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SERIES B (Marine)

No. 20 (1979)

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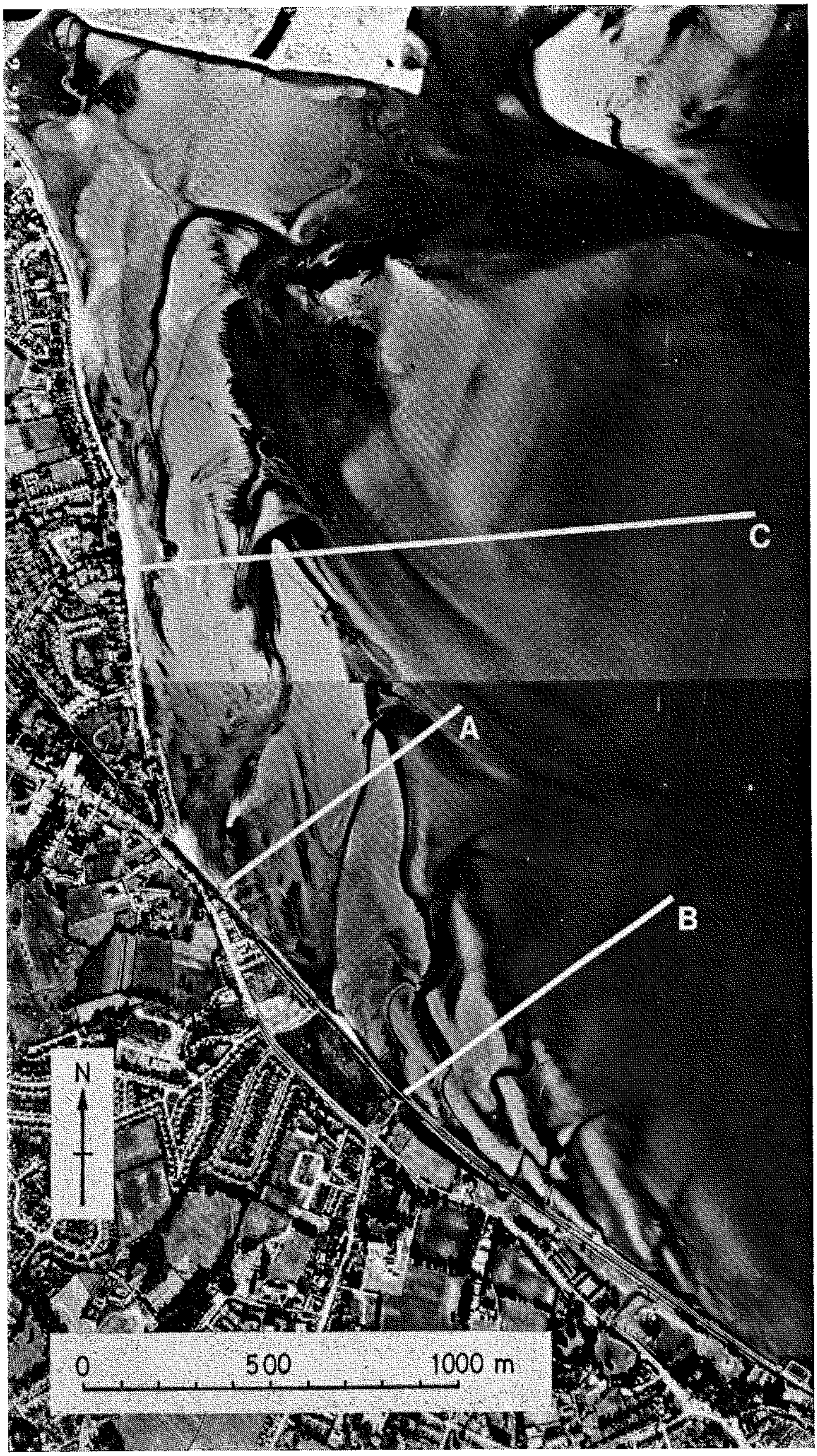

PLATE 1. Aerial photograph of the South Bull taken in October 1971 on a falling tide at about mid-water, showing the positions of transects A, B and C. Note the undulating nature of the beach and the pattern of drainage channels running in a northerly direction initially, more or less parallel to the high water mark, before turning eastwards. This photograph is reproduced by courtesy of Land Surveys (Ireland) Ltd.

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A. B. West, J. K. Partridge and A. Lovitt.

THE COCKLE *CERASTODERMA EDULE* (L.) ON THE SOUTH BULL, DUBLIN BAY: POPULATION PARAMETERS AND FISHERY POTENTIAL.

The cockle *Cerastoderma edule* (L.) on the South Bull, Dublin Bay: population parameters and fishery potential.

by

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ABSTRACT

The history of the Dublin Bay cockle fishery is reviewed briefly with emphasis on the period 1893-1913. Prior to 1900 some 80 tonnes of cockles are said to have been landed annually. In the subsequent decade the fishery declined and in recent times has been defunct.

The population of cockles on the South Bull, Dublin Bay, was investigated in 1971 and 1972. Cockles were distributed throughout the beach, but occurred in greater density in the mid-shore region. The mean density, however, was low (9-13 cockles per m^2) and the maximum recorded was only 51 per m^2; this is consistent with the relatively exposed nature of the beach. The population was dominated by 0+ and 1+ age groups, though cockles as old as 9+ were collected. The age structure was consistent with regular annual recruitment, and the mean mortality figure for cockles in their second, third, fourth and fifth years was $Z = 0.76$. The mean lengths at the end of the first four winters were 6.5, 22, 28.5 and 32 mm. The value of L_{∞} was 40 mm, and $K = 0.6$. The relationships between shell lengths and the weights of the shell, dry meat, wet meat, and shell + wet meat are described.

The potential of this cockle population for commercial exploitation is considered, although in view of the low population density the catch per unit effort would probably be too small to be commercially viable at present. Yield curves indicate that a minimum legal length of 24 mm would be appropriate for protection of the breeding stock while allowing the optimum yield to be obtained. The potential sustained yield of the beach was estimated at 4 tonnes/km^2 annually at a fishing mortality of $F = 0.10$.

INTRODUCTION

Towards the end of the nineteenth century some 4,000 tonnes of cockles, *Cerastoderma edule* (L.), were landed annually in Ireland and about 250 people were employed picking them. There was a substantial export trade. After 1900 the industry went into decline and gradually became defunct. It has never recovered although in England, even still, cockle landings exceed in weight those of any other species of shellfish (Kensler, 1976).

The object of this paper is to describe the cockle population of the South Bull, Dublin Bay. This was investigated with a view to gathering fundamental information about population density, size and age structure, growth rates and yield. The study was initiated as a consequence of the increasing interest in Irish bivalve fisheries, related in particular to the expansion of the export trade; and because of the paucity of information about cockles here, despite their former commercial importance.

History of the fishery

The fishery for cockles in Ireland is poorly documented. Undoubtedly this is due in part to the majority being collected by the poor, either for their own consumption or for sale locally, though there was a significant export trade to Britain. Fortunately, detailed records of landings were kept by the coastguards for the period 1893-1913 (Reports of Inspectors, 1894-1914). By coincidence these document the collapse of both the Belfast Lough and the Dublin Bay fisheries, and a steady decline in the landings for the whole country. Other important sources of information which relate to this period are the reports of Browne (1904) and McWeeney (1904). The landings of cockles which were usually recorded in gallons are cited here in tonnes, there being approximately 250 gallons per tonne.

Landings amounting to around 280 tonnes annually were recorded for the whole of Ireland in the 1890's (Table 1). This figure reflects only those cockles which reached the open market and, since the vast bulk were taken by local people for home consumption, it is a gross under-estimate of actual landings. Thus, Browne

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(1904) estimated that about 4,000 tonnes of cockles were landed annually throughout the country at that time. The recorded landings declined gradually between the years 1893 and 1913 to a level of about 120 tonnes at the end of that period.

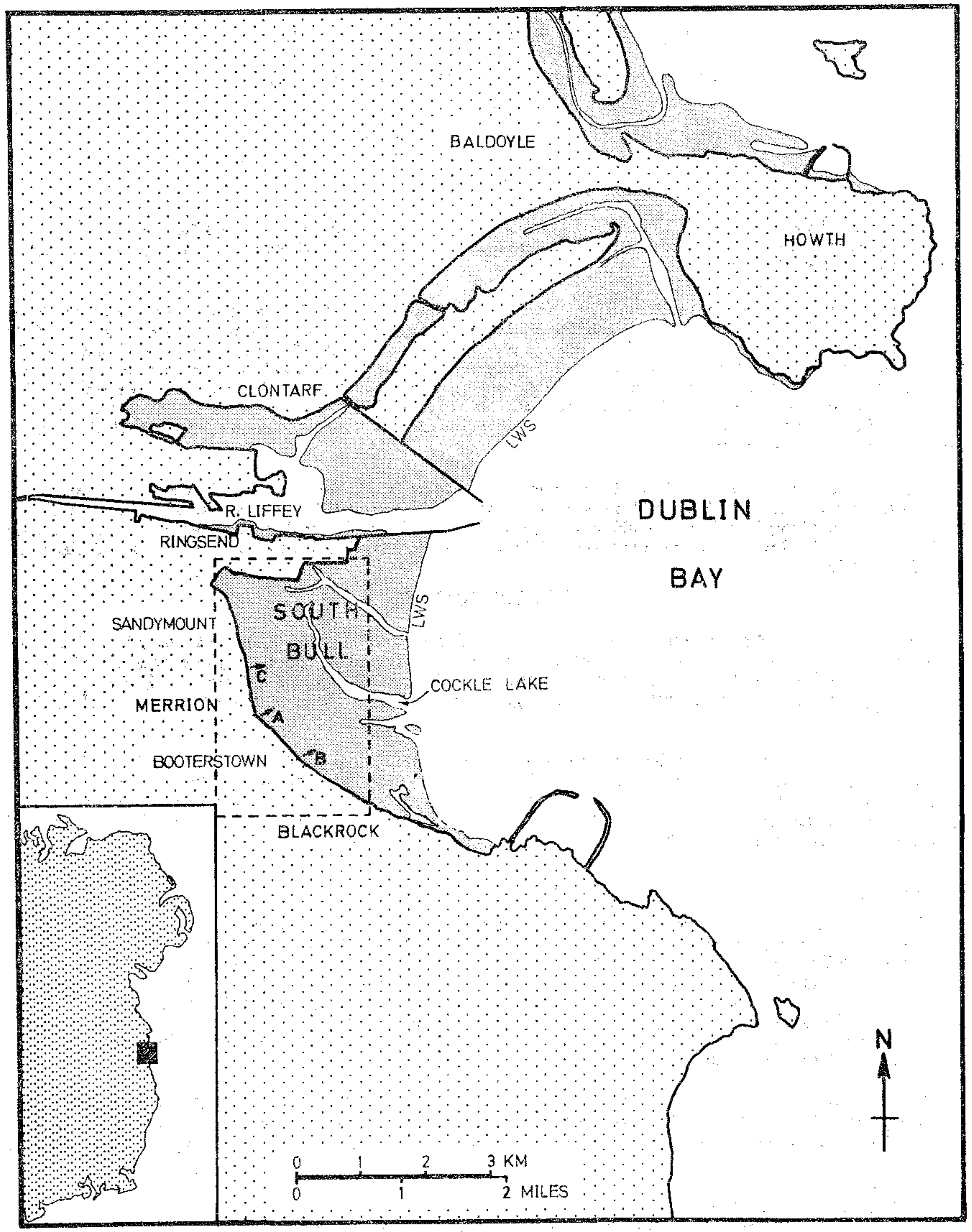

Fig 1. Map of Dublin Bay showing the location of the South Bull and some other important cockle-gathering areas. LWS = approximate line of extreme low water spring tides. In the boxed area, which is shown in detail in Plate 1, arrows indicate the points of origin and the directions of transects A, B and C.

In Dublin, cockles were collected on the strands of Baldoyle, Clontarf and the South Bull (Fig. 1), and also at Malahide and Portmarnock. Official sources give a figure of 80-104 tonnes landed annually in Dublin between 1893 and 1901 (Table 1), and Browne (1904) estimated that some 80 tonnes per year were eaten in the city at that time, three quarters of them in the raw state. Thereafter production declined, at first only slightly, but dramatically in 1908. Between 1908 and 1913 only about 6 tonnes per year were recorded. There is considerable circumstantial evidence to suggest that the collapse of the fishery was associated with the incrimination of cockles as causative agents of enteric fever. In particular, in 1904 Browne had reported that the Dublin cockle beds were grossly polluted and had attributed the high incidence of typhoid in the city to the eating of contaminated cockles; and his associate, McWeeney, had found that 60% of the Dublin Bay cockles he examined contained bacterial indicators of sewage.

Records of landings subsequent to 1913 are not readily available, though for the last 40 years at least the commercial fishery throughout the country has been defunct. Nevertheless collecting cockles for home consumption has persisted as a common practice even in Dublin, despite the warning notices of the Medical Officer of Health which up to recent times were posted near the cockle beds. Within the last decade there has been a slight revival of the industry and beds at Omeath, Co. Louth, and Mornington, Co. Meath, have been fished, the processed cockles being exported to the Continent.

Not surprisingly in view of the lack of interest in the fishery in Ireland, the cockle has been little studied here and the only published report is that of Meaney (1972).

METHODS

Site

The intertidal part of the South Bull is a sandy beach in Dublin Bay extending south-eastwards for about 6 km from Sandymount to Blackrock (Fig. 1, Plate 1). It is exposed to gales from the east but sheltered from other quarters. The beach shelves gently, if irregularly, towards the sea and in places the low water mark is more than 2 km from the strand line (mean tidal rise in Dublin Bay (Poolbeg) is 3.4 m on spring tides, 1.8 m on neaps). The exposed beach is undulating: low banks, which are usually less than 50 cm higher than the surrounding areas and submerged at high water, are separated by shallow depressions some of which are permanently wet, e.g. the Cockle Lake. For a general description of Dublin Bay see Crisp (1976).

The cockles in the study area are now unexploited by man, except for the occasional casual cockle digger. Wading birds, notably oystercatchers *Haematopus ostralegus* (L.), frequent the strand in considerable numbers and may be important cockle predators.

Sampling

Three transects were sampled (Plate 1): A at Merrion Gates (800 m); B at Booterstown Station (900 m); and C at Sandymount (1700 m). Samples were taken from 100 m out from the top of the shore (sea wall or approximate mean high water mark) (Quadrat number 1), down towards the low water mark along each transect at 100 m intervals. No sublittoral areas were sampled. Quadrat B1 fell in a pool in 1972 and for comparative purposes a second quadrat, B0, was sampled on dry sand nearby.

At each sampling site a quadrat 1 m^2 in area was dug either to a depth of 15 cm or to 5 cm into the anaerobic zone, whichever was the shallower. The sand removed was washed through a sieve with square meshes of 6 mm side, and all the live cockles retained were collected. In the laboratory each cockle was aged and its total antero-posterior length and the length of each winter ring were measured to the nearest mm. The flesh was removed from the shell, dabbed dry and weighed both wet and after drying to constant weight at 105°C. The weight of the shell, wiped dry, was also measured.

Collections were made on the three transects in 1970, 1971 and 1972, all in the month of February. The 1970 investigation was of a preliminary nature and most of the data presented here relate to 1971 and 1972.

RESULTS

Distribution and population density

Cockles were distributed from the upper to the lower limits of the transects (Table 2) and numbers were generally greatest in the midshore region. The mean cockle weight was usually highest in the middle or lower shore, although there was considerable variation (Table 3).

Apart from the effects of the unequal lengths of transects there were no obvious differences in the distribution of cockles in A, B and C and the mean density was similar in all three (Table 2). The overall mean density in 1970 was 8.9, in 1971 10.8 and in 1972 13.3 cockles per m^2. The differences between transects are insignificant.

The total cockle biomass and total dry meat weight per quadrat (Tables 4 and 5) were generally highest around the mid-shore level, and were greater in 1972 (total weight 76.9, dry meat weight 2.40 g) than in 1971 (52.0 and 1.89 g). The higher values in 1972 were due in part to the greater densities of cockles recorded in that year.

Age structure and mortality

Since the sampling technique missed some cockles less than 9 mm long, and most less than 7 mm, the 0+ age group to which these small individuals belong is under-represented. The age structure of the population, therefore, is expressed in terms of the population aged 1+ and greater (Table 6).

In both 1971 and 1972 the bulk of the cockles were in the age group 1+, 2+ and 3+; in 1971 only 14% were aged 4+ and more, in 1972 only 10%. In 1971 the 1+ individuals comprised 43% of the population, but the percentage was much higher in 1972 (67%). The 3+ group was proportionately better represented in 1971 than in 1972. The pattern in transects A, B and C in 1972 is very similar, the combined 1+ and 2+ age groups dominating the population (85%, 92% and 78% respectively).

The population, therefore, is made up predominantly of young cockles, few being 3+ and very few 4+ and older. When the 0+ group is considered also, even in the absence of complete data, the contribution of the upper age groups (in terms of numbers of individuals at least) becomes even less significant.

From catch curves (Fig. 2) the total mortality coefficient was estimated for all age groups excluding 0+ in 1971 (Z = 0.69) and in 1972 (Z = 0.83). By following in 1972 the age groups first sampled in 1971 Z was also calculated for each separate age group (Table 7). Taking Z = 0.76 as an average value, the survival of 100 cockles, aged 1+ in February, would be 47 at the age 2+; 22 at 3+; 10 at 4+; and 5 at 5+.

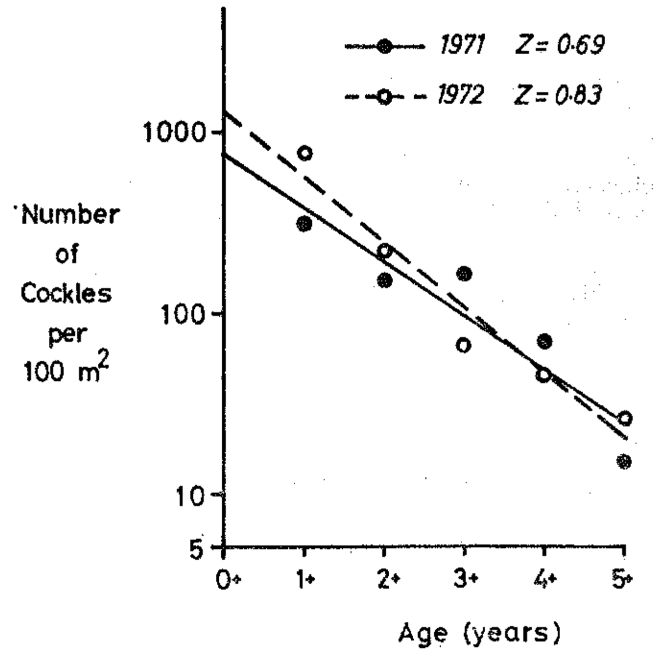

Fig. 2. Catch curves for 1971 and 1972. Regression lines were obtained by the method of least squares. For 1971, r = 0.9284, .05>p>.01; for 1972, r = 0.9741, .01>p>.001. The Y-intercept for 1971 is 763, for 1972, 1,293 cockles aged 0+.

Growth rate

The length frequency distributions (Fig. 3, Table 8), which are complete only for cockles over 9 mm long, show similar patterns for 1970, 1971 and 1972. Peaks at less than 10 mm and at 20-25 mm are evident, representing the 0+ and 1+ age classes. At greater lengths, however, the age classes are less clearly defined.

The mean lengths of cockles of different ages in 1971 and 1972 (Tables 9 and 10, values on the extreme right in each row) are clearly separated from one another, and are similar in the two years. The mean lengths of the equivalent rings in cockles of different ages (reading down the columns in Tables 9 and 10) are also consistent both between ages and between years, suggesting a fairly stable pattern of growth over at least five years. The high mean value for ring No. 1 in the 0+ age group in Table 10 (10.8 mm) contrasts with the means for this ring in older cockles, illustrating the sampling bias in the 0+ age group in favour of larger individuals.

In view of the constancy of the lengths of equivalent rings, mean lengths of all winter rings were calculated using data from as many cockles as were available, irrespective of their ages. The results for the 1971 and 1972 samples are shown in Table 11. On average during the period 1965-1972 the lengths of successive winter rings were about 6.5, 22, 28.5, 32, 35, 37, 38.5, 40 and 41 mm.

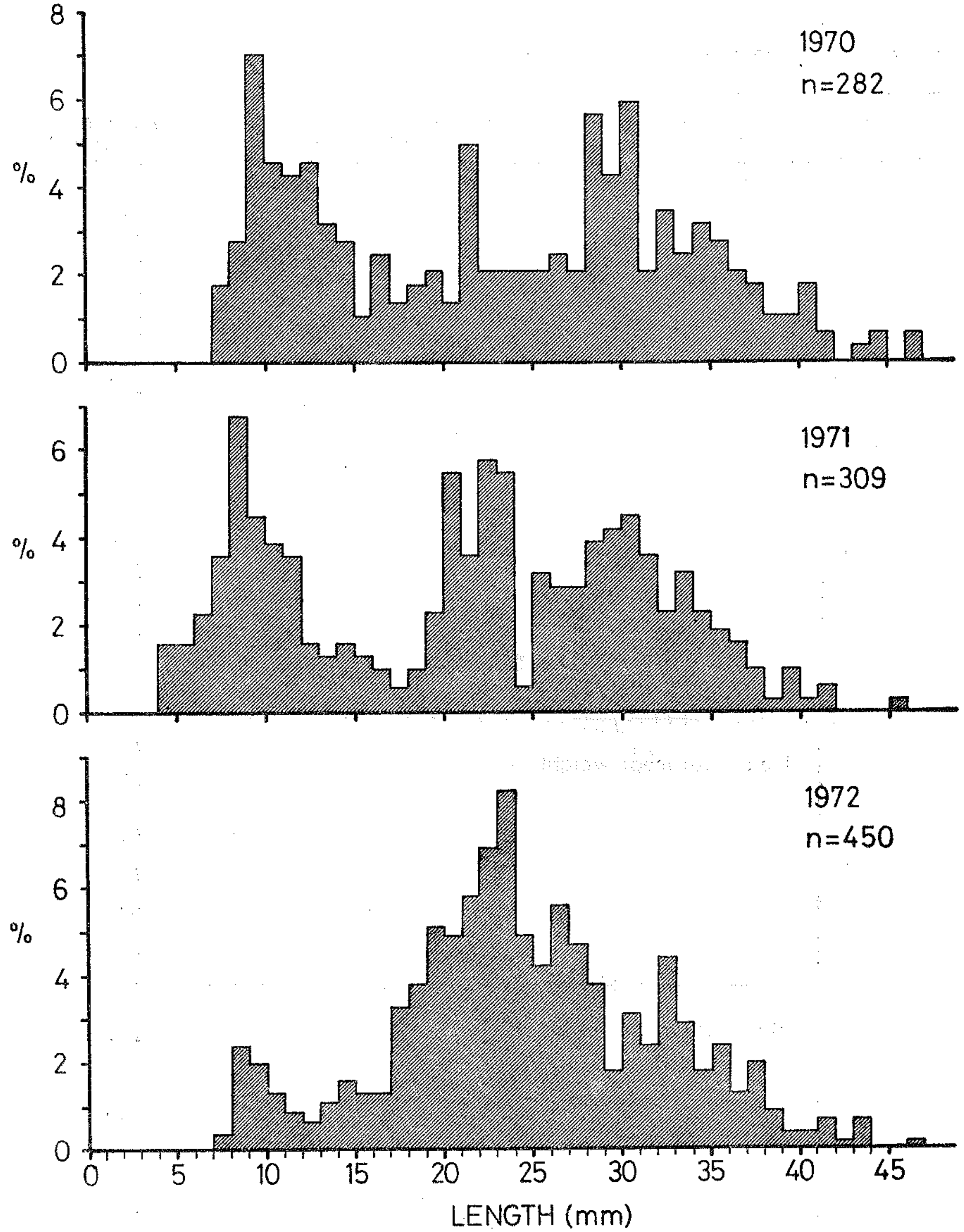

Fig. 3. Length frequency distributions of the cockles gathered in 1970, 1971 and 1972 (*cf* Table 8).

Estimates of asymptotic length (L_∞) and of the coefficient of catabolism (K) were derived using different groups of these data (Table 12), assuming that the growth pattern follows the equation

$$L_t = L_\infty [1 - e^{-K(t-t_0)}].$$

Values for L_∞ fall close to 40 mm in all cases, with a maximum of 42.4 mm, and although individuals of up to 46 mm long have been taken (Fig. 3), this is probably a reasonable estimate for the whole population (Knight, 1968). The estimates of K are more variable, but the highest value (0.60) is probably the most realistic since it is the only one taking into account the relatively very large increase in lengths which occur between the 0+ and the 1+ rings.

Length-weight relationships

The relationships between shell length and each of the parameters shell weight, wet meat weight, dry meat weight, and total (= shell + wet meat) weight for all cockles collected in 1971 and 1972 are illustrated in Fig. 4 In each case the majority of points lies on a smooth curve, except where the length exceeds 35 mm and the small numbers of specimens have resulted in a wide scatter of the means.

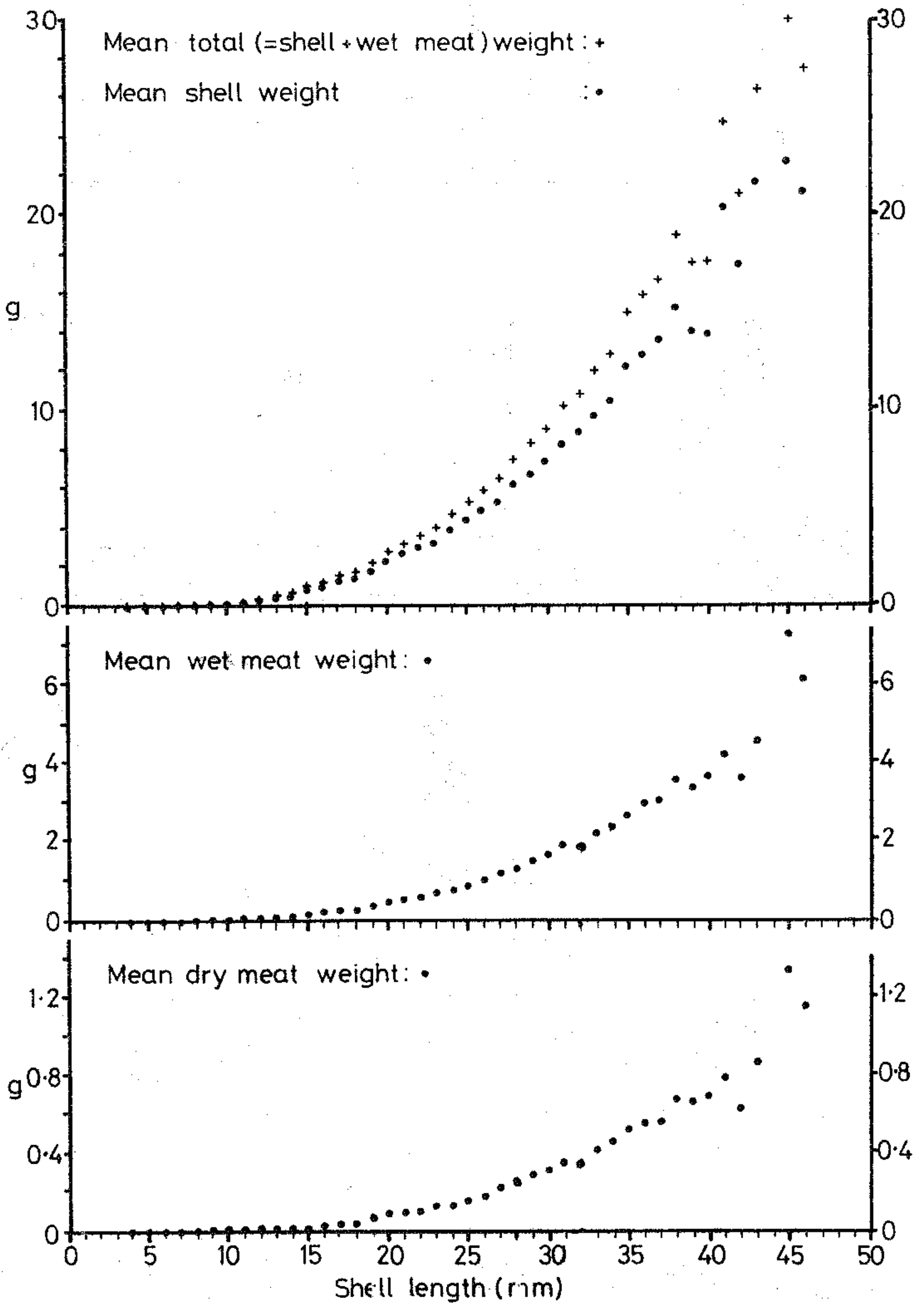

Fig. 4. Graphs of mean weights (of shell, wet meat, dry meat, and shell + wet meat) of cockles in each length group *versus* length. The data are from 755 cockles collected in 1971 and 1972.

The values of m and c for the various length-weight relationships according to the equation

$$\ln W = m.\ln L + c$$

are shown in Table 13. For any weight parameter, the values for 1971, 1972 and both years combined are extremely close. The mean flesh yield for all cockles collected (wet meat weight/shell + wet meat weight) was 18.2% (SEM = 0.2).

Length-weight relationships in molluscs have been reviewed by Wilbur and Owen (1964): the formula

$$W = b.L^a$$

is usually appropriate for bivalves. Kristensen (1957) found that weight of *C. edule* was proportional to the shell length cubed, though for our data the value of a was higher, falling between 3.3 and 3.7 (Table 13, m).

DISCUSSION

Sampling

The sampling method was shown to be satisfactory for collecting cockles greater than 9 mm in length, none of which passed through the sieve. Smaller individuals did pass through the mesh and were under-represented in the samples, but since they were all in the 0+ age class the data relating to the older cockles are unaffected and are suitable for analysis. All samples were taken in February before significant spring growth had begun, as was evident from the presence of winter rings at the edges of all the shells.

Distribution and population density

Without knowing the level of each sampling point, interpretation of the "vertical" variations in population density (Table 2) and mean cockle weight (Table 3) is difficult in view of the undulating nature of the beach. Local factors undoubtedly influence the cockle density, as can be seen in Table 2: quadrat B1 (1972) fell in a depression containing water 4 cm deep whereas B0 and B2 were on dry sand, and thus B1 was atypical of the upper beach. Also, storms may affect the vertical distribution of the cockles either directly by throwing them up or along the beach (Kristensen, 1957), or indirectly by altering the contours of the beach itself. In general terms, however, the distribution of cockles on the South Bull conforms with that found elsewhere: occurring between the tide marks but with a preference for the area between mean tide level and the mean level of low water neaps (Cole, 1956; Kristensen, 1957; Wright, 1926). Exceptionally, cockle beds occur on a high shore plateau where the local topography limits their downwards distribution, as in the Burry Inlet, South Wales (Hancock and Urquhart, 1965). In Poole Harbour they were found amongst the roots of *Spartina* near the high tide mark (Cole, 1956).

By comparison with other cockle populations which have been described, and most of which are fished commercially, the density of the South Bull population is very low, even considering the fact that most 0+ individuals were missed. Wright (1926) recorded a figure of 8,000 one year old cockles per m^2 on Maplin Sands and Cole (1956) reported densities of cockles aged one year or more of 2,300 per m^2 in Burry Inlet, adding that this figure is probably typical. In Southampton Water, densities were very variable with an average of about 170 per m^2 in an area of good cockle density (Barnes, 1973). The maximum number recorded on the South Bull was only 51 per m^2 (Table 2, 1972 B1).

In their study of the intertidal macrofauna of beaches in Co. Down, Seed and Lowry (1973) found cockles only on the more sheltered beaches with a high organic content and finer-grained sand. In terms of density of cockles (13/m^2) and total wet meat biomass (*c.* 14g/m^2) the semi-sheltered beach at Kircubbin compares closely with the South Bull (Tables 2, 3). On the more sheltered, muddier beach at Island Hill cockle densities reached 142/m^2 and total biomass 717g/m^2. Meaney (1972) surveyed ten transects in Dundalk Bay, Co. Louth, with a view to commercial fishing, and found average densities per transect ranging from 10 to 37 cockles per m^2 within the cockle bearing area.

In the present study the mean density for all transects in the three years 1970-1972 was 11.0 per m^2. This low figure may be related to the relatively exposed nature of the beach and the coarse quality of the substrate.

Age structure and mortality

The numerical domination of the South Bull population by young cockles (Table 6), evident even in the absence of complete data for 0+ individuals, is similar to the situation in Burry Inlet where Hancock and Urquhart (1965, Appendix III) found that 0+ and 1+ cockles comprised respectively 84.9 and 14.1% of the population in November 1960 and 96.5 and 2.1% in February 1961. Changes in the age structure are dependent mainly on the two variables spatfall and mortality, and in stable populations with regular annual recruitment the newly-settled spat normally greatly outnumber individuals belonging to older year classes, except under adverse settlement conditions. Instances of populations being dominated by cockles aged 5-6 years have been reported (e.g. Boyden, 1972) but this can often be due to the smaller individuals having been overlooked in the absence of sieving or when too large a mesh is used. Cockle populations can undoubtedly be dominated by one year-class (as happened in Burry Inlet when the exceptionally severe winter of 1962-3 was followed by a massive spatfall), but it is unlikely that such dominance could persist for more than a few years, considering the regularity with which cockles reproduce in these waters and the high level of natural mortality.

The total mortality coefficients for the cockles of the South Bull (Fig. 2, Table 7) were in the same range as the values cited by Franklin and Pickett (1976) for Burry Inlet. Hancock and Urquhart (1965) found much higher mortalities there among cockles in their second winter, though the values for other age groups were similar to ours.

Growth rate

Growth of bivalves is notoriously variable from area to area (Wilbur & Owen, 1964) and cockles are no exception. A large range of sizes of individual winter rings has been reported in the literature. This variability is due to the interaction of the various factors which determine growth, among which are: level on the shore, salinity, food, substrate, temperature, density and competition. Important considerations are time of settlement and growth rate, fast-growing early settlers having the advantage of entering the first winter at a larger size (Hancock, 1967). This advantage is perpetuated in later years.

In the South Bull cockles the first ring is small (mean 6.5 mm), probably as a result of late spawning and settlement since growth picks up between the 1st and 2nd, and the 2nd and 3rd rings. The first ring, however, is often obscure or even entirely absent (Cole, 1956) and therefore liable to have been missed in some studies. Compared with data on other European cockle populations abstracted from the literature by Boyden (1972), growth in Dublin Bay is average. The overall range of mean sizes (mm) reported for the first ring is 8.0-22.0, for the second 17.9-31.0, and for the third 21.0-38.0. On the important commercial bed at Burry Inlet growth appears slower, with rings occurring at 9.5 mm, 17.9 mm and 24.3 mm (Cole, 1956), though because of the much greater population density and the commercial exploitation there it is difficult to make comparisons.

The L_∞ value for South Bull cockles (*c.* 40 mm) is higher than that for the Burry Inlet (*c.* 30 mm; Hancock, 1965) but the K values are similar (both about 0.6). The L_∞ value for a population at Vigo, Spain has been calculated at 50 mm (Figueras-Montfort, 1967).

Length-weight relationships

The relationship between weight and length in this species is influenced by several factors, including exposure of the beach, salinity, substrate, immersion time, height on the shore, and season (Stephen, 1932; Purchon, 1939; Kristensen, 1957; Hancock and Franklin, 1972), and is different for 0+ and older cockles (Kristensen, 1957). Within the South Bull population, however, length can be used as a reliable index of weight in late winter, using the formulae in Table 13.

The potential for commercial exploitation

In the past, when the cockles of the South Bull were regularly fished, the sustained yield was probably in the range 10-20 tonnes. (The recorded landings at Ringsend ranged from 1,120 to 2,520 gallons (4 to 10 tonnes) in 1883-1896, and excluded those picked for home consumption). Nowadays cockles from this area could, with careful purification and rigorous quality control, be brought to the high standards of purity required for marketing. It is of interest, therefore, to examine the present-day potential of the fishery for redevelopment, though the density of the cockles (Table 2) is low enough to make the possibility of commercial fishing by present methods remote (Franklin and Pickett, 1976).

From the age structure in 1971 and 1972 (Table 6) it is evident that recruitment has been satisfactory for at least five consecutive years. The surviving spat grows reasonably fast, and commercial size (*c.* 20 mm long) is reached by the end of the second summer (Tables 9 and 10). Mortality rates are average (Table 7; *cf* Kristensen, 1957; Hancock and Urquhart, 1965; Franklin and Pickett, 1976), and considerably lower than in Burry Inlet where commercial fishing, predation by oystercatchers and other natural causes have resulted in mortalities as great as 90% among 1+ cockles during their second winter (Horwood and Goss-Custard, 1977). Few individuals older than 5+ are found on the South Bull.

In order to assess the potential yield of the population the method set out by Gulland (1969) was followed, though it has the disadvantage of assuming that natural mortality is constant for all age groups. The

population parameters used were those derived in the previous section. Two levels of selection were examined: grading by sieves of 17.5 mm and 20.5 mm square mesh, for which the 50% retention lengths are 21 mm and 24.5 mm, respectively (Hancock, 1967).

Both of the resulting yield curves are of the flat-topped type (Fig. 5), and they are very similar in shape and position. The yields obtained using the two mesh sizes are nearly identical for any value of F<2 (Table 14). Since grading with the 20.5 mm square mesh sieve would maintain a larger stock of breeding cockles in the population (assuming that the 1+ cockles breed on the South Bull, as elsewhere in the British Isles) and would also result in a larger average size of harvested cockle, for negligible diminution in yield, it is to be preferred to the smaller mesh size. This would be equivalent to setting a minimum length limit of 24 mm (Hancock, 1967). The optimum time for harvesting is after the completion of summer growth, preferably in autumn and early winter as there is a progressive decrease in meat dry weight from October to March (Hancock and Franklin, 1972) as well as significant mortality, especially as the numbers of predatory birds are greatest during this period.

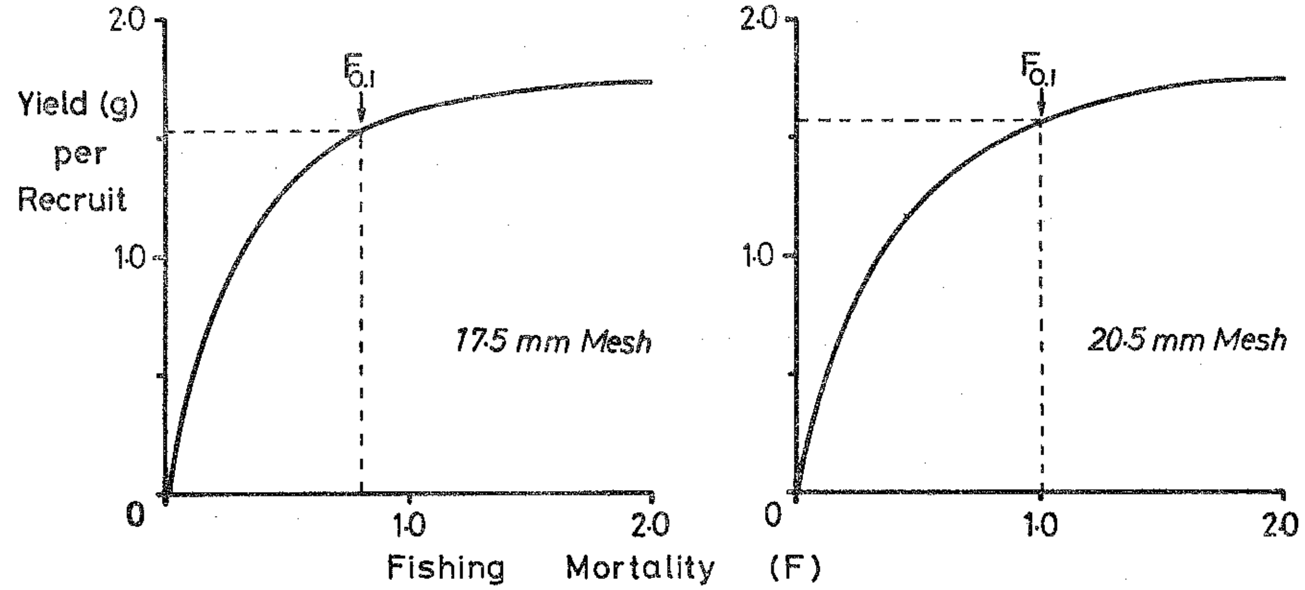

Fig. 5. Yield curves for the South Bull cockle population showing the effects of using 17.5 mm and 20.5 mm square mesh sieves as selectors. The curves were obtained by the method in Gulland (1969), assuming for convenience that in February 0+ cockles were 1.0 years old, and using the following values (derived from data presented earlier): M = 0.76, W_∞ = 24.6g, K = 0.50, to = 0.60 year, tr = 1.0 year, R = 1028 cockles/100 m². For 17.5 and 20.5 mm square mesh sieves lc = 21 mm and 24.5 mm (Hancock, 1967), and tc = 2.14 and 2.50 years, respectively.

The optimum sustained yield, calculated from the flat-topped yield curve using the $F_{0.1}$ technique, occurs at F = 1.00 and is 16 tonnes/km² (Fig. 5, Table 14). In view of the low population density, however, the effort required to achieve such a high fishing mortality would probably be excessive and a value of F closer to 0.1 seems more realistic. If half of the beach area were fished at this level of F the expected yield would be approximately 19 tonnes, a figure which is in good agreement with historical estimates of the sustained yield of the beach.

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Table 1. Annual landings of cockles for 1893-1913, as recorded in the Reports of Inspectors, 1894-1914 (250 gallons = 1 tonne, approximately).

	DUBLIN BAY			ALL IRELAND		
Year	Landings (Gallons)	Value (£)	No. persons engaged	Landings (Gallons)	Value (£)	No. persons engaged
1893	25,000	840	40—70	c. 77,000	2,400	c. 500
1894	20,120	670				371
1895	23,960	799	32			c. 360
1896	24,520	817	35			c. 360
1897	22,987	766	35	71,453	2,367	258
1898	23,300	782	32	61,725	1,687	199
1899	26,000	1,058	36	60,302	1,762	239
1900	25,821	860	35	67,571	1,727	419
1901	21,520	705	52	48,854	1,274	239
1902	15,922	515	45	30,562	885	213
1903	21,121	699	36	43,661	1,251	265
1904	19,973	658	42	49,853	1,235	247
1905	21,373	701	40	59,155	1,626	329
1906	18,641	616	46	39,537	1,083	251
1907	18,700	618	43	44,425	1,319	276
1908	4,050	237	30	33,540	852	272
1909	1,550	58	29	37,998	958	283
1910	1,460	58	24	33,138	687	259
1911	1,560	63	29	37,750	843	273
1912	1,540	62	29	24,550	658	215
1913	1,700	68	46	29,142	790	278

Table 2. Numbers of cockles in the quadrats sampled in 1970, 1971 and 1972, in transects A, B and C.

Quadrat No.	A			B			C		
	1970	1971	1972	1970	1971	1972	1970	1971	1972
0	—	—	—	—	—	4	—	—	—
1	1	0	0	0	20	51	0	0	1
2	6	3	3	7	6	9	3	0	4
3	3	2	4	10	12	19	8	26	13
4	19	32	20	9	8	15	10	17	39
5	14	18	21	12	29	21	13	15	9
6	11	14	18	6	4	19	15	25	11
7	9	4	20	3	1	11	11	8	27
8	0	—	9	1	2	7	16	6	10
9	—	—	—	1	—	2	17	13	11
10	—	—	—	—	—	—	24	10	24
11	—	—	—	—	—	—	30	14	14
12	—	—	—	—	—	—	7	3	4
13	—	—	—	—	—	—	10	—	7
14	—	—	—	—	—	—	10	—	9
15	—	—	—	—	—	—	9	—	8
16	—	—	—	—	—	—	7	—	6
17	—	—	—	—	—	—	0	—	—
Total	63	73	95	49	82	158	190	137	197
Mean	7.9	10.4	11.9	5.4	10.3	15.8	11.2	11.4	12.3
Grand Mean		10.0			10.3			11.6	

Table 3. Mean cockle weight (g) (shell + wet meat) in each quadrat in transects A, B and C in 1971 and 1972.

Quadrat No.	A		B		C	
	1971	1972	1971	1972	1971	1972
0	—	—	—	7.2	—	—
1	—	—	2.3	3.8	—	3.1
2	2.5	2.1	6.9	2.1	—	6.6
3	2.0	5.0	3.8	3.4	1.2	2.7
4	4.3	2.7	9.2	5.3	6.0	4.8
5	5.2	2.9	3.8	6.0	3.2	2.1
6	2.9	5.2	0.4	6.9	7.0	8.5
7	1.5	11.3	0.1	12.0	14.7	7.5
8	—	9.5	0.4	8.6	10.6	6.0
9	—	—	—	14.1	7.2	8.9
10	—	—	—	—	6.9	6.0
11	—	—	—	—	7.2	6.5
12	—	—	—	—	4.8	5.5
13	—	—	—	—	—	12.6
14	—	—	—	—	—	4.2
15	—	—	—	—	—	7.5
16	—	—	—	—	—	7.2

Table 4. Total biomass of cockles and dry meat weights (g) in each quadrat sampled in 1971.

Quadrat No.	Transect A		Transect B		Transect C	
	Total	Dry meat	Total	Dry meat	Total	Dry meat
1	0	0	46.75	1.73	0	0
2	7.40	0.32	41.27	1.26	0	0
3	4.03	0.12	45.28	1.57	31.35	0.97
4	136.39	5.04	57.42	1.95	101.72	3.81
5	93.56	3.04	109.20	4.16	47.75	1.49
6	40.94	1.79	1.46	0.05	173.89	6.59
7	5.93	0.26	0.07	0	117.34	4.59
8	—	—	0.78	0.04	63.76	2.33
9	—	—	—	—	93.22	3.29
10	—	—	—	—	68.72	2.61
11	—	—	—	—	100.21	3.40
12	—	—	—	—	14.36	0.55
Total	288.25	10.57	302.23	10.76	812.32	29.63
Mean	41.18	1.51	37.78	1.35	67.69	2.47

Table 5. Total biomass of cockles and dry meat weights (g) in each quadrat sampled in 1972.

Quadrat No.	Transect A		Transect B		Transect C	
	Total	Dry meat	Total	Dry meat	Total	Dry meat
0	—	—	28.62	1.11	—	—
1	0	0	192.58	7.50	3.05	0.10
2	6.41	0.17	19.04	0.71	26.22	0.66
3	20.12	0.70	65.54	1.78	34.91	0.98
4	54.56	1.32	79.30	2.46	186.37	5.26
5	60.64	1.47	125.13	3.83	18.76	0.37
6	93.48	2.77	130.98	4.40	93.91	3.13
7	225.25	6.85	131.65	4.50	203.87	6.73
8	85.46	2.81	60.02	2.05	59.51	1.44
9	—	—	28.19	1.12	97.85	3.15
10	—	—	—	—	145.13	4.30
11	—	—	—	—	90.28	2.53
12	—	—	—	—	21.84	0.58
13	—	—	—	—	88.26	2.62
14	—	—	—	—	37.93	1.10
15	—	—	—	—	60.01	1.98
16	—	—	—	—	43.32	1.17
Total	545.92	16.09	861.05	29.46	1211.22	36.10
Mean	68.24	2.01	86.11	2.95	75.70	2.26

Table 6. Age structure of the cockle population in 1971 and 1972, expressed as a percentage of all those greater than one year old.

Age	1971	1972			
	All Transects	All Transects	Transect A	Transect B	Transect C
0+	(53)	(13)	(12)	(6)	(19)
1+	43	67	59	76	59
2+	20	19	26	16	18
3+	22	6	5	3	9
4+	9	4	2	1	8
5+	2	2	1	3	2
6+	2	2	2	1	3
7+	1	1	1	1	1
8+	0	1	2	0	0
9+	0	0	1	0	0
Sample size	202	387	85	148	164

Table 7. Mortalities of the major age groups of 1971 during the following year. Based on the percentage age structure of the population and the mean density per m² in 1971 (10.8) and 1972 (13.2).

Age in 1971	No./10m² in 1971	No./10m² in 1972	Total mortality coefficient
0+	(37)	76	—
1+	31	22	0.34
2+	14	7	0.69
3+	16	5	1.16
4+	7	3	0.85
			Z = 0.76

Table 8. Length frequency distributions of cockles collected in 1970, 1971 and 1972 (*cf*. Fig. 3).

Shell length	Numbers			Shell length	Numbers		
(mm)	1970	1971	1972	(mm)	1970	1971	1972
4	0	5	0	26	7	9	25
5	0	5	0	27	6	9	21
6	0	7	0	28	16	12	17
7	5	11	2	29	12	13	8
8	8	21	11	30	17	14	14
9	20	14	9	31	6	11	11
10	13	12	6	32	10	7	20
11	12	11	4	33	7	10	13
12	13	5	3	34	9	8	8
13	9	4	5	35	8	6	11
14	8	5	7	36	6	5	6
15	3	4	6	37	5	3	9
16	7	3	6	38	3	1	4
17	4	2	15	39	3	3	2
18	5	3	17	40	5	1	2
19	6	7	23	41	2	2	3
20	4	17	22	42	0	0	1
21	14	11	26	43	1	0	3
22	6	18	31	44	2	0	0
23	6	17	37	45	0	1	0
24	6	2	22	46	2	0	1
25	6	10	19	Total	282	309	450

Table 9. Mean lengths (mm) of annual rings in cockles of different ages collected in 1971 (± standard deviations).

Age	Sample size	Ring 1	2	3	4	5	6	7	8	9
0+	97	9.3 ± 3.4								
1+	84	*	21.4 ± 2.4							
2+	33	*	22.9 ± 2.2	27.2 ± 1.3						
3+	40	*	23.3 ± 3.4	28.6 ± 1.8	31.5 ± 1.7					
4+	17	*	24.4 ± 3.5	29.5 ± 1.8	32.2 ± 1.6	34.5 ± 1.0				
5+	3	*	23.0 ± 3.6	30.3 ± 2.0	34.0 ± 1.4	36.3 ± 1.9	38.0 ± 1.4			
6+	3	*	19.7 ± 4.0	27.3 ± 0.5	32.2 ± 1.3	35.3 ± 1.3	37.0 ± 0.8	38.3 ± 0.9		
7+	2	*	22.0	30.0	32.5	36.0	38.0	39.0	40.0	
8+	1	*	20	28	33	35	38	39	40	41

*not measured.

Table 10. Mean lengths (mm) of annual rings in cockles of different ages collected in 1972 (±standard deviations).

Age	Sample size	Ring 1	2	3	4	5	6	7	8	9	10
0+	50	10.8 ± 2.8									
1+	258	6.7 ± 4.1*	22.0 ± 3.7								
2+	75	6.1 ± 3.2**	22.5 ± 3.0	29.4 ± 3.8							
3+	23	5.0 ± 2.7	21.4 ± 3.0	28.4 ± 2.2	32.6 ± 2.6						
4+	16	5.4 ± 3.5	18.9 ± 6.3	26.9 ± 3.4	31.6 ± 2.8	34.9 ± 2.8					
5+	9	5.1 ± 2.0	20.2 ± 4.6	27.2 ± 3.4	31.4 ± 2.5	33.4 ± 2.5	35.7 ± 2.6				
6+	9	4.9 ± 1.3	21.3 ± 3.5	28.4 ± 2.8	32.9 ± 4.4	35.1 ± 4.3	37.2 ± 4.2	38.6 ± 4.0			
7+	3	9.0***	25.0 ± 1.4	21.0 ± 2.2	34.0 ± 2.9	36.0 ± 2.5	37.3 ± 2.6	38.7 ± 2.4	39.3 ± 2.6		
8+	2	5.5	15.0	29.0	34.5	36.5	38.0	39.5	41.0	42.0	
9+	1	5	13	26	30	33	35	36	38	40	41

* sample size 249   ** sample size 73   *** sample size 2

Table 11. Mean lengths (mm) of annual rings in all cockles collected in 1971 and 1972.

Ring Number	1971 Mean length	1971 Sample size	1972 Mean length	1972 Sample size
1	—**	—**	6.3*	384*
2	22.4	183	21.9	396
3	28.3	99	28.7	138
4	31.9	66	32.3	63
5	35.0	26	34.7	40
6	37.7	9	36.6	24
7	38.7	6	38.5	15
8	40.0	3	39.7	6
9	41.0	1	41.3	3

*Figures derived from cockles aged 1+ and greater in order to avoid sampling bias for the larger 0+ individuals.

**not measured.

Table 12. Estimates of asymptotic length (L_∞) and coefficient of catabolism (K) of cockles, obtained from Ford-Walford plots.

Sampling year	Ages of cockles included	Parameters analysed	L_∞ (mm)	K
1971	2—6	Mean total lengths of cockles of different ages	42.2	0.34
1971	2—6	Mean lengths of annual rings	42.4	0.34
1972	2—7	Mean total lengths of cockles of different ages	39.7	0.49
1972	2—7	Mean lengths of annual rings	41.2	0.40
1972	1—7	Mean lengths of annual rings	39.0	0.60

Table 13. Values of *m* and *c* for various length-weight relationships according to the equation
ln *Weight* (g) = *m*. ln *Length* (mm) + *c* (geometric mean regressions after Ricker, 1973).

Year	1971		1972		1971 + 1972	
n	308		447		755	
Weight Parameter	*m*	*c*	*m*	*c*	*m*	*c*
Total weight	3.39	− 9.26	3.37	− 9.23	3.37	− 9.23
Wet meat weight	3.35	−10.78	3.38	−11.08	3.32	−10.80
Dry meat weight	3.56	−13.13	3.74	−13.96	3.57	−13.31
Shell weight	3.44	− 9.64	3.38	− 9.46	3.42	− 9.58

Table 14. The potential sustained yield, in tonnes/km², of the South Bull cockle population at different values of F (fishing mortality). Data derived from Fig. 5 using the mean value of R = 1028 cockles/100m² (0+ cockles, Fig. 2). The total area of the beach is about 9 km². Asterisks mark the yields for $F_{0.1}$.

F	YIELD (tonnes/km²) 17.5 mm Mesh	20.5 mm Mesh
0.01	0.6	0.5
0.10	4.7	4.3
0.50	13.5	12.6
0.80	15.8*	15.1
1.00	16.6	16.2*
2.00	17.9	18.0

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