ISSN 0332-4338

A preliminary account of fisheries for the surf clam *Spisula solida* (L) (Mactracea) in Ireland

by

Edward Fahy, Jim Carroll, Margaret O'Toole

Marine Institute, Snugboro Rd, Blanchardstown, Dublin 15

and John Hickey

Bord Iascaigh Mhara, Kilmore Quay, Co Wexford.

Fisheries Bulletin No. 21, 2003

The Marine Institute, Marine Fisheries Services Division, Abbotstown
Dublin 15

SUMMARY

Surf clams from seven stocklets on the west and south coasts are examined to provide a preliminary account of the fishery in Ireland. *Spisula solida* is the species harvested in every case. Most of the material was collected by commercial (box or hydraulic) dredge. A quantitative account of a surf clam bed is based on sampling by Day grab in Waterford Harbour.

Ageing was by external shell sculpture. A limited comparison of this method with ageing by internal shell structure confirmed the method was usable and the results are presented on this basis with, however, reservations on the reliability of the approach. *S. solida* in Ireland had L*inf* of *c* 43 cm. Material gathered in Clifden, Co Galway, had an L*inf* of 35 mm. The Clifden stocklet was heavily fished when the material was gathered and a low value for L*inf* is attributed to the Lee phenomenon. A growth curve is constructed for only one stocklet, that in Waterford Harbour. Growth was slower than for *S. solida* in the North Sea, a possible consequence of heavy fishing also.

The clam bed in Waterford Harbour was a low elevation bank of coarse (*Spisula*) sand. The area of the bed had become reduced during the preceding year by the invasion of silt grades displaced by earthworks upstream; these were injected into the coarse material to form a perimeter of the clam patch. Within the bed, the highest biomass of *S. solida* was 600 g/m^2.

Representation of age frequencies within samples suggests that heavy spatfalls of *S. solida* occur at irregular intervals and this complicates the calculation of F values from a catch curve. A yield per recruit curve is prepared for the clam patch in Waterford Harbour.

1. INTRODUCTION

The bivalve mollusc superfamily Mactracea contains two species with economic potential in Irish coastal waters: *Mactra stultorum* and *Spisula solida*. *Mactra stultorum* has been captured in large numbers in association with *Ensis siliqua* by hydraulic dredges operated in fine sand on the east coast (see references in Fahy and Gaffney, 2001). Although it reaches acceptable dimensions and is palatable, little effort has been made to market *M. stultorum*, probably because larger volumes of razor clams were harvested at the same time and marketing effort was directed at disposing of these. Three species of *Spisula* are said to be common in the waters around Britain and Ireland (Tebble, 1966, Hayward and Ryland, 1994, other references in Fahy *et al*, 2002); *S. solida* and *S. subtruncata* range from south Iceland and Norway to Spain and Morocco while *S. elliptica* extends north from these islands to the Barents Sea.

In the course of recent exploratory surveys by hydraulic dredge (and therefore carried out in depths of mainly 2-10 m) local, dense but small concentrations of *S. solida* were encountered. Small landings of this species, probably not exceeding 500 t annually, have been harvested over the past seven years in Ireland and the industry is anxious to locate virgin populations as an alternative to other interstitial bivalve species whose fisheries have been depleted by over-fishing. This paper gives data on the growth rates of various populations of *S. solida* and explores the consequences of fisheries at various stages of exploitation for age structure within clam beds. An account of a small *Spisula* bed in Waterford Harbour is provided.

1.1 The clam bed in Waterford Harbour

The clam patch in question may have been one of several in earlier years although it was the only known patch in its vicinity when investigations were undertaken in 2001. *Spisula* have been harvested from it at irregular intervals, approximately six boats, most fishing box dredges, participating in the fishery at any time, landing approximately 2 t each per day. The principal dealers handled 400 t of *Spisula* in 1996; no landings were traced from 1997 or 1998 and only 6 t in 1999. In 2000 338 t were accounted for and in the following two years the bed was fallowed. However, other dealers might have bought clams from the Waterford patch and the writers are aware of attempts by the fishermen themselves to export some material directly without going through local dealers.

The quality of the catch was 60 – 80 pieces per kg in 1996, the maximum number acceptable to the market being 100. Prices ranged from 32 p (equivalent to Euro 0.41) per kg in 1996 and 40 p (equivalent to Euro 0.51) per kg in 2000.

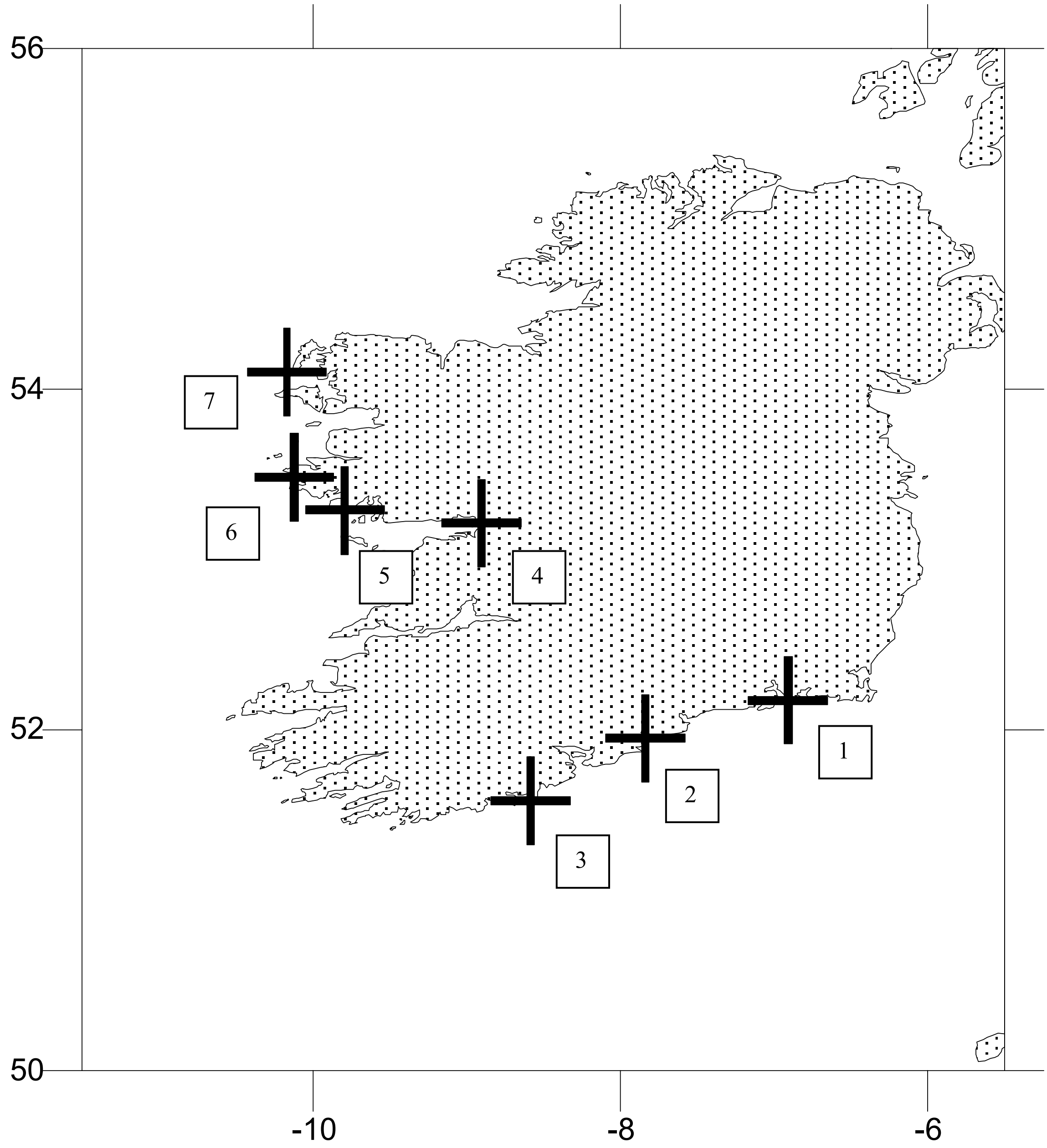

Fig 1. Locations of stocklets of *S. solida* which provided material for analysis in this survey: 1, Waterford Harbour bed; 2, Youghal,; 3, Soverign Rocks; 4, Clarinbridge; 5, Kilkieran Bay; 6, Clifden; 7, Iniskea Islands/Blacksod Bay.

2. METHODS

Samples of *Spisula solida* were obtained from commercial fishing operators using hydraulic dredges at six of the seven locations from which material was sourced (Fig 1). In Waterford Harbour, commercial samples were collected by box dredge but the quantitative work there was undertaken using a Day grab (0.1 m^2). Processors provided graded material originating in Youghal. In all of these cases, the samples were of entire clams held for examination in alcohol, the commercial samples having been frozen first. The sample from the Soverign Rocks consisted of shells only. Various details of the material examined are set out in Table 1.

Table. 1. Origin and details of samples of *S. solida*.

Collection	C/E	Date of collection	Numbers in sample	Age range in sample	Source of material	Exploitation status
Iniskea/Blacksod	C	July-02	35	2 to 13	Pickled, whole	Heavily fished
Clifden	C	March-02	200	4 to 10	Pickled, whole	Heavily fished
Kilkieran	C	January-02	113	2 to 11	Pickled, whole	Not fished
Clarinbridge	C	August-02	346	1 to 11	Pickled, whole	Fished
Soverign Rocks	C	Unknown	47	2 to 13	Shell only	Fished
Youghal	C	2000	18	2 to 10	Frozen then pickled	Fished
Waterford Harbour	CE	2000-2001	2199	0 to 10	Pickled, whole	Heavily fished

C: from commercial dredge E: experimental, from Day grab

In the laboratory the clams were removed from preservative and excess moisture was dried off. A number of data were collected, though not from every animal. Shell length, maximum distance in the anterior-posterior direction, measured by vernier callipers to the nearest 0.1 mm, was the most frequent observation; for some the height and width were also recorded (Fig 2). When weight (entire or meat only) was weighed, it was to the nearest 0.1g.

Spisula were aged by counting apparent annuli on the shell. Such marks were not registered until they were clearly visible as a result of some further plus growth having occurred. The veracity of this technique was tested by sectioning one valve of each of ten individual *Spisula* from which an acetate peel was prepared. The acetate peels were prepared in the School of Ocean Sciences, University of Wales, Bangor and interpreted by Dr Chris Richardson. The age of the intact valve was interpreted by one of us (J C); comparing the two sets of readings, our interpretations differed by an average –0.7 years from the true age, which is consistent with our registering a plus age.

Using the ages and lengths obtained, estimates were made of the length growth coefficient and parameters from the von Bertalanffy growth equation (Ricker, 1975):

$$Lt = Linf(1-exp[-k(t-t0)])$$

Where *Lt* is the length at age at time *t,* L*inf* is the theoretical maximum length, *t0* is the theoretical age at length zero and *k* is the growth coefficient. The growth parameters L*inf* and *k* were estimated by Ford-Walford plot and *t0* was calculated using these values and the averaged length at age measurements.

More detailed examination of a *Spisula* patch in Waterford Harbour which had been intensively exploited, was undertaken in May 2001. Transects were worked across the bed in north-south and east-west directions to establish its boundaries, 69 Day grab samples being collected at intervals within the clam patch; sampling was more intense where the density of *Spisula* was greater. Grab contents were washed through a fine sieve (mesh size, 4 mm), whatever was retained (including larger sediment grades) being removed to the laboratory for further examination. Each quadrat was georeferenced by latitude and longitude and these readings were decimalised. At each station the depth (m) was recorded.

Table. 2. Ford-Walford plots of Lt inf in *Spisula* stocklets. No=Number of age groups.

Locations	**Lt inf**	**r^2**	**No**	**P**
Iniskea/Blacksod	41.4	0.4269	11	>0.05
Clifden	33.2	0.2573	7	>0.05
Kilkieran	***40.2***	0.9176	9	<0.001
Clarinbridge	***43.1***	0.8974	10	<0.001
Soverign Rocks	***42.8***	0.7905	11	<0.01
Youghal	41.9	0.1302	8	>0.05
Waterford Harbour	***42.9***	0.9440	10	<0.001

At 11 stations the entire contents of the Day grab were removed for sediment analysis. These sites were selected as representative of the range of variation encountered. In the laboratory entire grab samples were air dried and sieved through the following meshes 16.0, 8.0, 4.0, 2.0, 1.0, 0.50, 0.25, 0.125, 0.063 mm and the fraction retained by each grid size was weighed. The percentage frequency occurrence of sediment sizes was the measurement on which further analyses were undertaken. Sieve measurements were expressed in terms of Krumbein's ϕ scale where >16 mm is ϕ – 4, > 1 mm is 0 and >0.063 mm is 4. For computation purposes the class size mid-points were given arbitrary values (so that material retained on the – 4 ϕ scale was given an arbitrary class midpoint of – 4.5, material retained on the 1 mm sieve was given an arbitrary class midpoint of ϕ – 0.5 and material retained on the 0.063 sieve was given an arbitrary class value of ϕ 3.5). The weight in each class was expressed as a percentage of the total weight in a sample which had been sieved and the following statistics were then calculated:

Mean grain size

$$\overline{X}_{\phi} = \frac{fm}{n}$$

where n = 100

Sorting coefficient

$${}^{\lambda}\sigma_{\phi} = \frac{1}{100}.fm^2 - \overline{X}^2$$

Skewness

$$Sk\phi = \frac{\frac{1}{100}.fm^3 - \frac{3}{100}.\overline{\mathrm{X}}.fm^2 + 2\overline{\mathrm{X}}^3}{{}^{\lambda}\sigma_{\phi}}$$

A template for the calculation of certain variables used in the analysis of sediment is set out in Fahy *et al* (2002).

In order to prepare maps of the Waterford Harbour clam bed, interpolation of the available data was used to obtain continuous coverage of the area using geostatistical software (Surfer 7.0). Kridging was the interpolation algorithm applied to bathymetric data. Inverse squared distance was used to interpolate coarse grades, biomass, number and average age per quadrat. Interpolated data were presented in contour format and exported into GIS (ArcView 3.1) for mapping purposes.

Maps were prepared for each variable using contour polygons created in Surfer 7.0. The relevant Admiralty chart (Sheet 2046) was scanned, rectified and projected in ArcInfo as a backdrop for the study area map (Fig 11).

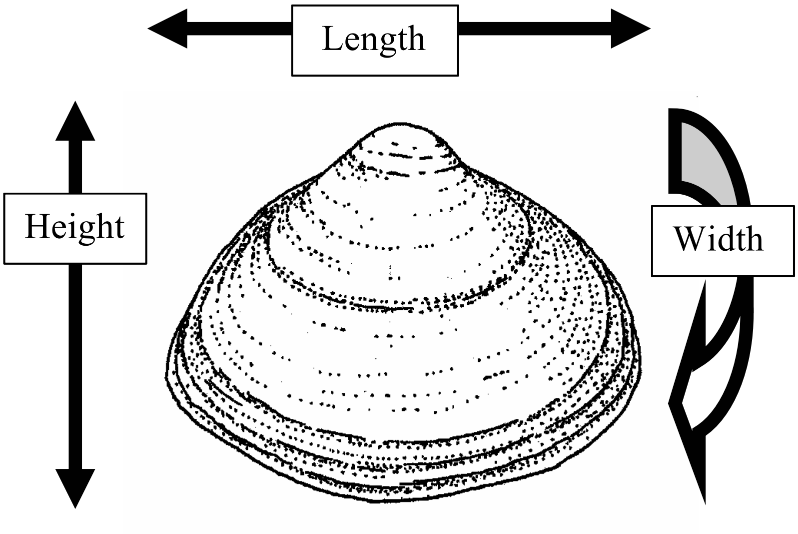

Fig 2. *S. solida* showing which dimensions were used in this analysis.

3. RESULTS

3.1 Dimensions and growth

Commercial fishing methods screen *Spisula* catches so that the smaller and younger individuals are not retained by the dredge. The largest of certain medium age groups will be retained and probably only the oldest age groups are representative of the size range within the population. The youngest annual growth increments are largest and as the animal approaches asymptotic length the annual growth increments reduce. The calculation of L*inf* from commercial samples is considered a valid exercise (Table 2) whereas the growth coefficient and all parameters were estimated only for the Waterford Harbour population which was sampled by Day grab. In that case the additional values were k = -0.2314 and t0 = -1.0562 (Fig 3).

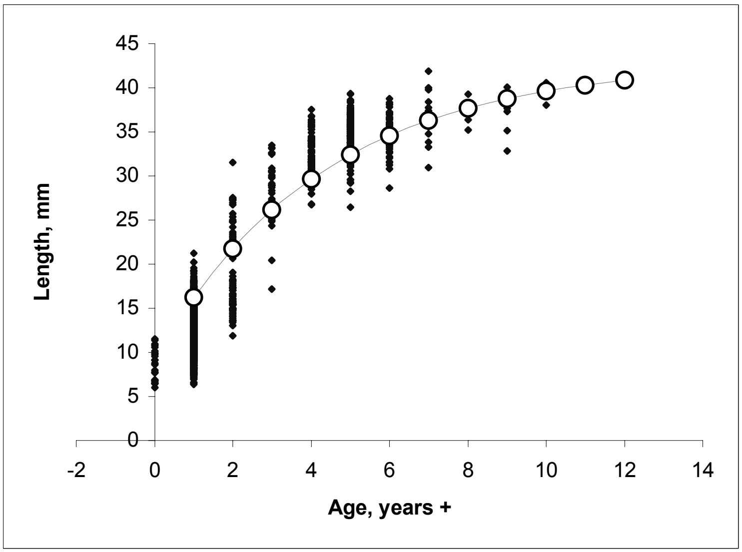

Fig 3.Calculated growth curve for *S. solida* in Waterford Harbour (N=2,190).

Calculations of true, as opposed to plus, growth were made from the ten acetate peels of sectioned *Spisula* shells. The shells came from several sources. In order to use this method, a relationship was established between the length of the shell and its height (Fig 4). Direct measurements of length at age were obtained from back-calculations of shell height (from sections) by application of the formula:

Length = (Height*1.2525) +1.1920

The resulting von Bertalannfy growth curve is described by the coefficient and parameters k=-0.2614, L*inf* = 46.85 and t0=-1.3936. In this case the Ford-Walford plot was highly significant (N = 8, r^2 = 0.9797 P <0.001) but the sample was small, a criticism that can also be applied to the L*inf* values obtained for *Spisula* sampled from Iniskea/Blacksod and Youghal, neither of which was significant.

Table 3. Weight at length of *Spisula solida* from various stocklets

Length, mm	**Iniskea/Blacksod**	**Clifden**	**Kilkieran**	**Clarinbridge**	**Youghal**	**Waterford Harbour**
N	35	200	113	344	19	2023
r^2	0.8918	0.8669	0.8662	0.9307	0.8570	0.9820
Intercept	-11.1398	-8.3081	-10.3060	-10.9125	-9.2570	-9.3321
X variable	3.7743	2.9523	3.5501	3.6639	3.2869	3.2416
Weight (g) at length						
Length, mm						
5	0.0	0.0	0.0	0.0	0.0	0.0
10	0.1	0.2	0.1	0.1	0.2	0.2
15	0.4	0.7	0.5	0.4	0.7	0.6
20	1.2	1.7	1.4	1.1	1.8	1.5
25	2.7	3.3	3.1	2.4	3.8	3.0
30	5.5	5.7	5.9	4.7	6.8	5.4
35	9.8	8.9	10.1	8.3	11.3	9.0
40	16.2	13.2	16.3	13.5	17.6	13.8

Regressions of LNweight on LNlength established the parameters set out in Table 3. Greatest weight at length was achieved by the Youghal sample which however, was of graded, hence selected, material. Lowest weight at 40 mm is reported for the Clifden sample although its weight at lower length was relatively better. A selection of this weight: length curves is plotted in Fig 5.

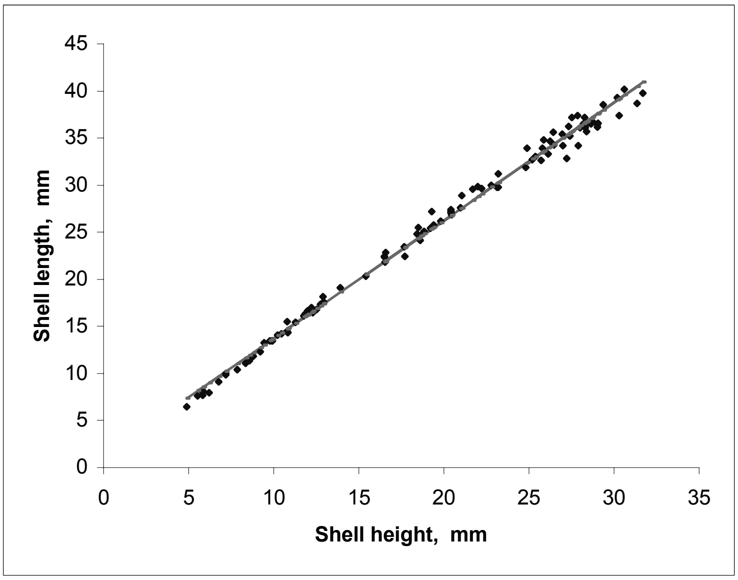

Fig 4.Shell length in *S. solida* correlated with shell height (N = 103).

Table 4. Sediment analysis of selected samples from the vicinity of the clam patch in Waterford Harbour.

			Stations - see Fig 13										
Phi scale	**mm scale**	**M values**	**4**	**34**	**35**	**22**	**7**	**56**	**49**	**67**	**59**	**28**	**64**
-4	**>16**	**-4.5**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-3	**>8**	**-3.5**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-2	**>4**	**-2.5**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.2	0.0
-1	**>2**	**-1.5**	0.6	0.4	1.1	0.0	0.6	0.0	4.7	0.2	0.9	5.9	0.0
0	**>1**	**-0.5**	20.9	2.7	3.6	0.2	1.9	0.9	24.4	0.9	2.6	40.7	11.2
1	**>0.5**	**0.5**	60.4	25.8	8.7	0.9	5.4	3.5	50.5	9.6	5.7	42.8	26.1
2	**>0.25**	**1.5**	17.7	59.7	11.8	2.8	12.1	6.4	20.0	21.5	2.0	10.1	10.3
3	**>0.125**	**2.5**	0.2	7.8	43.1	45.8	50.6	40.1	0.2	55.4	26.0	0.2	11.2
4	**>0.063**	**3.5**	0.2	3.4	30.8	48.8	28.3	47.1	0.2	11.0	58.0	0.0	40.6
pan	**<0.063**	**4.5**	0.0	0.1	0.9	1.5	1.0	2.0	0.1	1.4	2.3	0.0	0.7
		Totals	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Mean grain size		0.467	1.326	2.381	2.967	2.491	2.852	0.373	2.197	2.752	0.076	1.962
	fm2		64.926	236.394	696.816	921.360	714.393	884.302	78.934	560.950	943.393	60.209	614.507
	fm3		73.775	486.076	2111.410	2955.330	2137.710	2853.270	71.263	1538.910	3067.410	16.620	2019.090
	Sorting coefficient		0.43	0.61	1.30	0.41	0.94	0.71	0.65	0.78	1.86	0.60	2.30
	Skewness		0.4	0.5	-0.8	-3.2	-1.3	-2.1	-0.2	-0.8	-0.9	0.1	-0.1
	% fines (</equal to 2 on Phi scale)		18.1	71.1	86.6	98.9	92.0	95.6	20.4	89.3	88.3	10.4	62.8
	Modal point (Phi scale)		1	2	3	4	3	4	1	3	4	1	4

Reflecting the rapid increase in size in the first years, the number of *Spisula* per kg declined rapidly from ages 2 to 3 (769 to 227 pieces per kg); over the following three years it halved again (to 101 pieces) (Fig 6).

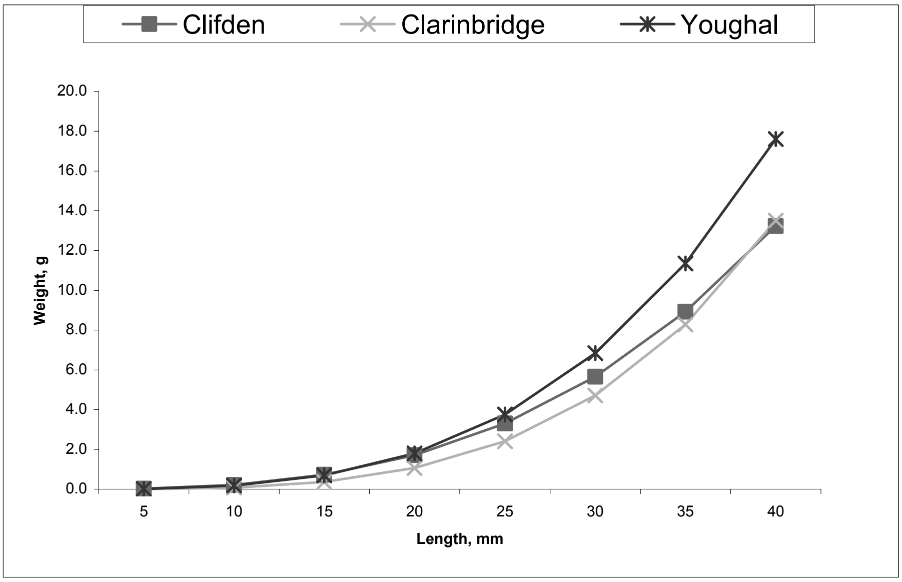

Fig 5. Total weight at length of *S. solida* from three locations.

In addition to total weight of the organism, meat weight was noted for the sample of *Spisula* from Clarinbridge; meat is a small proportion of the total weight (Fig 7) and it contributes a declining percentage of the total weight as the animal enlarges (Fig 8).

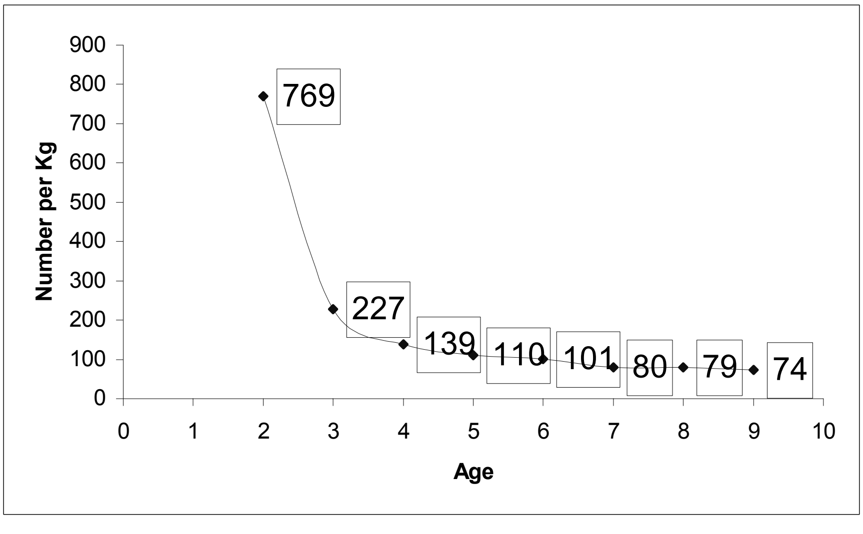

Fig 6. Numbers of *S. solida* per kg, (based on samples taken from the Waterford Harbour clam bed).

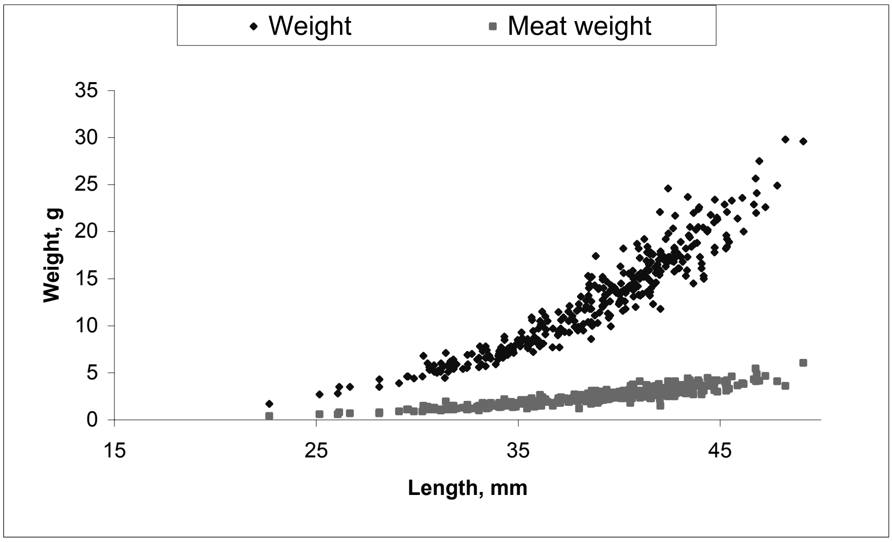

Fig 7. Total weight and meat weight at length in the Clarinbridge sample (N = 348).

A minimum size limit of 25 mm length for surf clams is imposed by European Union Council Regulation 850/98, Annex XII. The dimension which is critically effective in implementing this regulation is the width of the animal as defined in Fig 2 because this dimension determines what is retained by the bars of a dredge. The relationship between width and length is described in Fig 9 which is based on material from the Waterford Harbour clam bed and which suggests that bars on a clam dredge should be a minimum of 11 mm apart, assuming of course, that the dredge is not so overloaded during fishing operations that selection is obstructed. A width of 11 mm corresponds with age 3 (Fig 10).

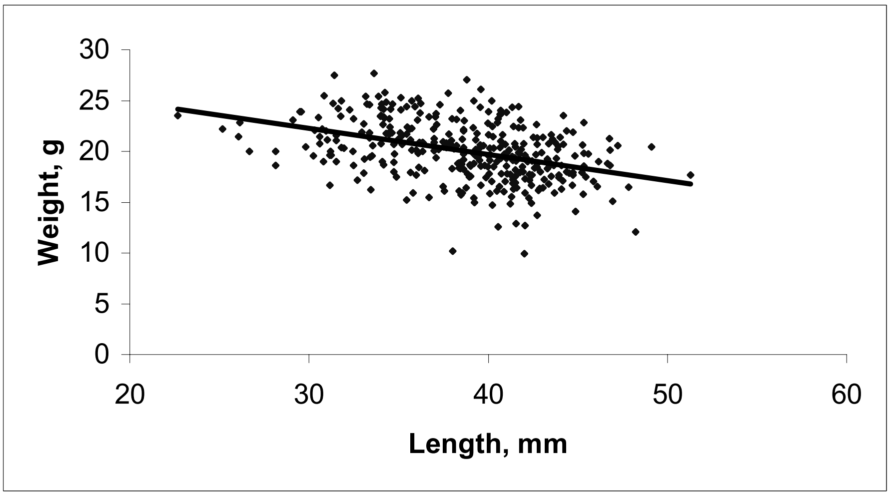

Fig 8. Variation in meat weight as a percentage of total weight at length in *S. solida* from samples collected in Clarinbridge (N = 348).

3.2 Surf clam bed in Waterford Harbour

The location of the Waterford clam bed which was examined in some detail in 2001 is shown in Fig 11. The previous year a fisherman harvesting by suction dredging recorded the areas of the bed providing heaviest catches and these can be compared with the most productive areas one year later. The location of heaviest catches had moved slightly to the northwest in the interim. According to fishermen, the changes had occurred because part of the existing bed had silted up in the meantime. If this interpretation is correct, the clam bed had reduced in size over a period of 12 months.

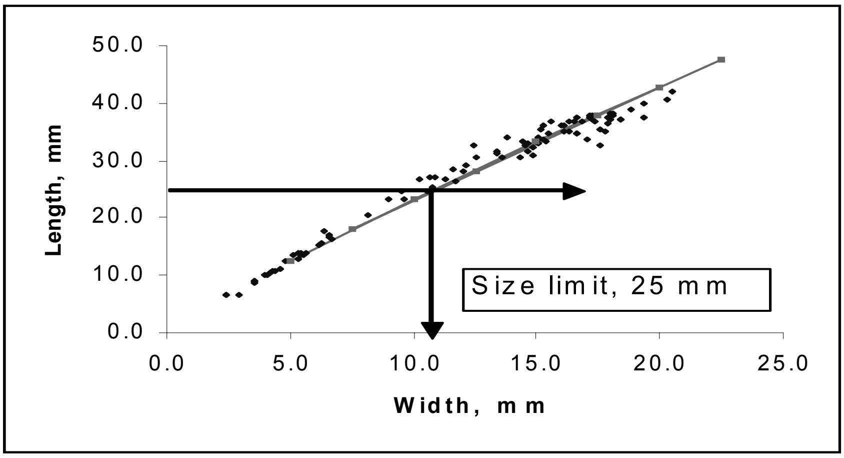

Fig 9. The relationship between length and width of *S. solida*, Waterford clam bed, showing the critical width at capture.

The length (north-south) of the clam bed in 2001 was approximately 2.25 km and it was 1.1 km in width, in area approximately 2.5 km². The bed itself, identified by the presence of *Spisula* (two specimens of *Ensis arcuatus* were the only other bivalves recovered during sampling), was situated on a slope from land out into the Harbour channel. The southern margin of the highest density was marked by a low elevation (from 2.0 to 1.7 m in depth. Fig 12) suggesting the clams occupied a sand bank.

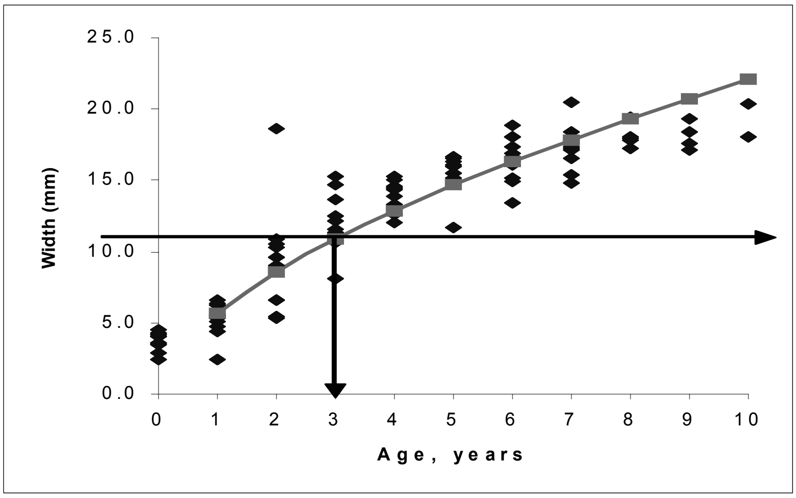

Fig 10. The relationship between width and age of *S. solida* from the Waterford clam bed.

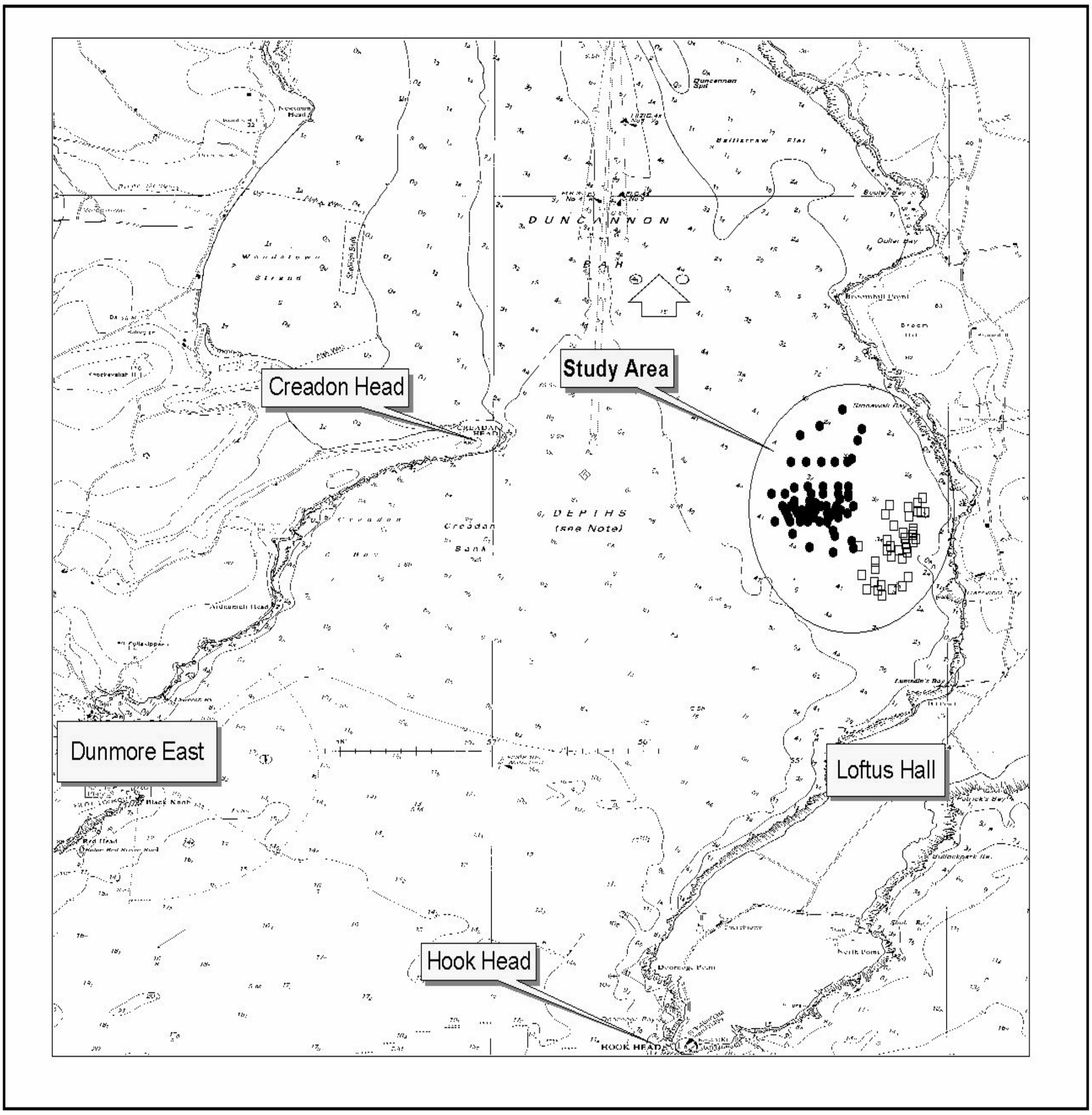

Fig 11. Map showing the location of the surf clam bed in Waterford Harbour. The study area is surrounded by an oval. Open squares mark best fishing way points in 2000; solid dots indicate the distribution of the clam bed one year later. Greater densities of the clams are marked by heavier concentration of dots.

The limits of the clam bed were marked by the occurrence of silt which, according to local opinion, had been displaced from earth-works further upstream, and then inter-mixed with coarse sand. Among the materials retained by the sieve were a number of larger pebble particles whose distribution is shown in Fig 13. Their heaviest concentration is among the greatest densities of sampling points outside which they rapidly fell away. The stations from which sediments were removed for laboratory analysis are identified in Fig 13.

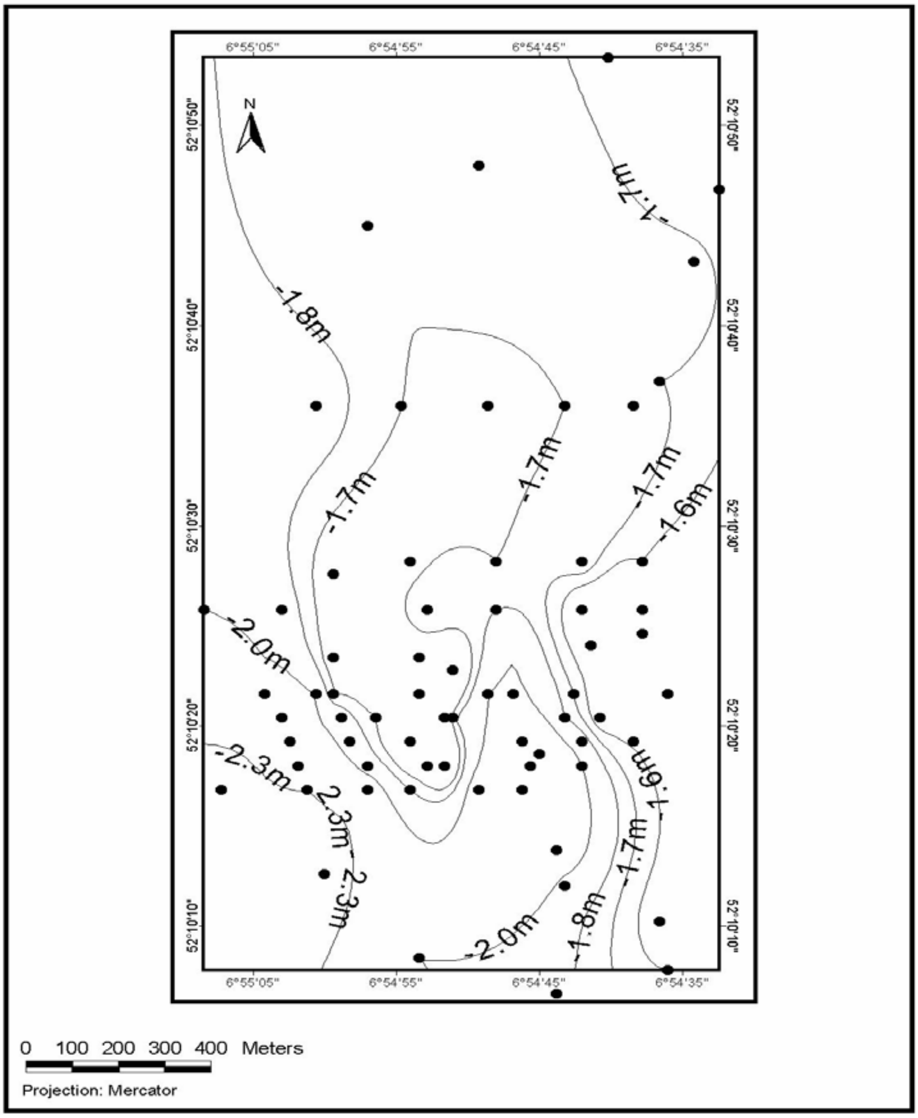

Fig 12. Bathymetry of the clam bed in Waterford Harbour.

In the course of the survey of this bed in 2001 2,023 clams were sampled and individually aged. The distribution of age groups and their biomass within the samples are set out in Fig 14. The collection method, particularly the sieve opening, did not allow comprehensive sampling of 0 group *Spisula* which are under-represented. Above that age group however, representation of age groups should reflect their presence in the sediment. Recruitment to the bed would appear to be irregular, the 1 y.o. clams outnumbering all the others.

The distribution of *Spisula* by number (Fig 15) appears to observe a pattern, an elongated north-south central concentration of numbers on either side of which they decline. The average age within samples (Fig 16) indicates that the older animals are concentrated in the southern half of the surveyed area, as is most of the biomass (Fig 17). The maximum biomass contour is 600 g/m². The biomass of the total clam patch when it was surveyed in 2001 was estimated at less than 1,000 t.

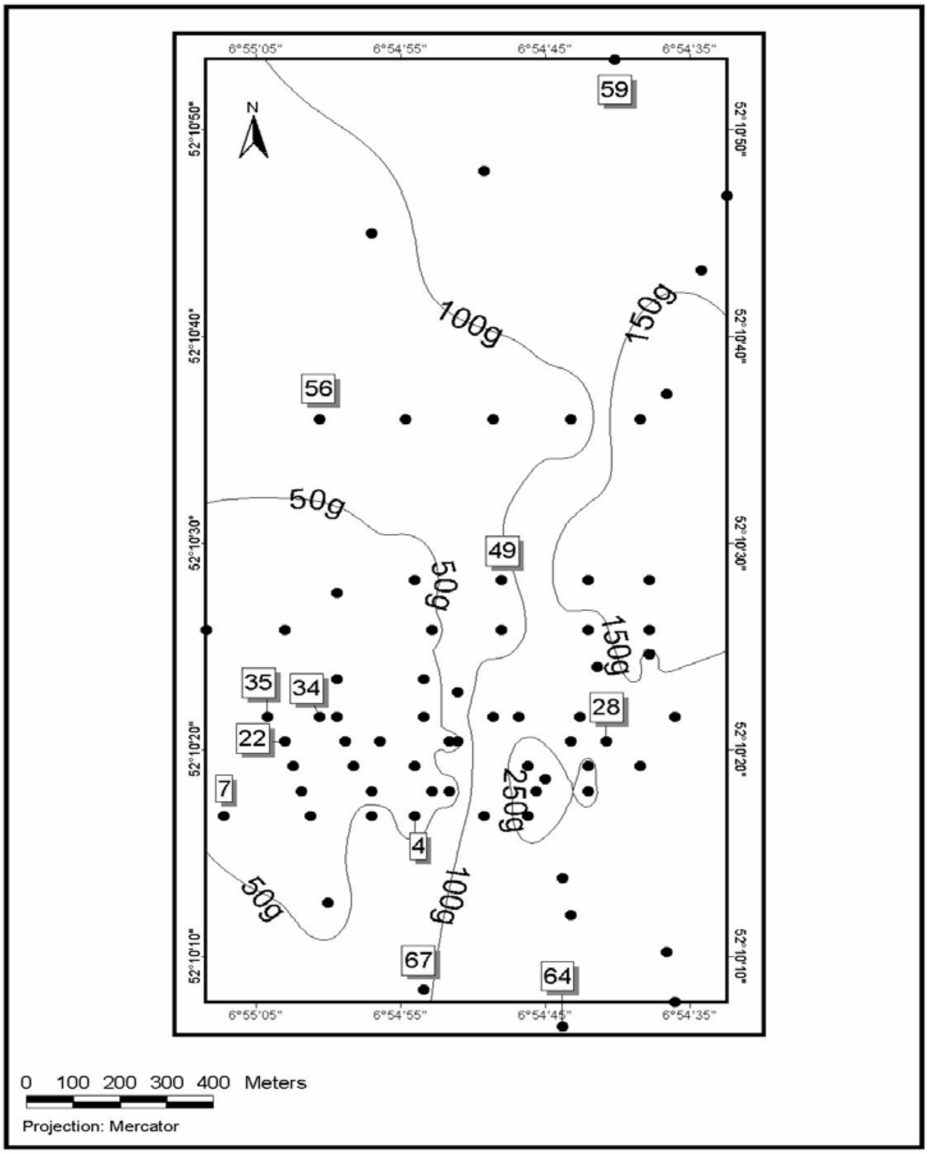

Fig 13. Contours describing the distribution of larger particle sizes retained with biological samples from the Waterford clam bed. The numbers in squares are samples whose granulometry is more comprehensively described in Table 4.

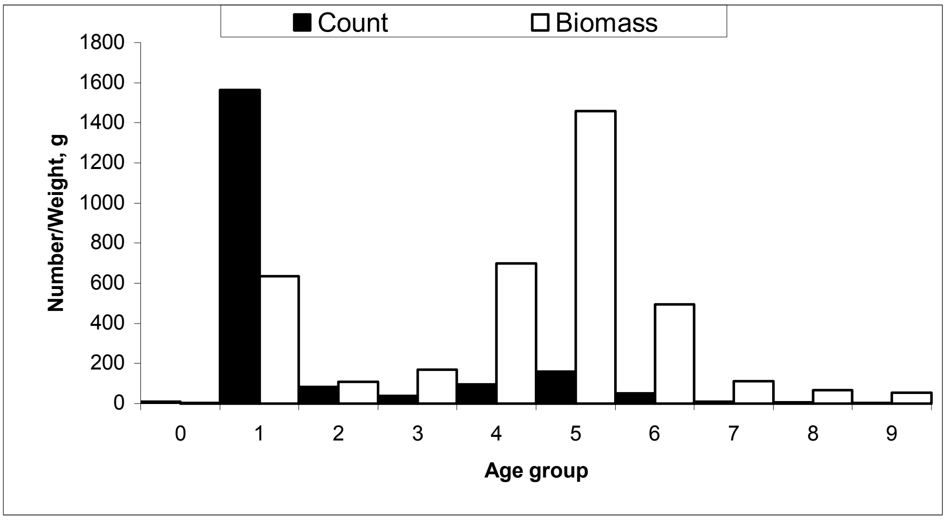

Fig 14. Numbers and biomass of *S. solida* sampled from the Clam bed in Waterford Harbour.

3.3 Granulometry of the Waterford clam patch vicinity

Details of the sediments recovered from eleven samples collected in the course of the *Spisula* survey of 2001 confirm their variability (Table 4). The modal points of the grain frequencies range from ϕ 1 (>0.5 mm) to ϕ 4 (>0.063 mm). Mean grain size (on the ϕ scale higher values indicate smaller mean grain size) correlates positively with percentage fines (</= 2 on ϕ scale) ($N = 9$; $r^2 = 0.9375$; $P < 0.001$; Fig 18). A supposition that *Spisula* biomass would correlate negatively with increasing ϕ values was not confirmed ($P > 0.05$).

4. DISCUSSION

Jones *et al* (1978), working on *S. solidissima*, a North American surf clam species of considerable economic importance and on which a corresponding amount of research effort has been spent – identified three options of establishing the age of this species which he summarised as: 1: Planting the clams and periodically recovering them, measuring increases in size. 2: Marking clams which were released and attempting to recover them later. 3: Identification of annual growth checks on the exterior of the shells. None of these was considered ideal: periodic measurement should be done at annual intervals but this technique requires settings from which the animals may be recovered and these may be unsuitable and inhibit growth. The only method which allows comparisons is the third and that could be misleading because it might lead to overestimating age. The authors recommended the study of internal banding.

Although clear shell sculpture marks occur on *S. solida*, suggesting annual rings, their interpretation is not straightforward.

Taylor *et al* (1969 and 1973) described shells of the superfamily Mactracea as composed of two layers of aragonite: a white, opaque, outer layer, consisting of crossed-lamellar crystalline structure which is separated by the pallial myostracum from a grey, somewhat translucent, inner layer. The white outer shell layer and the chondrophore are streaked periodically with dark lines (internal growth lines). This structure confirms the presence of true annuli which external sculpture alone might not indicate.

To prepare shell sections for interpretation, they were sectioned across the umbo to the ventral margin. The cut surfaces were ground, polished and etched in 0.01 M Hcl for 10 minutes after which acetate peel replicates were prepared using the technique of Richardson *et al* (1979); the replicates were mounted on glass slides and read. A variation of the technique was described by Ropes *et al* (1979) who used sections of the chondrophore of *S. solidissima* for ageing.

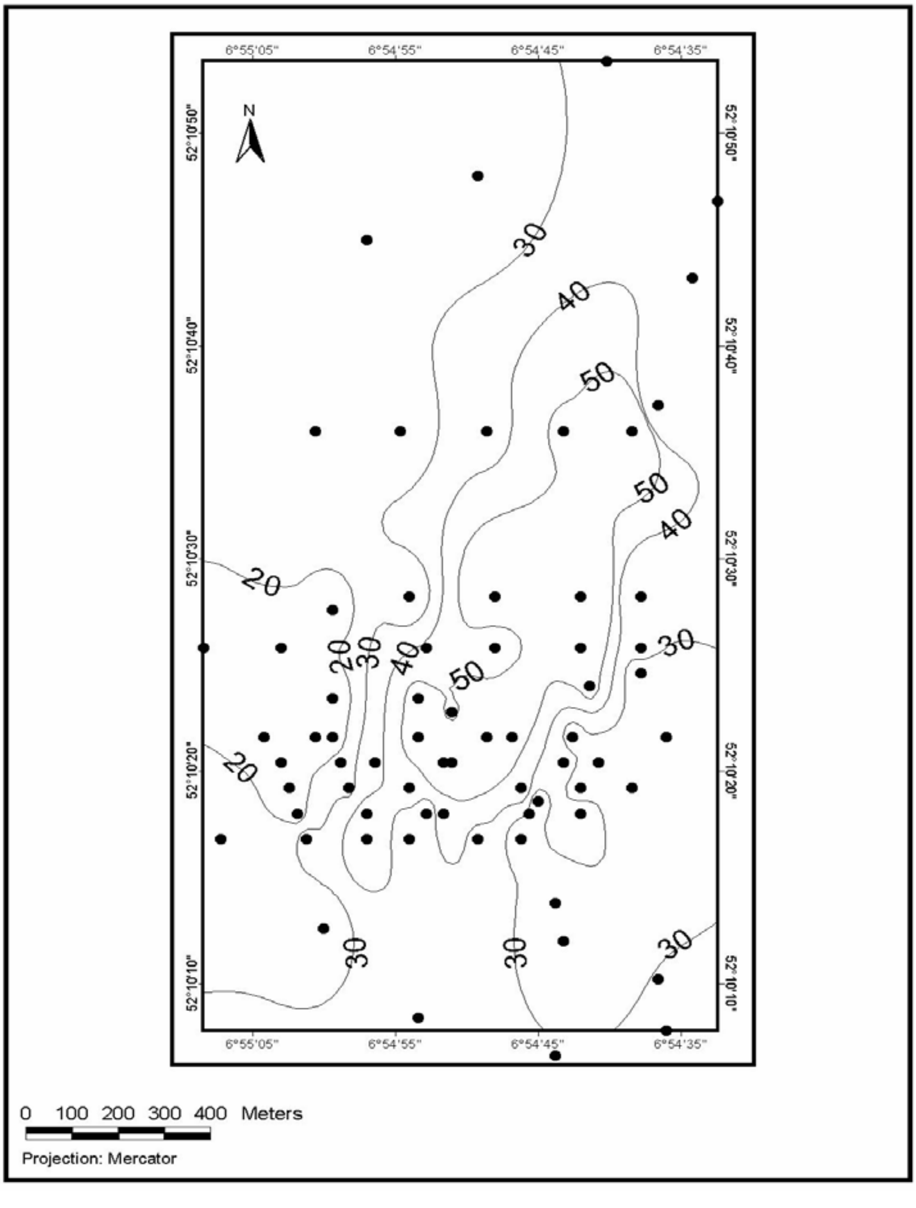

Fig 15. Numbers of *S. solida* per 0.1 m² in the Waterford Harbour bed.

The shell microstructure displayed alternating patterns of widely spaced light (winter) and narrow dark (summer) zones, the latter being associated with clefts at the shell margin (Fig 19). The external clefts on the shell margin are easily recognized in most years, except the first, and thus, they provide a means of ageing surf clams. Kristensen (1996) remarked that surface growth rings are easy to interpret although not so reliable as acetate peels. While sectioning the shell is the most accurate it is costly and time consuming and while it validated our interpretation of external shell sculpture, it would not have been suitable for an investigation of large numbers of surf clams.

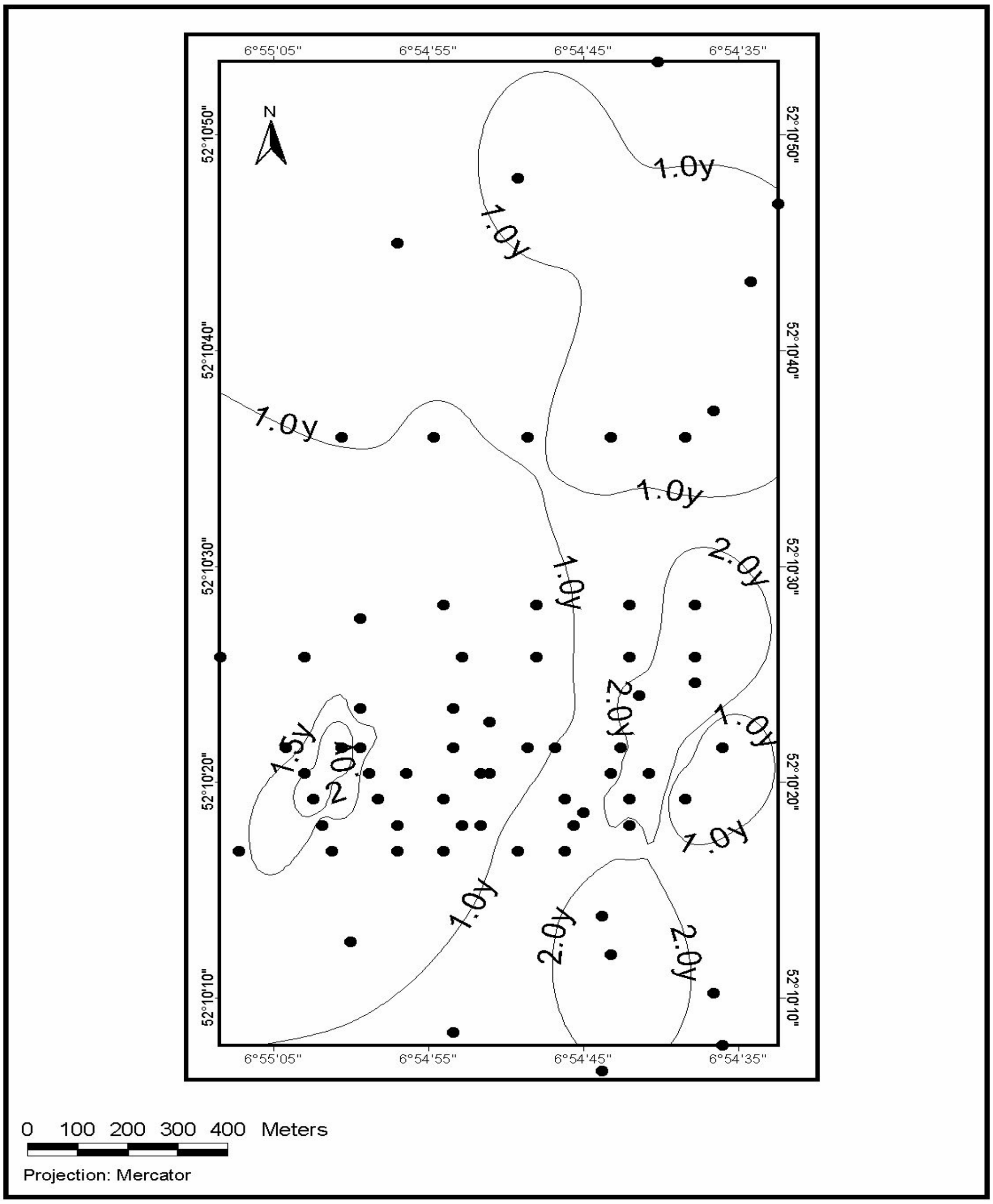

Fig 16. Contours describing the average age of *S. solida* in the Waterford Harbour clam bed.

Jones *et al* (1983) reported external sculpture on the shell of *S. solidissima* as indistinguishable from true growth lines. But there are two further complications with ageing by shell sculpture and these may involve internal as well as external structure. First, conditions which precipitate the formation of annual growth marks are not completely understood. Gaspar *et al* (1995) considered the association of such phenomena with spawning but discounted it because *S. solida* is believed to spawn in the spring and the formation of annuli takes place later in the year in southern Portugal. Instead, they speculated that the stress of post-spawning or of high temperatures might be responsible. Instances were provided of interruption of the regular pattern of growth bands by "disturbance lines" which were frequently associated with a deep cleft in the shell section, which they surmised, are related to a short-term cessation of growth, probably caused by sudden weather changes, predation, disease or dredging. Recording external sculpture marks which mimic annual growth clefts alters the growth curve, indicating a slower rate while failure to recognise an annual growth mark would have the opposite effect. Gaspar *et al* (1995) described two different growth curves on the basis of internal and external growth indicators: external surface rings described a slower growth curve than internal shell structure deciphered on acetate peels.

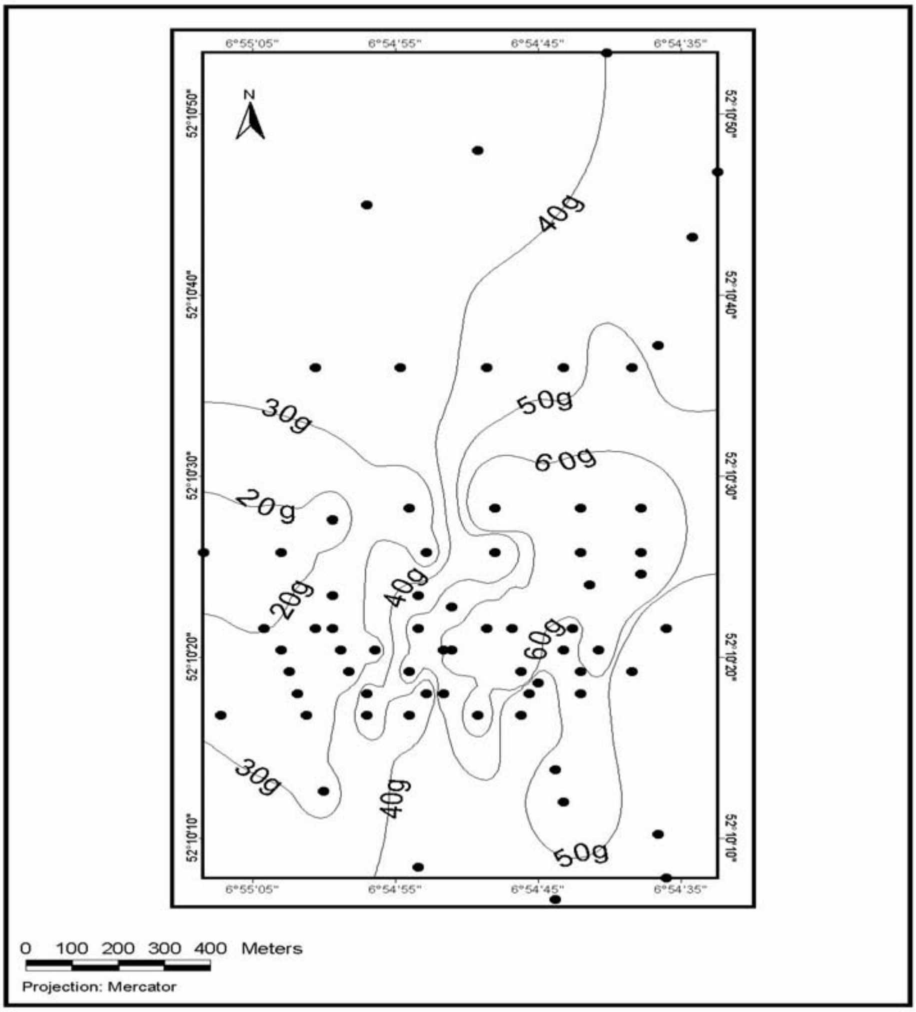

Fig 17. Contours describing biomass distribution within the Waterford Harbour surf clam bed. Values are in g per 0.1 m².

If disturbance through fishing causes the formation of additional annuli, then the selective effects of fishing have consequences for the growth curve of the animals which survive. Vaughan *et al* (1994) observed that statistical dependency of estimated lengths at age for individual fish is expected when there is size selective mortality: when faster growing individuals are removed from the population only slower growing ones are left to survive to older age groups. Obtaining smaller estimated sizes for younger age groups when back-calculated lengths at age are estimated from older fish than when they are estimated from younger fish is known as Lee's phenomenon (Ricker, 1969).

It was also suggested that harvesting might have depressed *k* and L*inf* in the case of the New Jersey/Delmarva *S. solidissima* fishery (Weinberg *et al*, 1996). Hydraulic dredging, the method of capture of some of the material examined in this survey, can reduce clam growth rates by damaging siphons, reducing feeding time and by dislodgement from the substratum which increases exposure to predators. Fishery-induced selective mortality which removes the larger and faster growing individuals from a population can reduce both parameters also (Ricker, 1969, Vaughan *et al*, 1994). The Lee effect is compounded when larger, faster growing individuals are removed and the smaller, slower growing ones are returned to the water where they survive. Of the several *Spisula* stocklets surveyed in the course of this work, it is likely that the Clifden population, which has the most distinctive growth rate and was in the course of being heavily exploited when material was collected for growth analysis, displays the Lee phenomenon most clearly.

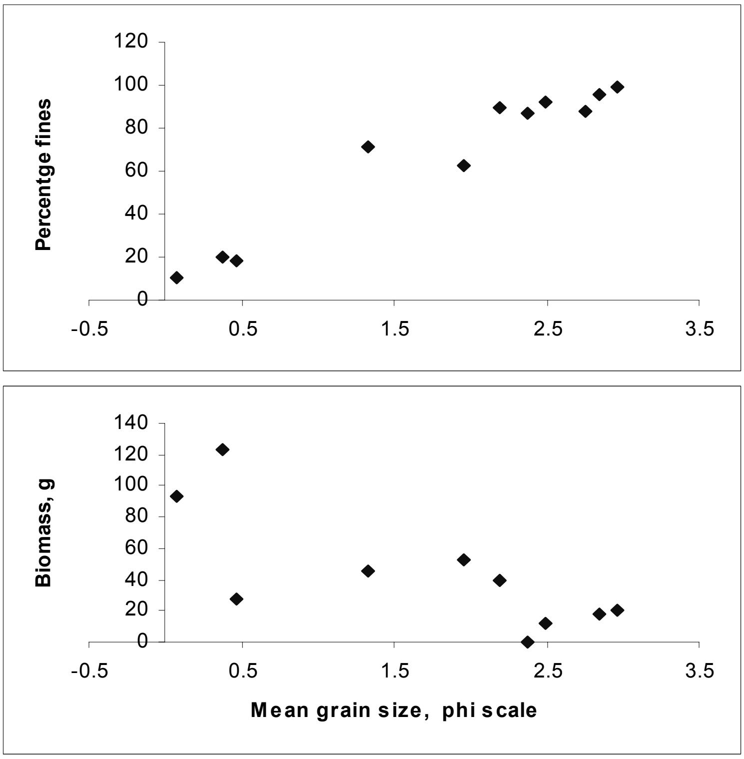

Fig 18. Association between *S. solida* and granulometry in the Waterford Harbour clam bed: above, the relationship between percentage fines and the mean grain size on the ϕ scale; below, the biomass of *S. solida* per 0.1 m^2 and the mean grain size on the ϕ scale.

Work undertaken on *S. solida* stocklets in Ireland assumed that apparent external growth sculpture marked true annuli formed at the same time each year. There are variations in this pattern however. Gaspar *et al* (1999) reported that *S. solida* reached maturity in the first year of life in Vilamoura, southern Portugal; July-September, when sea temperatures are highest, is a resting period there. A new spawning cycle begins in October, coincident with sea temperatures turning downwards. Condition in the animals is highest at lowest temperatures and spawning takes place as the temperatures tend upwards again – thus spawning and lowest temperatures closely coincide. There is a single protracted spawning period. Maturity is reached during the first year in life and is a function of age, not of size. Similar results were obtained for *Venus striatula* and *Ensis siliqua* (Gaspar *et al*, 1998) which, in the case of *Ensis siliqua*, are likely to be attributable to higher temperatures promoting faster development (Fahy *et al*, 2001).

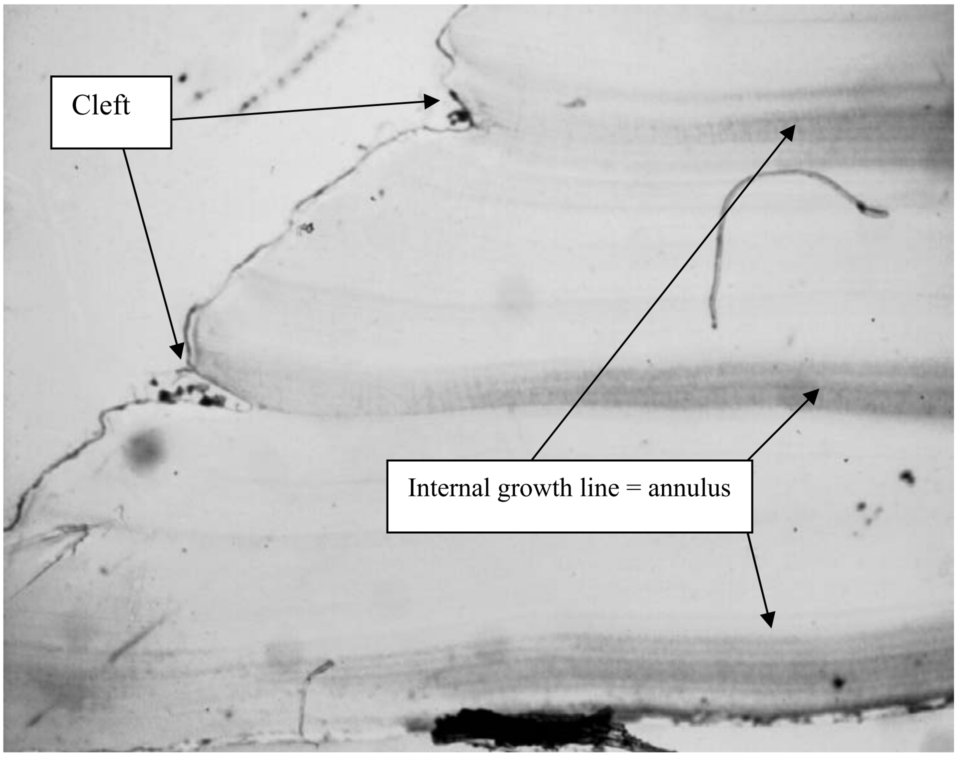

Fig 19. Acetate peel of a shell section of *S. solida* with the internal growth lines and clefts marked.

The formation of growth clefts has been attributed to low winter temperatures in a number of species [see Jones *et al* (1978) for details] but not for *S. solidissima* where the spawning cycle is implicated. Spawning behaviour is also plastic in this species: Ropes (1968) found a biennial reproductive cycle when sampling below the thermocline in offshore New Jersey while Jones (1981) reported an annual spawning cycle in inshore waters. According to Jones (1981) gametogenesis of inshore surf clams takes place over the winter months. In December temperatures were falling to their lowest of the year in February and by late May or June (rising temperatures) the gonads contained morphologically ripe eggs and sperm. Partially spawned individuals were first encountered in June or July (still rising temperatures). Spawning was heaviest in late summer-autumn (annual temperature rises to a peak and begins to decline) and all were spent in November and December (a time of falling temperatures again). However, Jones *et al* (1983) working with stable isotopes and annual shell increments demonstrated that shell growth was most rapid in spring-early summer; it slowed in late summer-autumn and was extremely slow or non-existent in winter. Thus, there is a coincidence between the end of spawning and the cessation of growth in winter.

In *S. solida*, gametogenesis took place between October and February, spawning between February and May and the animals were spent in November and December off Vilamoura, southern Portugal (Gaspar *et al*, 1999). They concluded that gametogenesis in *S. solida* is a response to falling temperature and spawning occurs when temperature begins to rise again, rather than occurring at a fixed temperature.

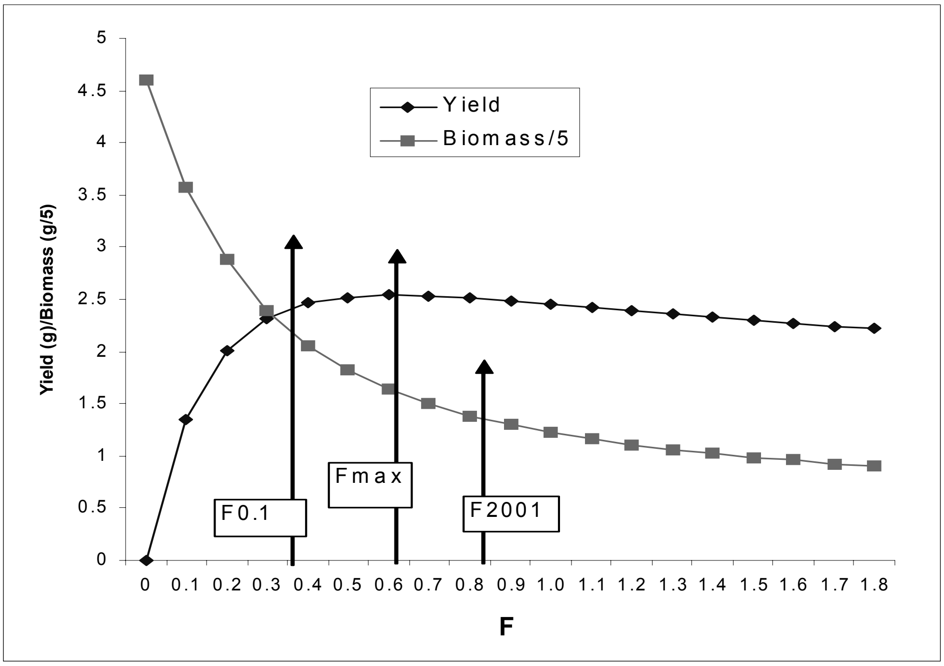

Fig 20. Yield per recruit and biomass per recruit curves for *S. solida* in Waterford Harbour.

Dimensions attained by Irish *S. solida* differ from those reported from other Northern European stocks of the species. Kristensen, 1996, reported L*inf* at 43 mm in *S. solida* harvested in Danish waters, similar to L*inf* in Irish stocklets. However, the growth rate he reported was faster than in the stocklets examined in this survey: acceptable commercial size in the Danish North Sea at 2-3 years was reached when a length of 35 mm and a width of 13 mm were achieved. Meixner (1994) reported that *S. solida* of that size in the German North Sea similarly averaged 2.5 years old while in the Waterford Harbour bed they were 5.27 years old at the same length.

Within the Mactracea growth can be influenced by environmental factors, particularly density. Weinberg *et al* (1996) compared growth curves of *S. solidissima* in two areas off the New Jersey/Delmarva and Long Island/South New England coasts following an hypoxia which resulted in heavy invertebrate mortalities in the southernmost in 1976. Both the growth coefficient *k* and the maximum shell length L*inf* declined between 1980 and approximately one decade later. They remained constant in the northern area which had not been affected by the hypoxia. In the south the data suggested that the clams grew more rapidly and attained greater asymptotic length in the earlier period. It is hypothesised that following the hypoxia, the first to re-colonise grew relatively more rapidly in the presence of a good food supply and without competitors. (see also Weinberg (1998) on the density effects on growth in *S. solidissima*.) Hancock (1973) observed the mean shell length of the cockle at age 2 in Wales correlated negatively with stock biomass which he attributed to competition for space and food. Murawski *et al* (1984) working on *S. solidissima*, assumed that, if growth rate is a negative function of clam density, then strategies that reduce clam abundance from one year to the next will result in compensatory growth. They also postulated that there is a positive relationship between stock density and M because dense populations may attract predators and result in increased stress and less food per individual. These authors did not however assume that density has an inhibiting effect on recruitment of subsequent cohorts while Hancock (1973) did.

The occasional occurrence of a large year class, as in the Waterford Harbour clam bed, can be attributed to a variety of factors and an association between adult density and juvenile recruitment cannot be discounted although in surf clams there is conflicting evidence for it. David *et al* (1997) found that the magnitude of recruitment to a patch of *S. ovalis* was independent of adult biomass. More likely to be effective was passive transport of juveniles or variations in abundance of food supply. Sasaki (1986) worked on the Sakhalin surf clam *S. sachalinensis*. The fishery was unstable owing to wide fluctuations in recruitment. Sasaki proposed a recruitment pattern of successive “normal”(several) and “strong” (once every three of four years) year classes.

Weinberg (1999) described surf clam habitat as dynamic: large sand grain sizes occurring in strong currents, a habitat in which the transport of individuals is likely to take place over time. Laboratory experiments by Snelgrove *et al* (1999) demonstrated that *S. solidissima* larvae were capable of sediment selection, with greater settlement in sand than in mud, this being representative of adult habitat. Mortensen (1921) showed that echinoderm larvae could delay or avoid settling in the absence of a particular sedimentary cue. Snelgrove *et al* (1999) stated that juvenile surfclams (*S. solidissima*) were highly active and that they jump around on the ocean bottom. A size difference among recently settled larvae suggested that habitat selection might be achieved either at larval settlement or by recently settled juveniles. They concluded that larval supply and habitat selection probably both play significant roles in determining temporal and spatial variability in faunal patterns of distribution.

Mackenzie *et al* (1984) also observed that surf clam preveligers select coarse sand over fine. In an experiment they observed that about 10% of clams died immediately after settling. Juveniles of a moon snail settled simultaneously and began to consume them and crabs were also important predators. When the hypoxia of 1976 off the Delmarva coast eliminated crab predators the next *Spisula* spatfall survived in very large numbers.

Snelgrove *et al* (1998) proposed that if *Spisula* larvae were capable of consistent habitat selection in flow, it is likely that larval choice plays a role in determining adult distribution. Selection, they observed, was not consistent in still water, suggesting that selective ability is related to flow. Larval selectivity did not preclude the possibility that post-settlement processes were important in determining adult populations and predation on juveniles was also likely to be an important source of variation in year class strength. Berthou *et al* (1988), working on *S. ovalis*, described negative interactions between recruitment and adult density and they stated that in a potential habitat, above a certain adult density level, no recruitment was observed. They also observed that suitable ground may be occupied by clusters of single age groups presumably resulting from greater settlement in these locations in different years.

Kristensen, 1996 reported *S. solida* to be associated with a grain size of 2-3 mm and occurred where investigations were undertaken in sand hills of several metres high above finer sand grains. The Waterford Harbour bed conforms to this description although it has a very low elevation. The poor association between biomass and sediment size (Fig 18) is likely to have resulted from a relatively recent alteration of parts of the bed into and away from which the clams were unable to move. The consequences for the granulometry of a clam bed being reworked by dredge are not known.

Densities of *S. solida* in the North Sea were provided by Kristensen (1996) as: at Røde Klit Sand, 0 – 2,046 g wet weight per m^2 and 0 -240 individuals per m^2; at Horns Reef, 0 - 632 g wet weight per m^2 and 0 - 45 individuals per m^2. A biomass of less than 200 g per m^2 was not considered worthwhile fishing. On these criteria, the Waterford Harbour clam bed in 2001 would have provided some worthwhile fishing. Kristensen (1996) also suggested an exploitation rate should be 10-15% and it is likely that this is/was exceeded whenever surf clam patches are harvested in Ireland. Indeed, the pattern of exploitation of the Waterford Harbour clam patch would appear to be excessive harvesting followed by fallowing.

Irregular recruitments appear to be commonplace in *Spisula* patches. Of the stocklets sampled for this work, the distribution of age groups in the Clarinbridge, Clifden and Waterford Harbour beds were considered as the basis for a catch curve. A curve was calculated only for the Waterford Harbour stocklet, taking age 4 as the age of full recruitment; the previous year, in which the bed was fished, this age group, at 3 y.o. would have been elegible for capture (Fig 10) although such animals are not highly valued in the landings (Fig 6). A Thompson-Bell yield per recruit curve was devised for the Waterford Harbour clam patch. Assuming that full recruitment occurred at age 4, a value for F = 0.67 was calculated; on the assumption that age at full recruitment was one year later, the value of F was 0.80. Both estimates of F exceed F0.1, the lower one coincides with F*max* while the higher estimate exceeds F*max* (Fig 20).

Optimum sustainable yield in from a clam bed would, where recruitment is fairly constant, be determined by considerations of growth rate and size at maturation. In the case of *Spisula solida*, the size at which the animal is worth harvesting is however, likely to be an important consideration.

ACKNOWLEDGEMENTS

This work was undertaken with the support and assistance of a number of people who are sincerely thanked for their efforts: Leo Whelan of Clifden, Co Galway, provided samples of *S. solida* from clam patches in the vicinity. Samples from the Iniskea Islands and Blacksod bay were collected by one of us (E.F.) on his vessel. Samples from Kilkieran were gathered in the course of a bivalve survey financed by an Bord Iascaigh Mhara. William Nolan of Cave, Clarinbridge, made his boat and gear available to collect surf clams there. Brian Polly of Ardgroom, Beara, Co Cork, supplied shells of *S. solida* fished in the vicinity of the Soverign Rocks and he also made GPS way point data from the Waterford Harbour clam patch in 2000 available. The fish processing firm Tawnagh, of Dunmore East, provided samples from the *Spisula* bed at Youghal and the company also gave us details of landings from the Waterford clam patch. Quantitative sampling of the Waterford Harbour clam bed was undertaken using a boat and crew chartered from Billy Dwyer of Ballyhack, Arthurstown, New Ross, Co Wexford. Sinead Macken carried out the analyses of data from the Waterford Harbour clam patch and she prepared the maps of the bed. Dr Chris Richardson of the School of Ocean Sciences, University of Wales at Menai Bridge, prepared and interpreted acetates of sections of *S. solida* shell. Mark Norman of Taighde Mara Teó kindly read through the MS and suggested a number of modificiations to the text.

REFERENCES

Berthou, P and M Glemarec (1988) Distribution temporelle et spatiale des cohortes de *Spisula ovalis* (Sowerby). ICES C.M. 1988/K:35

David P, P Berthou, P Noel and P Jarne (1997) Patchy recruitment patterns in marine invertebrates: a spatial test of the density dependent hypothesis in the bivalve *Spisula ovalis*. Oecologia 111: 331-340

Fahy, E, J Carroll, R Browne, A ni Rathaille, P Casburn, S Breathnach, M Norman and D Stokes (2002) A survey by hydraulic dredge of interstitial bivalves with commercial potential in Cill Chiaráin and Beirtreach buí Bays and along their connecting shoreline, Co Galway. Fisheries Bulletin (20): 23 pp.

Fahy, E and J Gaffney (2001) Growth statistics of an exploited razor clam (*Ensis siliqua*) bed at Gormanstown, Co Meath, Ireland. Hydrobiologia: 465:139-151

Gaspar, M B, M Castri and C C Monteiro (1995) Age and growth rate of the clam*,* *Spisula solida* L., from a site off Vilamoura, south Portugal, determined from acetate replicas of shell sections. Scientia Marina 59 (supl. 1): 87-93

Gaspar, M and CC Monteiro (1998) Reproductive cycles of the razor clam *Ensis siliqua* and the clam *Venus striatula* off Vilamoura, southern Portugal. Journal of the Marine Biological Association of the U K 78: 1247 – 1258.

Gaspar, M B and CC Monteiro (1999) Gametogenesis and spawning in the subtidal white clam *Spisula solida*, in relation to temperature Journal of the Marine Biological Association, UK. 79: 753 – 755.

Hancock, D A (1973) The relationship between stock and recruitment in exploited invertebrates. Rapport Proces verbal Conseil Int Explor Mer 164: 113-131

Jones, D S (1981) Reproductive cycles of the Atlantic surf clam *Spisula solidissima* and the ocean quahog *Arctica islandica* off New Jersey. Journal of Shellfish Research 1(1): 23-32

Jones, D S, I Thompson and W Ambrose (1978) Age and growth rate determinations of the Atlantic surf clam *Spisula solidissima* (Bivalvia: Mactracea), based on internal growth lines in shell cross-sections. Marine Biology 47: 63-70

Jones, D S, D F Williams and M A Arthur (1983) Growth history and ecology of the Atlantic surf clam, *Spisula solidissima* (Dillwyn), as revealed by stable isotopes and annual shell increments. J. Exp. Mar. Biol. Ecol, 73: 225 - 242

Kristensen, P S (1996) Biomass, density and growth of *Spisula solida* in the Danish part of the North Sea, south of Horns Reef. International Council for the Exploration of the Sea C.M. 1996/K:27

Mackenzie, C L, D Radosh and R N Reid (1984) Sediment preferences and mortality in young surf clams (*Spisula solidissima* Dillwyn) (abstract only). National Shellfisheries Association, Tampa, Florida. Annual meeting 25-28 June 1984.

Meixner, R (1994) Über die Trogmuschel und deren Nutzung in der Deutschen Bucht.Inf. Fischwirtsch 41(4): 166 - 170

Mortensen, T (1921) Studies of the development and larval forms of echinoderms. 1 - 266 Gad Kovenhavn.

Murawski, S A and M J Fogarty (1984) A spatial yield model for bivalve populations accounting for density dependent growth and mortality. ICES C.M. 1984/K:26

Richardson, C A, D J Crisp and N W Runham (1979) Tidally deposited growth bands in the shell of the common cockle, *Cerastoderma edule* (L). Malacologia 18: 277 – 290.

Ricker, W E (1969) Effects of size-selective mortality and sampling bias on estimates of growth, mortality, production and yield. Journal of the Fisheries Research Board of Canada 26: 479 – 541.

Ricker, W E (1975) Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191: 382 pp.

Ropes, J W (1968) Reproductive cycle of the surf clam, *Spisula solidissima*, in offshore New Jersey. Biological Bulletin (Woods Hole) 135: 349 – 365.

Ropes J W and L O’Brien (1979) A unique method of ageing surf clams. ICES C.M. 1979/K:28

Sasaki, K (1986) The surf clam beam trawl fishery and its biological management in Sendai Bay. Bulletin of the Japanese Society of Scientific Fisheries 52(3): 399 – 409.

Snelgrove, P V R, J P Grassle and C A Butman (1998) Sediment choice by settling larvae of the bivalve *Spisula solidissima* (Dillyn), in flowing and still water. Journal of experimental Marine Biology 231: 171 - 190

Snelgrove, PVR, J P Grassle, J F Grassle, R F Petrecca and H Ma (1999) In situ habitat selection by settling larvae of marine soft-sediment invertebrates. Limnol. Oceanogr 44(5): 1341 - 1347

Taylor, JD, W J Kennedy and A Hall (1969) The shell structure and mineralogy of the Bivalvia. Introduction. Nuculacea-Trigonacea Bulletin of the British Museum of Natural History (Supplement) 3: 1-125

Taylor, JD, W J Kennedy and A Hall (1973) The shell structure and mineralogy of the Bivalvia. II Lucinacea-Clagagellacea, Conclusions. Bulletin of the British Museum of Natural History (Series D, Zoology) 22: 255-294

Vaughan, D S and M L Burton (1994) Estimates of von Bertalanffy growth parameters in the presence of size-selective mortality: a simulated example with red grouper. Transactions of the American Fisheries Society 123: 1-8

Weinberg, J R (1998) Density-dependent growth in the Atlantic surfclam, *Spisula solidissima*, off the coast of the Delmarva Peninsula, USA Marine Biology 130: 621 – 630.

Weinberg J R (1999) Age-structure, recruitment and adult mortality in populations of the Atlantic surfclam, *Spisula solidissima*, from 1978 to 1997. Marine Biology 134: 113-125

Weinberg, J R and T E Helser (1996) Growth of the Atlantic surfclam, *Spisula solidissima*, from Georges Bank to the Delmarva Peninsula, USA. Marine Biology 126: 663 – 674.