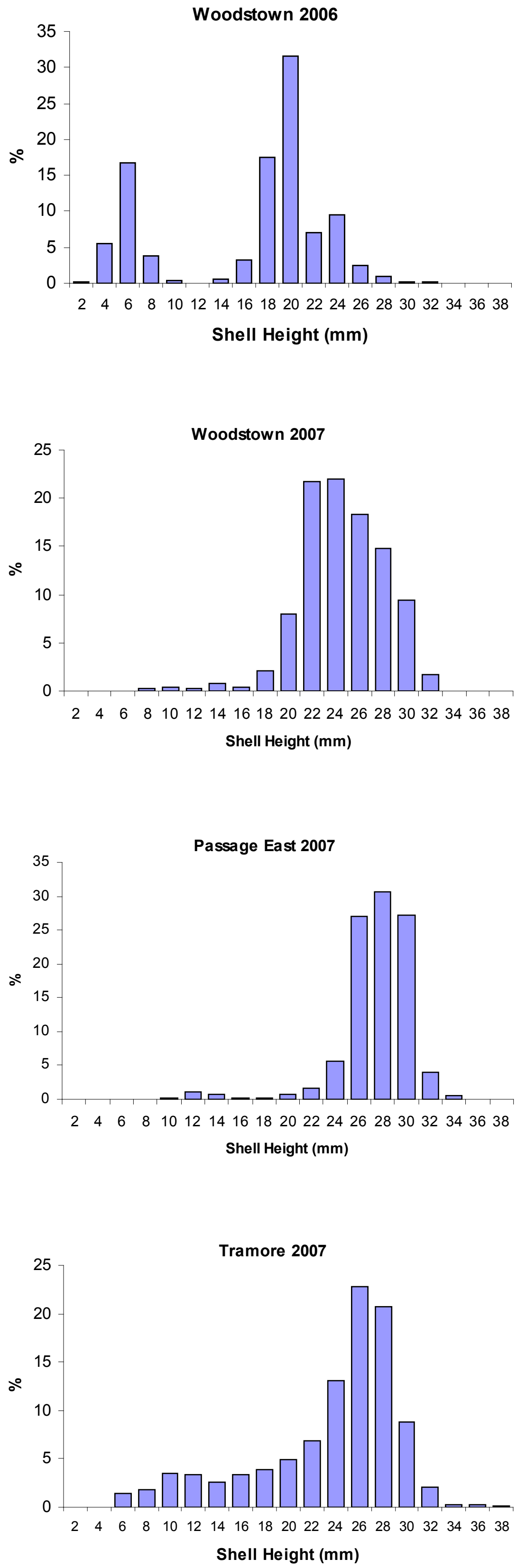


Figure 16. Size distribution of cockles for each sub-area of the Waterford Estuary in March 2007.

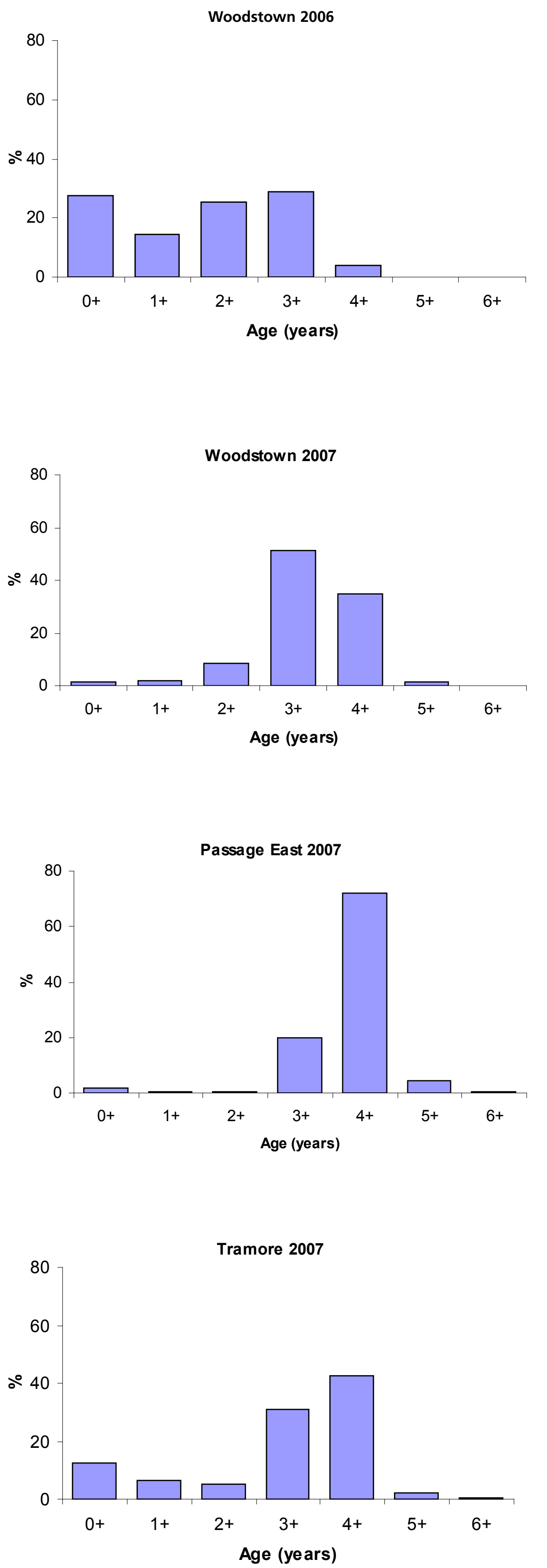


Figure 17. Age distribution of cockles for each sub-area of the Waterford Estuary in March 2007 and for Woodstown in August 2006.

Six age classes were identified (Fig. 18). Growth parameter estimates were; H_{∞}= 41.66mm, K=0.19 and t_0= -1.67.

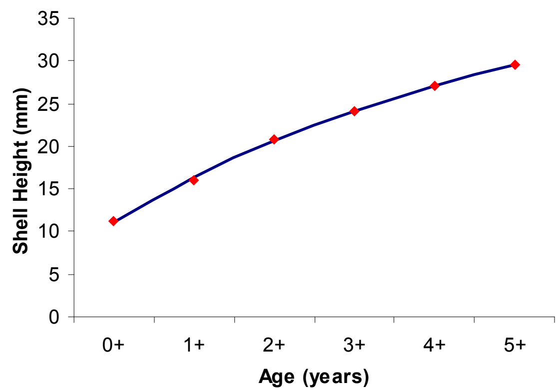


Figure 18. von Bertalanffy growth curve for cockles in the Waterford Estuary.

Table 11. Size at age data used to fit growth curve (Fig. 18) for cockles from the Waterford Estuary. N = Number of measurements; O (H) = Observed mean shell height; E (H) = Expected shell height; CL = Confidence limit.

Age	0+	1+	2+	3+	4+	5+
N	180	47	34	180	254	19
O (H) (mm)	11.21	16.00	20.79	24.17	27.12	29.56
E (H) (mm)	11.11	16.28	20.58	24.16	27.12	29.59
CL (95%)	0.38	0.54	0.49	0.29	0.20	1.07

Overwintering mortality

Overwintering mortality of cockles was calculated for the Annagassan area in Dundalk Bay and for the Woodstown area in the Waterford Estuary. In Annagassan the average density of cockles in October 2006 was 35±7m^{-2} and 25±8m^{-2} in March 2007. In Woodstown the average density of cockles in August 2006 was 122±56m^{-2} and 22±8m^{-2} in March 2007. As presumably there was no major recruitment between August 2006 and March 2007 this suggests that the overwintering mortality in Dundalk was 29±27% or expressed as the instantaneous rate (M) 0.33±0.31 and 82±11% or 1.69±0.11 (M) in Waterford. Overwinter mortality was highest in the 0+ age class.

Yield per recruit (YPR) assessment

Methods

The YPR model (Beverton and Holt, 1993) is used in the assessment of fisheries to provide growth overfishing reference points that indicate the optimum exploitation rate, which balances gains in yield due to growth and losses due to mortality. Growth overfishing occurs when fish are captured before they have grown large enough to maximize YPR. The YPR model assumes that the population is in a stationary state or that the population is not changing with respect to size composition, growth rates, mortality and/or recruitment over time. Under the stationary state assumption the total annual yield from the population at any one time is the same as that from the fishable lifespan of any one of its component year classes. Cockle populations are not usually in a stationary state (Dare *et al*., 2004). Therefore the use of the YPR, in the assessment of cockle population, to define biological reference points can be misleading. However, if the YPR is only used to investigate the size at recruitment that maximises yield and the model is not used to advise on biological reference points then the assumption of stationarity and constant recruitment is not so relevant.

In this study the size at recruitment at which YPR was highest was estimated. YPR curves were computed for 17mm, 20mm and 22mm shell width at three different rates of natural mortality; 0.3, 0.5 and 0.7. The model (following Haddon, 2001) was run for 1000 recruits from age at 17mm shell width, or the lowest size at recruitment, to t_{max}=15 years, which gave a sufficiently large number of years to run the cohort to extinction.

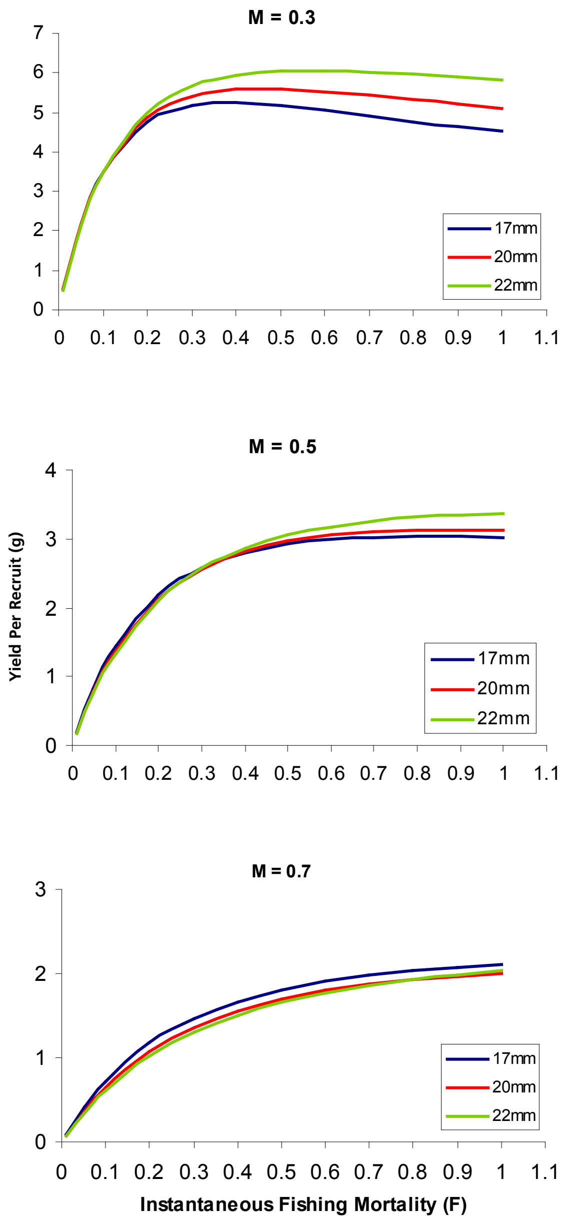


Figure 19. YPR curves for Dundalk Bay for sizes at recruitment of 17, 20 and 22mm shell width for M values of 0.3, 0.5 and 0.7.

Results

Dundalk Bay

At M of 0.3 and F values greater than 0.2 YPR was greatest for size at recruitment of 22mm shell width (Fig. 19). YPR was lowest for 17mm shell width. At M of 0.5 the highest YPR was at 22mm but this was attained only at high values of F. At M of 0.7 highest YPR was at 17mm although the difference in yield compared to that at 20 and 22mm were small.

Waterford Estuary

In the Waterford Estuary YPR, for given values of F and M, increased with size at recruitment (Fig. 20).

At M of 0.3 differences in YPR between 17mm, 20mm and 22mm size at recruitment were insignificant at all values of F. At M of 0.5 and 0.7 highest YPR was at 17mm and lowest at 22mm.

In general, as M increased the optimum recruitment size that maximised YPR decreased. This concept can be visualised by plotting the biomass at age as a balance of growth and natural mortality (Fig. 21). As M increases the critical age, the age at which biomass is greatest, decreases and therefore the size/age at recruitment to the fishery that maximises yield also decreases.

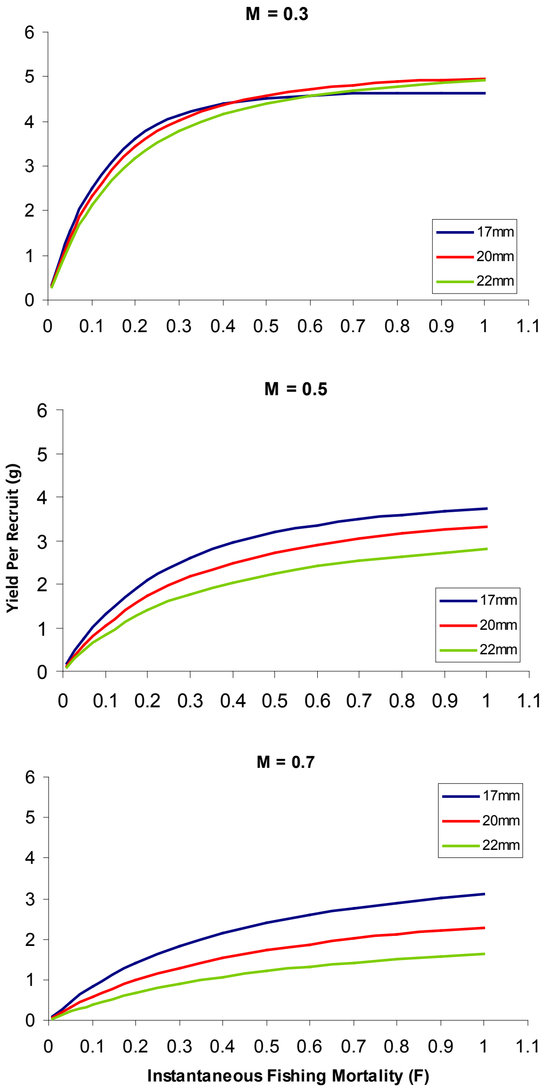


Figure 20. YPR curves for Waterford Estuary for sizes at recruitment 17, 20 and 22 mm in shell width in relation to M.

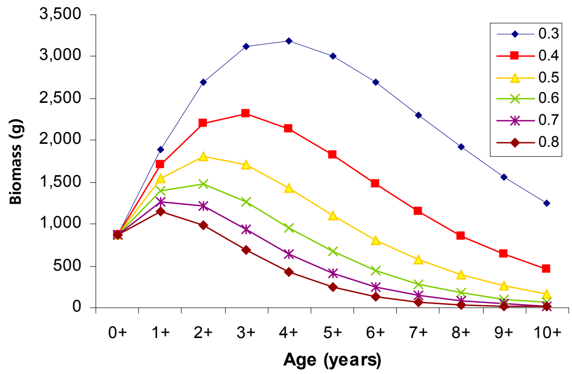


Figure 21. Biomass at age per 1,000 recruits as a balance of growth and natural mortality (F=0).

Cockle fishery management plans 2007

Cockle survey data, which provided estimates of the biomass of cockles in Dundalk Bay and Waterford Estuary and its distribution, together with information on the size and age of cockles at these sites was used to formulate fishery management plans for these areas in 2007. The plans were agreed and appropriate legislation enacted before the fisheries were opened.

Basis and objectives

The management plans were designed to

1. Limit the total removals (through a total allowable catch, TAC) of cockles from the Bays in order to protect spawning potential and future recruitment
2. Limit the total removals of cockles to protect the food base for overwintering birds during the winter of 2007-2008
3. Minimise disturbance and allow for the recovery of benthic fauna by restricting the spatial and temporal distribution and extent of the fishery
4. Provide for fair and equitable access to the TAC for cockle fishermen

Dundalk Bay

Fishing methods

Fishing using hydraulic suction and non-suction dredges and hand raking were allowed. Fishing vessels were registered on the Irish Sea Fishing Register or on the Fishing Vessel Register in Northern Ireland. Hand raking was open to any member of the public and was unrestricted.

In order to reduce the possibility of exceeding the daily allowable catch (see below) maximum dredge blade widths of 0.75m, in the case of suction dredges, and 1.0m for non-suction dredges were allowed (Statutory Instrument (SI) 532/2007).

Geographic boundary of the fishery

Fishing activity was allowed in areas where generally cockle densities were, on average, greater than $4m^{-2}$. This was deemed by fishermen to be a minimum commercial density.

The boundary of the fishery (Fig. 22, Table 12) and as specified in SI 532/2007 was a practical compromise between allowing fishing only where commercial densities of cockle existed, allowing for reasonably contiguous fishing areas and minimising the percentage of the environmentally designated areas that were to be fished. The fishery area was 35% of the area over which cockles were distributed, 9% of the area designated as SPA and 11% of the area designated as SAC. The percentage of mud and sand flat, which is the habitat of qualifying interest, under the Habitats Directive, that was exposed to fishing, was higher, but not calculated, as not all the SAC is mud and sand flat.

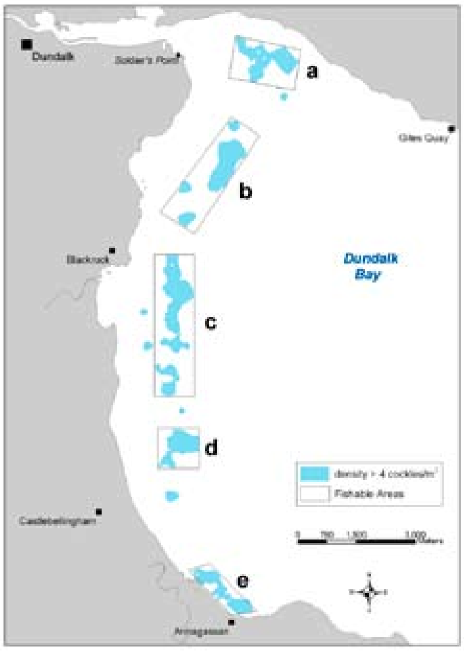


Figure 22. Boundaries of the fishery for cockles in Dundalk Bay in 2007 enclosing areas where the density of cockles is over $4m^{-2}$. The co-ordinates are given in Table 12.

Table 12. GPS co-ordinates for the boundary of the cockle fishery in Dundalk Bay in 2007.

ID	Area_sqm	Region	X(degree)	X(min)	X(sec)	Y(degree)	Y(min)	Y(sec)
a	1781615	North Bull	6	19′	14.91″ W	54	0′	29.78″ N
			6	17′	45.32″ W	54	0′	16.28″ N
			6	17′	57.37″ W	53	59′	43.53″ N
			6	19′	27.06″ W	53	59′	55.36″ N
b	2812078	South Bull - Top	6	19′	25.54″ W	53	59′	23.04″ N
			6	18′	47.64″ W	53	59′	6.98″ N
			6	20′	24.02″ W	53	57′	48.47″ N
			6	21′	10.35″ W	53	58′	6.88″ N
c	3723827	South Bull - Middle	6	21′	28.83″ W	53	55′	36.04″ N
			6	21′	21.49″ W	53	57′	32.08″ N
			6	20′	24.73″ W	53	57′	30.81″ N
			6	20′	31.90″ W	53	55′	34.82″ N
d	1047374	South Bull - Middle	6	21′	26.74″ W	53	54′	36.52″ N
			6	21′	24.67″ W	53	55′	9.21″ N
			6	20′	27.98″ W	53	55′	7.97″ N
			6	20′	30.06″ W	53	54′	35.26″ N
e	850722	Annagassan	6	20′	49.33″ W	53	53′	11.42″ N
			6	20′	19.71″ W	53	53′	16.53″ N
			6	19′	16.74″ W	53	52′	35.99″ N
			6	19′	51.10″ W	53	52′	33.04″ N

Table 13. Estimated biomass of cockles over 17mm width in commercial densities in Dundalk Bay in 2007.

Area		Biomass (t)
a	North Bull	329±75
b	Top section South Bull	456±50
c & d	Mid sections South Bull	880±58
e	Lower Section South Bull	171±15
Total		1,836±108

The Total Allowable Catch (TAC)

Survey estimates of the total biomass of cockles in the Bay in March 2007 was 2,277±172 tonnes of which 2,049±153 tonnes was distributed in commercial densities in areas a-e (Table 13). The biomass of cockles over the MLS of 17mm shell width was 1836±108 tonnes.

A total allowable catch of 950 tonnes, was agreed with the fleet. This was 41% of the total biomass and 52% of the biomass of commercial sized cockles in the fishable areas. Because of uncertainty in the biomass estimates, and given the minimum economically viable daily catch per vessel, the fishery was also to be closed, even if the TAC was not taken, if the daily catch, averaged for all vessels for any Monday to Friday period, fell to 250kg.

The TAC was not written in legislation in order to protect licence holders from unintentional taking of catch above the quota which could occur as the TAC limit was approached. Nevertheless, compliance with the TAC was ensured by daily monitoring of landings of all vessels. These data were submitted to BIM within 72 hours of the end of fishing on each Friday (SI 532/2007). A Fishery Management notice was also to be issued when 80% of the TAC had been taken in order to forewarn the fleet of a pending closure.

Restriction on fishing time

Commercial fishing took place from Monday to Friday, inclusive, and only between the hours of 07:00 and 19:00. The daily allowable catch had to be taken between those hours (SI 532/2007).

Daily allowable catch

The maximum allowable daily catch for each vessel was 1 tonne (SI 532/2007).

Minimum landing size and grading

The MLS was set at 17mm shell width (SI 532/2007). In effect, however, the actual landing size was higher than this because of the 22-24mm bar spacing used in the graders on board the vessels. The use of a grader at sea, to facilitate compliance with MLS was mandatory. The bar spacing was chosen by fishermen because the price per kg was higher for larger cockles.

Seasonal Closure

The area of Dundalk Bay was to be closed to cockle fishing on February 28th of 2008 irrespective of TAC or catch rate. The objectives of the closure were to allow for a re-assessment of the cockle population in the spring of 2008 and to protect recruiting cockles from disturbance.

Waterford Estuary

The objectives of the management plan and the fishery regulations for Waterford were similar to those in Dundalk (SI 531/2007).

The geographic boundaries of the fishery are in Fig. 23 and Table 14.

Total Allowable Catch (TAC)

There are 3 distinct beds of cockles in Waterford; Woodstown, Passage East and the Back Strand Tramore. The biomass of cockles, over 17mm shell width and distributed in commercial densities, in each of these areas in March 2007 was 2789±404 tonnes (Table 15).

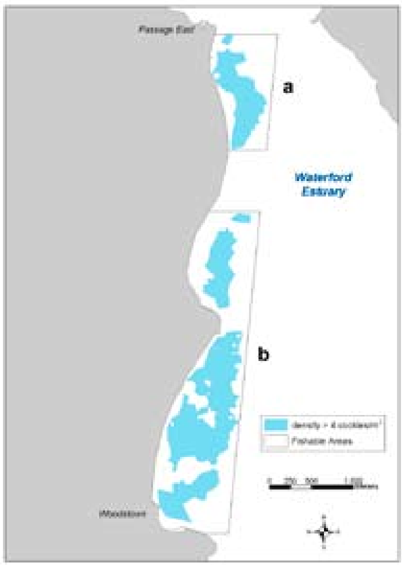


Figure 23. Boundaries for the fishery in Passage East and Woodstown in 2007.

Table 15. Biomass of cockles over 17mm width and TAC for cockles in Waterford in 2007.

Area	Biomass (t)	TAC
Woodstown	308±21	102
Passage East	280±25	92
Tramore	2,201±403	-
Total	2,789±404	194

The total allowable catch was set at 33% of the biomass for areas that had an agreed Management Plan. The TAC for Tramore remained at zero because no management plan was agreed.

Seasonal Closure

The fishery was to close on January 15th irrespective of the catch rate or whether the TAC had been taken.

Table 14. Geographic boundaries of the fishery in Passage East and Woodstown in 2007.

		Longitude			Latitude	
Area	X(deg)	X(min)	X(sec)	Y(deg)	Y(min)	Y(sec)
a	-6	58′	14.76″ W	52	14′	19.20″ N
	-6	57′	32.61″ W	52	14′	18.48″ N
	-6	58′	7.96″ W	52	13′	34.54″ N
	-6	57′	41.76″ W	52	13′	34.09″ N
b	-6	58′	22.18″ W	52	13′	10.79″ N
	-6	57′	46.72″ W	52	13′	10.16″ N
	-6	58′	12.39″ W	52	11′	6.48″ N
	-6	58′	26.87″ W	52	11′	6.72″ N

Monitoring of the fishery in 2007

Catch and effort data

Daily catch and effort data was recorded by each vessel in a Fishing Activity Record (FAR) as required by SI 532/2007. For each day, the hours fished, the catch (kg) and the area(s) fished were recorded.

The total area dredged, in each of the fishing areas, was calculated using the product of towing speed, dredge width and dredge hours.

Catch and effort data were submitted to BIM within 72 hours of landing. Cumulative catch, the proportion of the TAC taken and dredge effort in each area were calculated at the end of every fishing week.

Calculation of pre-fishery biomass and exploitation rates using catch and effort data

The catch and effort data were analysed, using the Leslie and Davis (1939) depletion method, to provide an estimate of pre-fishery abundance that could be directly compared with the pre-fishery survey data and to estimate actual exploitation rates or the proportion of the biomass that was taken by the fishery.

Local depletion of stocks, over short time scales and at fine spatial scales, can be estimated under certain conditions. Leslie and Davis (1939) and Delury (1947) developed, what today, are known as the classic depletion methods to estimate population size. Application of these models to fisheries was discussed by Hilborn and Walter (1992) and Smith and Addison (2003). The Leslie model examines how successive, measured, removal of individuals influences the catch rate of the remaining population. The catchability is estimated from the decline in catch rate which is then used to estimate initial abundance. The model assumes a closed system, with no gains or losses in biomass other than that due to fishing.

The Leslie estimator is based on declines in the rate of catch as the total removals from the population accumulates and is obtained from the linear model:

$$LPUE_t = qN_1 - qK_{t-1} \qquad (8)$$

Where $LPUE_t$ is the landing per unit effort at a given time and expressed in kgs of cockles landed per hour, N_1 is the initial population abundance, q is the catchability coefficient and K_{t-1} is the cumulative catch prior to time t.

The use of CPUE as an index of abundance assumes that CPUE is proportional to stock abundance. Analytically this can be expressed as:

$$LPUE = q*N \qquad (9)$$

If *LPUE* is proportional to stock abundance then the coefficient q of the above equation is constant and any changes in *LPUE*, in this circumstance, are due to changes in N.

An analysis of variance of *LPUE* for non-suction and suction dredges, for different times during the season, was carried out to determine whether catchability of the two dredge types was different.

The following assumptions must be met if $LPUE_t$ is to be regarded as an unbiased population estimator:

1. The catch rate is proportional to abundance as defined by the expression $LPUE=q*N$, where q is the catchability.
2. The population in the study area is closed except for the removals. There is no immigration, emigration, recruitment, growth or natural mortality.
3. The catchability coefficient is constant. The fishing effort and the fish resource are considered randomly distributed and all fish are equally vulnerable to the fishing gear.

The LPUE estimate used to model the decline in catches was aggregated by week.

Results

Dundalk Bay: Landings and fishing effort

The Dundalk Bay fishery started on the 16th of July and ended on the 12th of October. During that time a total number of 652 tonnes of cockles were landed by dredgers. Fishing effort, in terms of boat days, and landings were highest in areas ***c*** followed by areas ***b***, ***a*** and ***d*** respectively (Table 13, Table 16). Fishing effort and landings in area ***e*** were almost non existent because of the logistical difficulties of operating dredges in this area because of shallow water. Fishing effort was highest in area ***d***, where the fishing ground was swept by the dredges 1.2 times, followed by areas ***b***, ***c*** and ***a*** where the ground was covered by the dredges 1.14, 1.12 and 0.57 times.

Table 16. Fishing effort (expressed in boat*days and proportion of area swept) and landings (tonnes) for each of the fishing areas of Dundalk bay in 2007.

Fishing Area		Fishing Effort		
Area ID	Area (km^2)	Boat*Days	Proportion Area Swept (%)	Landings (t)
a	1.782	152	57	89.9
b	2.812	383	112	208.9
c	3.724	481	114	272.2
d	1.047	137	124	79.7
e	0.851	1	0.7	0.8

At the start of the fishing season average daily landings per boat were approximately 800kgs of cockle for an average of 3.0hrs fishing (Fig. 24). Landings declined during the first six weeks and thereafter stabilised at approximately 450kgs per boat per day. Fishing times per boat per day increased to an average of 3.5hrs at the end of the season. On average LPUE was between 400-500 kg/hour at the start of the fishing season and 100-200 kg/hour at the end of the season (Fig. 25).

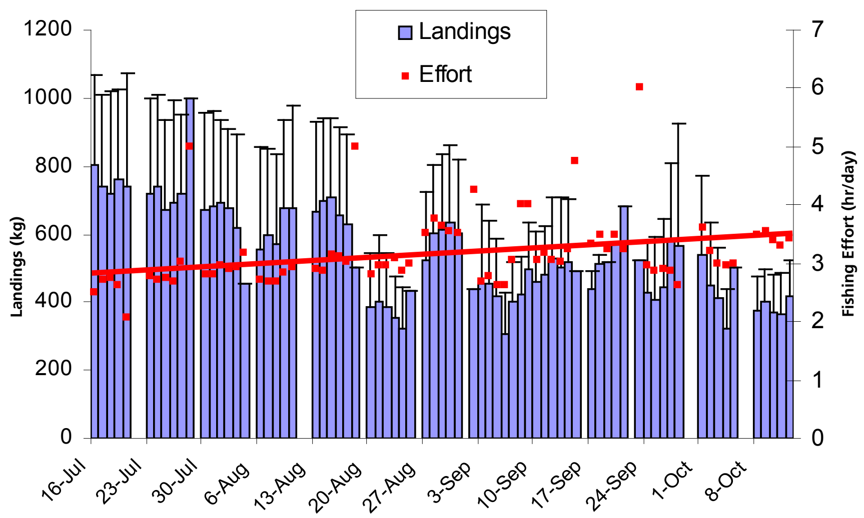


Figure 24. Trend in cockle landings and fishing effort during 2007 in Dundalk Bay. Blue bars show daily average landings ± standard deviation.

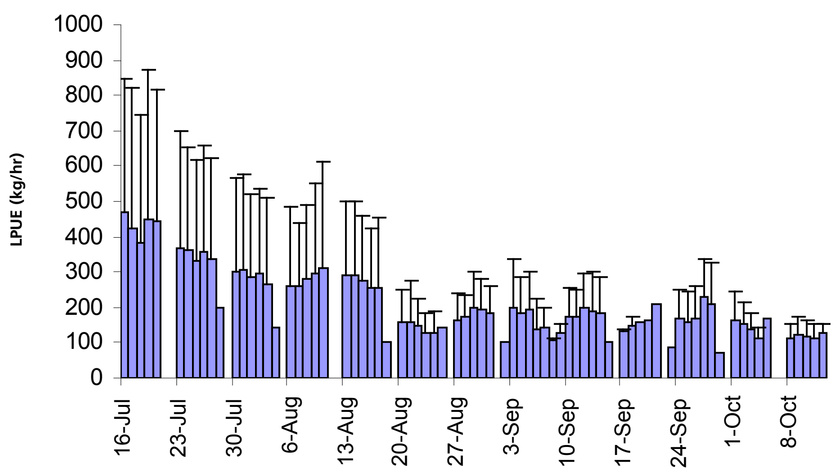


Figure 25. Trends in daily average LPUE(± standard deviation) during the 2007 cockle fishing season.

Depletion model estimates of biomass and exploitation rate

Suction dredges were the main dredge type used in area ***b***. In areas ***a***, ***c*** and ***d*** both types of dredges were used (Fig. 26). An analysis of variance of LPUE in relation to dredge type and week number showed that variability in LPUE due to dredge type was not significant (Table 17). Therefore catch rate data from both dredge types were combined to model the decline in catches.

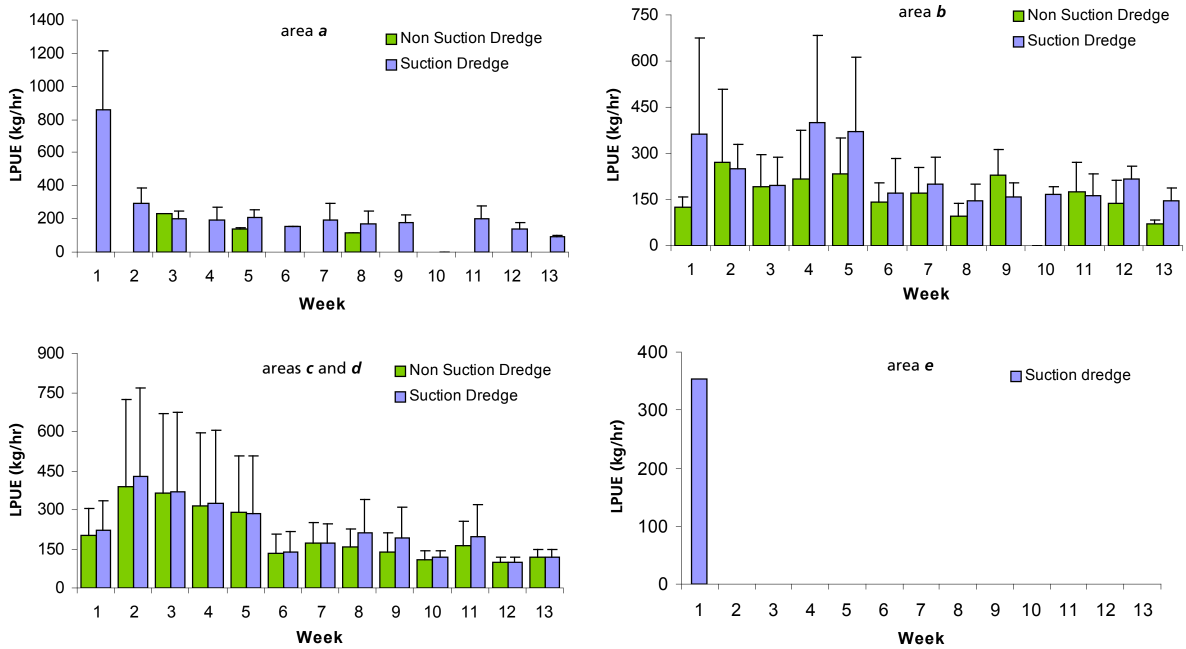


Figure 26. Trends in weekly landings per unit effort (LPUE) in cockle fishing areas ***a-e*** in Dundalk Bay. Average landings per unit effort and standard deviation are shown for non-suction and suction dredges.

Table 17. Analysis of variance of LPUE for non-suction and suction dredge type in different weeks.

	Area a					Area b					Area c-d				
Source	df	SS	MS	F-ratio	Prob	df	SS	MS	F-ratio	Prob	df	SS	MS	F-ratio	Prob
Const	1	1.14E+07	1.14E+07	559.2	<0.0001	1	1.67E+07	1.67E+07	886.6	<0.0001	1	6.36E+07	6.36E+07	2097.7	<0.0001
Week	11	1.99E+06	181256	8.9	<0.0001	12	1.18E+06	98089	5.2	<0.0001	13	4.11E+06	316360	10.4	<0.0001
Dredge	1	4678	4679	0.2	ns	1	20079	20079	1.1	ns	1	14199	14198	0.5	ns
Dredge week interaction	2	7149	3575	0.2	>0.5	11	513371	46670	2.5	<0.01	12	2.58E+06	214972	7.1	<0.0001
Error	138	2.82E+06	20443			355	6.68E+06	18826			1134	3.44E+07	30310		
Total	152	1.03E+07				379	9.09E+06				1160	4.85E+07			

Catch rate declined as cumulative catch increased in 3 areas selected for analysis (Fig. 27 and Table 18). Between 42-59% of the variance in catch rate was explained by the cumulative catch.

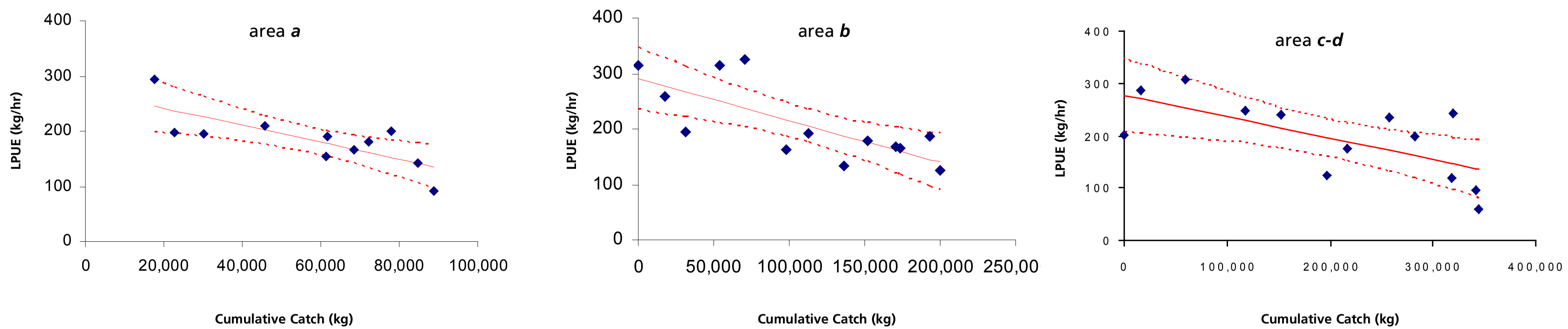


Figure 27. Relationship between LPUE and cumulative catch for fishing areas ***a-d***.

Table 18. Regression statistics for the Leslie Depletion model.

Fishing Area	DF	F-ratio	q	P	R
a	9	13.5	-0.001	0.0058	58.9
b	11	13.7	-0.00075	0.0035	55.4
c-d	11	8.7	-0.00041	0.0132	44.2

Initial population abundance, removals and exploitation rates in the 3 areas in which the depletion process was modelled are shown in Table 19. Exploitation rates varied between 51.7-54.2% in the areas fished.

Table 19. Leslie population estimators. Total cockle landings, pre-fishery biomass (N1) and Exploitation rates (E) in areas of the Dundalk Bay cockle fishery in 2007.

	Area a	Area b	Area c-d
N1 (kg)	176,386±20,614	385,404±15,134	676,836±106,964
Landings (kg)	89,880	208,943	350,801
E(%)±95%CL	51.7±6	54.20±2	51.8±7

Waterford Estuary

The cockle dredge fishery in the Waterford estuary began on the 13th of August and finished on the 14th of November. During that time 146.8 tonnes of cockles were landed of which 72.3 and 74.5 tonnes were landed in areas ***a*** and ***b*** respectively (Table 20). Total fishing effort, expressed in boat days, and landings were similar in both areas.

Table 20. Fishing effort and landings (tonnes) for each of the fishing areas of the Waterford estuary in 2007.

Fishing Area		Fishing Effort		
Area ID	Area Size (km^2)	Boat*Days	Proportion Area Swept (%)	Landings (t)
a	0.929	77	84	72.3
b	3.011	79	27	74.5

Daily landings per boat usually reached 1000kg throughout the season which was the maximum total daily catch allowed (Fig. 28). Fishing effort was irregular and tended to decrease during the season. There were no clear trends in LPUE (Fig. 29).

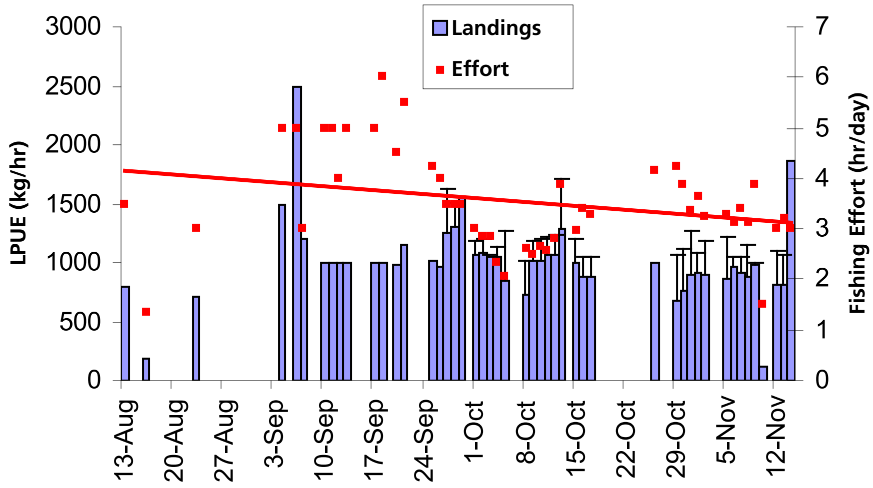


Figure 28. Trend in landings and fishing effort during the 2007 cockle fishing season in the Waterford estuary. Blue bars show daily average landings (± standard deviation).

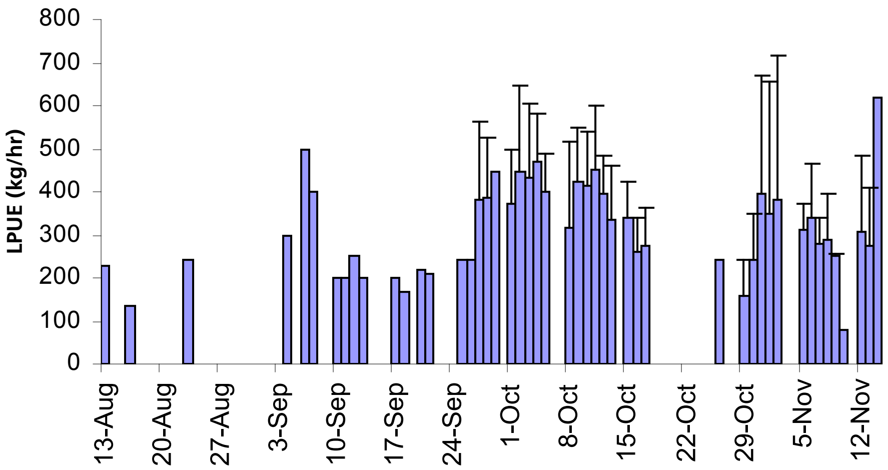


Figure 29. Trend in daily average LPUE (± standard deviation) in Waterford in 2007.

Depletion estimates of biomass and exploitation rate

The hydraulic suction dredge was used only at the end of the fishing season (Fig. 30). Catches were generally higher than catches using the non-suction dredge at this time. Analysis of depletion of the population, therefore, used the data for the non-suction dredge only.

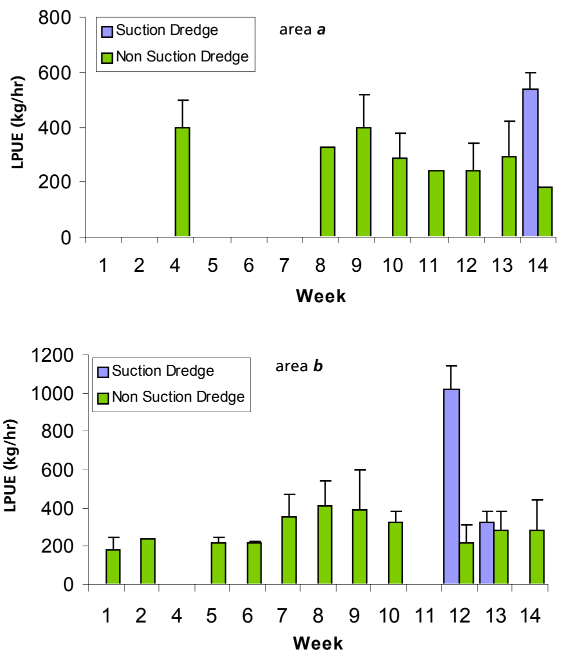


Figure 30. Trends in weekly landings per unit effort (LPUE) in cockle fishing areas ***a*** and ***b*** in the Waterford Estuary.

A decline in LPUE occurred, as cumulative catch increased, in area ***a*** but not area ***b***. Cumulative catch explained 74.8 % of variance in LPUE in area ***a*** (Fig. 31, Table 21).

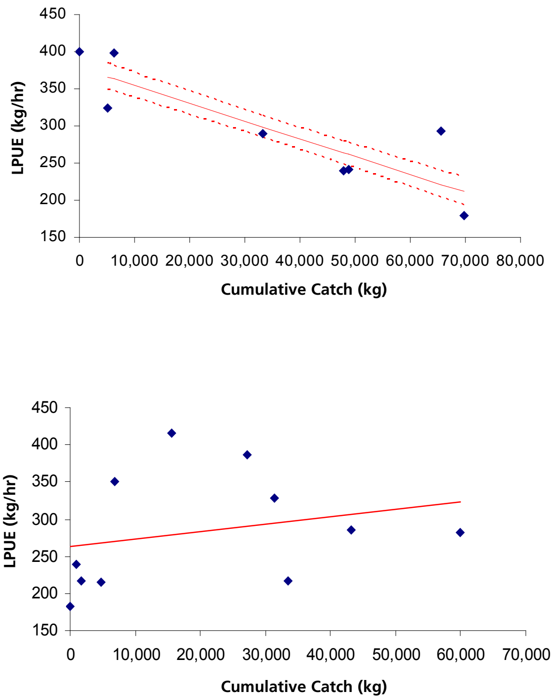


Figure 31. Relationship between LPUE and cumulative catch for fishing areas ***a*** (top) and ***b*** (bottom) in the Waterford estuary in 2007.

Table 21. Regression statistics for the Leslie Depletion model for the Waterford cockle fishery in 2007.

Fishing Area	DF	F-ratio	q	P	R (%)
a	6		-0.0024	0.0056	74.8
b	9		0.000996	0.4458	6.6

Landings, initial population abundance and exploitation rate in area ***a*** were estimated at 72 tonnes, 158 tonnes and 46% respectively.

Comparison of pre-fishery biomass estimates

Biomass of cockles was estimated separately by pre-season survey and by analysis of catch and effort data from the commercial fishery. Each approach has inherent limitations and assumptions. The survey sampled a small amount of the total ground accurately but nevertheless extensive interpolation was required i.e. estimation of cockle densities between sampling points was achieved statistically. Such surveys are particularly prone to uncertainty if the distribution of the target population is patchy and variable. Poor sampling in areas of high density in particular will lead to high variance. The planned two stage approach to sampling was designed to overcome this but was not fully achieved.

Retrospectively estimating the biomass from logbook data requires that a number of assumptions are met. The population should be closed with no recruitment or immigration and all cockles in the stock should have equal probability of capture. In particular the relationship between catch rate and the stock size (catchability) should be constant for all values of stock size used in the analysis. The length of the fishing season (3 months) is not a negligible period in relation to recruitment and/or natural mortality and the assumption of a closed system is a potential source of bias in the data. The closed system assumption may cause either positive or negative bias depending on which biological process has most effect; recruitment will lead to under estimation of exploitation rate while natural mortality will lead to overestimation of exploitation by the fishery. The assumption of constant catchability might be violated if there is not equal probability of capture as the stock is depleted. In this study CPUE was reported for relatively small areas and fishing effort within each of the areas was relatively high. Fishermen would have learnt about how cockles were distributed in the area as the fishing season progressed and may have targeted higher density patches first, or remained in such patches once they were found. They may also have been able to avoid areas that had previously been dredged thereby maintaining catch rate even as the stock size declined. There was in fact some indication that catch rate did not decline as quickly during the second part of the season compared to the first. On the other hand cockle density was relatively low and homogenous throughout the area which may have limited the information gained by fishermen on the best fishing locations during the season.

The pre-fishery survey estimated the biomass of all cockles. The fishery subsequently graded cockles prior to landing using a grader with a bar spacing of 22mm. To allow the two estimates to be compared directly the biomass of cockles over 22mm was re-estimated from the survey data. This estimate was lower than that calculated from the Leslie model in all fishing areas in Dundalk Bay (Table 22). Notwithstanding the assumptions above, the discrepancies between the estimates for cockles greater than 22mm may be accounted for by the unknown selectivity of the grader; the data used to model the depletion process may have included cockles less than 22mm thereby resulting in a greater biomass estimate than that of the survey.

Table 22. Comparison of biomass estimates and exploitation rates based on prefishery fishery independent survey and post-fishery analysis of logbook data (Leslie model). E(%) is the exploitation rate.

Dundalk							
Area	Name	Survey (t)		Leslie method (t)	Landings (t)	E (%) Survey	E (%) Leslie
		All sizes	>22mm	>22mm			
a	North Bull	383±91	157±27	176±20	89	57	50
b	Top Section South Bull	543±75	308±42	385±15	206	67	53
c & d	Mid Section South Bull	956±96	515±51	676±106	350	68	52
e	Lower Section South Bull	167±21	63±8	-	0	0	-
Waterford							
Area	Name	Survey (t)		Leslie method (t)	Landings (t)	E (%) Survey	E (%) Leslie
		All sizes	>22mm	>22mm			
a	Passage	269±26		158	72	27	46

Effectiveness of the management plan in 2007

The 2007 management plan limited total catch, dredging effort, the spatial distribution of dredging and the duration of the fishing season. Monitoring of catch and effort resulted in good quality catch and effort data which allowed, under a number of model assumptions, a post-fishery analysis of the exploitation rate to be calculated. The conditions under which the fishery would close were precautionary and pre-agreed in the management plan. Eventually, closure was in fact agreed before any of the pre-agreed conditions was reached because of concerns that the landings by hand rakers were high and difficult to estimate and because of concerns of uncontrolled access by both hand rakers and fishing vessels.

A number of weaknesses in the Management Plan can be identified which may limit the future capacity to manage and monitor the fishery.

Although the minimum landing size was set at 17mm the bar spacing on the graders used by the vessels was set at 22mm i.e. cockles above the minimum size between 17-22mm were discarded in addition to all cockles below the minimum size. The bar spacing on the grader used by the vessels was designed to optimise market value. High grading in catch limited fisheries is a common practice in many fisheries and introduces uncertainty about the true level of fishing mortality if the mortality rate of discards is not quantified. Given that in some cases over 100% of the fishable area was dredged some discarded cockles may have been caught more than once leading to cumulative increases in discard mortality. More information on discard survival is required or alternatively the fishing practice needs to be adjusted to reduce high grading or the fishery should be postponed until a larger proportion of the stock is above the desired commercial size.

In 2007 better correspondence between the minimum legal size (17mm), which was biologically based, and the effective commercial size (22mm), would have considerably reduced the amount of dredging required to take the TAC. This would have reduced impacts on undersized cockles and on non-target organisms. The best possibility for the maintenance of sustainable cockle populations is to reduce the frequency and intensity of dredging i.e. to use highly efficient dredges and reduce discard rates. Repeated dredging of undersized or 0-group cockles will increase mortality and may reduce recruitment to the fishery.

The number of vessels entering the fishery in 2007 was not controlled. As the main focus of the management plan was to take a TAC in only a proportion of the area over which cockles are distributed, and over a limited period of time, lack of control over the number of vessels entitled to enter the fishery could result in excessive pressures on the TAC and on fishing in restricted areas. It also puts at risk the economic viability of all vessels in the fishery and reduces the scope to find agreement on catch and effort levels. Agreement to limit the catch and the spatial extent of the fishery is only likely to be achieved if the number of vessels can be limited. Spatial restriction of fishing activity was a vital component of the management plan that provided a refuge to a proportion of the cockle stock and a habitat refuge for non-target organisms.

Hand raking was uncontrolled in 2007. Landings by handrakers were not estimated in this report but may have been as high as 200 tonnes and may have involved 100 individual rakers. This activity needs to be regulated and monitored if the landings are to be accurately estimated.

The management plan did not include an evaluation of the impact of the fishery on the habitat or on non target organisms. These areas are classified as SACs and SPAs and due consideration of the risks posed by the fisheries, to the conservation status of these sites, is necessary in this regard. Maintaining the functioning of the ecosystem is also vital to the future productivity of cockles. The approach taken was precautionary in limiting the spatial and temporal scale of the fishing activity. Nevertheless a more rigorous analysis of the impacts of fishing in relation to its scale and intensity needs to be undertaken ideally before, during and after the fishery and in fished and non-fished areas. The literature suggests that extrapolation of the effects of fishing from other sites may not always be valid (Dare *et al*., 2004). Although there is extensive literature on the impacts of dredging in cockle habitats none of this work has been done in Dundalk or Waterford. Environmental indicators should be identified that are easy to measure and quantify and that give more direct evidence, in these specific sites, for the level of impacts on non target organisms and on the sediment. Counts of over wintering waterfowl should be completed annually in order to correlate these with cockle biomass estimates and cockle fishing effort.

As spatial management of the site will be important in any future fishery and conservation management plans it is important to verify that the fishery is complying with spatial restrictions which may vary year on year depending on the pattern of cockle recruitment. The location of fishing activities should be verified using VMS technology or electronic logbook systems on the vessels which automatically record the vessel track.

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Appendix 1: The estimation of stock biomass

The numbers of cockles per sample were expressed in m^{-2}, assuming a linear relationship between number of cockles in a sample and area. Number of cockles m^{-2} were then contoured in ArcGIS using an Inverse Distance Weighting (IDW) algorithm which used the 3 nearest neighbour data points to provide interpolated density estimates throughout the survey domain. For each IDW class the mean number of cockles m^{-2} and the mean weight of cockles within the contour were used to calculate the mean biomass m^{-2}. The biomass and its confidence interval, within the geographic area encompassed by the contour, was calculated by raising the mean biomass m^{-2} to the area enclosed by the contour. The total biomass and its confidence interval was obtained by summing the biomass estimates and confidence interval of each of the IDW classes (or stratum). The number of algebraic steps involved in the estimation of cockle biomass is presented below:

1. The mean biomass m^{-2} and its confidence limits were calculated as:

   $$(X \pm x) * (Y \pm y) = X * Y \left(1 \pm \sqrt{\frac{x^2}{X^2} + \frac{y^2}{Y^2}}\right) \qquad (1)$$

   Where $(X \pm x)$ are the mean number of cockles m^{-2} and its confidence interval and $(Y \pm y)$ are the mean expected weight of cockle and its confidence interval. Mean biomass and confidence intervals were calculated as showed in Equation (3) of Elliott (1977).

2. For each contour the mean weight of cockles and its confidence interval $(Y \pm y)$ were calculated as follows:

   The relationship between shell height and weight is described by the power function:

   $$Weight_i = q*Height_i^b \qquad (2)$$

   where b is a constant that is close to the value of 3 if growth is isometric, and q is a constant that is determined empirically. Equation (2) is transformed to a linear form using the natural logarithms as:

   $$1\mathrm{n}(Weight_{i)} = 1\mathrm{n}q+b(1nHeight_i) \qquad (3)$$

   The sub-sample of cockles for which weight was obtained was used to estimate parameters q and b using equation (3). This was carried out independently for Dundalk Bay and Waterford Estuary fisheries. Once the parameters of equation (2) were estimated an expected weight was assigned to all cockles. The parameters of the size weight relationship were a = 0.00094 and b = 2.84 for Dundalk and a = 0.0002 and b = 3.31 for Waterford.

3. The biomass and its confidence interval for a given contour $(B_i \pm b_i)$ was then calculated by raising the biomass m^2 and its confidence interval to the total area of a given contour:

   $$(B_i \pm b_i) = (W_i \pm w_i) * A_i \qquad (4)$$

   Where $(W_1 \pm w_1)$ is the biomass m^{-2} and its confidence interval for a given contour i, and A_i is the area m^2 for a given contour i.

4. The total biomass and its confidence interval $(T \pm t)$ for a given fishing area were estimated by summing each contour estimate within each fishing area (Elliott, 1977).

   $$(T \pm t) = \sum_{i=1}^{n} (B_i \pm b_i) = \sum_{i=1}^{n} B_i \pm \sqrt{\sum_{i=1}^{n} b_i^2} \qquad (5)$$

5. As showed in Equation (6), the total biomass estimates were estimated by summing the estimates of each fishing area within Dundalk Bay or Waterford Estuary.

   $$(P \pm p) = \sum_{i=1}^{n} (T_i \pm t_i) = \sum_{i=1}^{n} P_i \pm \sqrt{\sum_{i=1}^{n} p_i^2} \qquad (6)$$

   Where $(P \pm p)$ is the population biomass of Dundalk Bay or Waterford Estuary.

Appendix 2:
Age length keys for cockles in Dundalk and Waterford

Age length key for cockles in Dundalk Bay in 2007.

Shell height	Number by size and age							Proportion of age class by size					
	0+	1+	2+	3+	4+	5+	totals	0+	1	2	3	4	5
2							0						
4							0						
6	2						2	1.00					
8	4						4	1.00					
10	10						10	1.00					
12	4						4	1.00					
14	11	1					12	0.92	0.08				
16	7						7	1.00	0.00				
18	1	2					3	0.33	0.67				
20		14					14	0.00	1.00				
22	1	69					70	0.01	0.99				
24	1	108					109	0.01	0.99				
26	1	38	7				46	0.02	0.83	0.15			
28		2	29	2			33		0.06	0.88	0.06		
30		0	26	5	1		32		0.00	0.81	0.16	0.03	
32		1	18	12	1		32		0.03	0.56	0.38	0.03	
34			5	14	3		22			0.23	0.64	0.14	
36				3	1		4				0.75	0.25	
38					3	2	5					0.60	0.4
40					2	1	3					0.67	0.33
42						3	3						1
44						1	1						1

Age length key for cockles in the Waterford Estuary in 2007.

Shell	Numbers by size and age								Proportion of age class by size						
Height	0+	1+	2+	3+	4+	5+	6+	total	0+	1	2	3	4	5	6
4								0							
6	18							18	1						
8	24							24	1						
10	47	1						48	0.98	0.02					
12	47	2						49	0.96	0.04					
14	23	17						40	0.58	0.43					
16		16						16		1.00					
18		11	5					16		0.69	0.31				
20			20	16	1			37			0.54	0.43	0.03		
22			7	54	0			61			0.11	0.89	0.00		
24			2	69	4			75			0.03	0.92	0.05		
26				32	48			80				0.40	0.60		
28				7	123	1		131				0.05	0.94	0.01	
30					66	8		74					0.89	0.11	
32					11	7		18					0.61	0.39	
34					1	0	1	2					0.50	0	0.5
36						3	0	3						1.00	0
38							1	1							1

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Fisheries Development Division,
Bord Iascaigh Mhara,
P.O. Box 12,
Crofton Road,
Dun Laoghaire,
Co. Dublin,
Ireland.

Tel: +353 1 2144 230
Fax: +353 1 2300 564
Web: www.bim.ie
Email: info@bim.ie

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